EVALUATION OF BLOCKCHAIN TECHNOLOGY FOR PROCESS IMPROVEMENTS IN SUPPLY CHAINS USING FUZZY QFD

(TEDARİK ZİNCİRLERİNDE SÜREÇ İYİLEŞTİRMEK İÇİN BLOKZİNCİRİ TEKNOLOJİSİNİN BULANIK QFD YÖNTEMİYLE DEĞERLENDİRİLMESİ)

by

Ayça MADEN, M.S.

Thesis

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

DOCTOR OF PHILOSOPHY
in
INDUSTRIAL ENGINEERING
in the
GRADUATE SCHOOL OF SCIENCE AND ENGINEERING
of
GALATASARAY UNIVERSITY

Supervisor: Assoc. Prof. Dr. S. Emre Alptekin

December 2021

ACKNOWLEDGEMENTS

This dissertation research would not have been written without the help and encouragement of many people. First and foremost, I would like to express my deep gratitude to Assoc. Prof. Dr. S. Emre ALPTEKİN, my advisor, for his consistent support, patience, and valuable guidance throughout my Ph.D. study. I am greatly indebted to him for generously sharing his vast knowledge and offering help whenever needed.

I would like to express my thanks to committee members Prof. Dr. Müjde Erol GENEVOIS and Assoc. Prof. Dr. Şeyda Serdar ASAN, for their comments and words of encouragement.

I am deeply grateful to my parents and sister for their continuous support and encouragement during the past few years.

December 2021
Ayça Maden

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LIST OF SYMBOLS

IT	: Information Technology
SCOR	: Supply Chain Operations Reference
KPI	: Key Performance Indicator
ISO	: International Organization for Standardization
IEC	: International Electrotechnical Commission
BPMN	: Business Process Model and Notation
QFD	: Quality Fucntion Deployment
DEMATEL	: Decision Making Trial and Evaluation Laboratory
TOPSIS	: Technique for Order Preference by Similarity to Ideal Solution
SCPMS	: Supply Chain Performance Measurement Systems
BSC	: Balanced Scorecard
AHP	: Analytic Hierarchy Process
MCDM	: Multi-Criteria Decision Making
ANP	: Analytic Network Process
VIKOR	: Vise Kriterijumska Optimizacija I Kompromisno Resenje
ERP	: Enterprise Resource Planning
EDI	: Electronic Data Interchange
IoT	: Internet of Things
RFID	: Radio Frequency Identification
GPS	: Global Positioning System
ANFIS	: Adaptive Network-Based Fuzzy Inference Systems
AM	: Additive Manufacturing
RDBMS	: Traditional Relational Database Management Systems
P2P	: Peer-to-Peer
DoS	: Denial-of-Service
DDoS	: Distributed Denial-of-Service
IaaS	: Infrastructure-as-a-Service
PaaS	: Platform-as-a-Service
SaaS	: Software-as-a-Service
GDPR	: General Data Protection Regulation
DLT	: Distributed Ledger Technology
DAG	: Directed Acyclic Graphics
DAO	: Decentralized Autonomous Organizations
BPM	: Business Process Management
IPFS	: Interplanetary File System
API	: Application Interface
B2B	: Business-to-Business
DHT	: Distributed Hash Table
TPS	: Transaction Per Second

FinTech : Financial Technology
ISM : Interpretive Structural Modelling
KVKK : Kişisel Verilerin Korunması Kanunu
SQuaRE : Software Quality Requirements and Evaluation
HOQ : House of Quality
FCM : Fuzzy Cognitive Map
TFN : Triangular Fuzzy Number
FPIS : Fuzzy Positive Ideal Solution
FNIS : Fuzzy Negative Ideal Solution
CC : Closeness Coefficient
ELECTRE : (ÉLimination et Choix Traduisant la REalité)
TCO : Total Cost OF Ownership
VM : Virtual Machine

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ABSTRACT

With the increasing complexity in globalized business environments, businesses encounter a significant challenge to optimize and innovate their processes to take advantage of a highly competitive market. With its unique characteristics, blockchain technology will change the way we handle business processes. This study aims to support the blockchain technology selection decision of a supply chain considering the requirements of its stakeholders, primarily focusing on its procurement process. We made a case study application seeing the problematic supply chain metrics and software-related characteristics of the case supply chain using an integrated Cognitive Map-QFD-TOPSIS methodology to select an appropriate enterprise blockchain alternative. Vague or imprecise process and metric definitions and imprecise quality definitions can create problems in the technology selection process, so these definitions should be set in a standard form. We used Supply Chain Operations Reference (SCOR) modelling and Business Process Modelling and Notation (BPMN) language to deal with the vague and imprecise process and metric definitions.

Furthermore, trade-offs are the most crucial decisions that must be made in an architectural design. To prioritize SCOR metrics and focus on specific metrics without losing information, we used Fuzzy Cognitive Maps since there are trade-offs between SCOR performance metrics. For global standardization, the International Organization for Standardization (ISO) and the International Electro-technical Commission (IEC) established information technology guidelines. In this study, ISO/IEC 25010-25012 standard software quality attributes were evaluated for focusing on problematic software attributes of the case supply chain. To prioritize ISO software characteristics and blockchain characteristics separately, we again applied Fuzzy Cognitive Maps. It is highly significant to determine complex relationships between ISO software

characteristics considering their contribution to the software quality. However, software stakeholders in the case supply chain cannot easily interpret the changes that the complex relationships between software characteristics can create. To the best of our knowledge, in literature, there is not a study evaluating the relationships between the software characteristics from both ISO/IEC 25010 and ISO/IEC 25012 standards using Fuzzy Cognitive Map. After inspecting all blockchain characteristics from the literature, we summarized blockchain characteristics to be able to support blockchain selection decisions of a selected enterprise. We also evaluated trade-offs between blockchain characteristics using Fuzzy Cognitive Maps. In literature, blockchain technology studies in supply chains are either too supply chain-specific or too technical in software topics. However, supply chain and software related topics need to be systematically linked to each other for the selection of a suitable blockchain alternative. In the end, we selected an appropriate enterprise blockchain alternative using Fuzzy (Technique for Order Preference by Similarity to Ideal Solution) TOPSIS. There is no QFD-Cognitive Map-TOPSIS integrated study on enterprise blockchain selection, specifically inspecting the trade-offs between blockchain characteristics.

In this study, SCOR metrics, ISO characteristics and metrics, blockchain design requirements, and the selection of alternative blockchains enabled us to support to-be processes of a selected supply chain. Blockchain became more understandable by using a standardized language in quality characteristics and performance dimensions (SCOR, ISO, etc.), also limited in the literature. Additionally, blockchain characteristics were evaluated in detail to be able to support enterprise blockchain selection decisions. Fuzzy Cognitive Map-based scenario analysis enabled us to consider the different effects of different scenarios in our study.

Keywords: Procurement process, Blockchain technology, Fuzzy Cognitive Map, Fuzzy QFD, Fuzzy TOPSIS

ÖZET

Küreselleşmiş iş ortamlarında artan karmaşıklık ile işletmeler, son derece rekabetçi pazarda avantajlar elde edebilmek için süreçlerini optimize etmek ve yenilemek için büyük bir zorlukla karşılaşmaktadırlar. Eşsiz özellikleri ile Blokzinciri teknolojisi, iş süreçlerini yönetme şeklimizi değiştirecektir. Bu çalışmada amaç, özellikle satınalma sürecine odaklanarak, paydaşların gereksinimleri doğrultusunda bir tedarik zincirinin Blokzinciri teknolojisi seçim sürecini desteklemektir. Entegre Bulanık Bilişsel Haritalama (BBH)-Bulanık Kalite Fonksiyon Yayılımı (KFY)-TOPSIS yöntemi kullanarak, problemli tedarik zinciri metrikleri ve yazılım özellikleri doğrultusunda uygun bir Blokzinciri alternatifi seçimi yapmak için bir vaka analizi çalışması yapılmıştır. Belirsiz veya kesin olmayan süreç ve metrik tanımları, kesin olmayan kalite tanımları ile birlikte teknoloji değerlendirme sürecinde sorunlar yaratabilir; bu nedenle bu tanımlar standart bir biçimde değerlendirilmelidr. Vaka olarak incelenen tedarik zincirinin belirsiz süreç ve metrik tanımları olduğundan, tedarik zinciri operasyonları referans modelini ve iş süreç modelleme ve notasyonu dilini kullandık. Ödünleşimler, bir tasarım aşamasında dikkat edilmesi gereken özelliklerdir. Tedarik zinciri operasyonları referans modeli metrikleri arasındaki ilişkileri ve önemli metrikleri belirlemek için BBH yöntemini kullandık. Küresel standardizasyon için, uluslararası standardizasyon kuruluşu ve uluslararası elektroteknik komisyonu bilgi teknolojileri alanında özel bir sistem kurdu. Bu çalışmada, kurulan bu sistemin belirli standart kalite özellikleri kullanılarak, uygulama yapılan tedarik zincirinin problemli kalite özelliklerine odaklanılmıştır. SCOR metrikleri ve ISO karakteristiklerinden önemli olanları belirlemek için de BBH kullandık. ISO karakteristik özellikleri arasındaki kompleks ilişkileri belirlemek, yazılımın kalitesi için önemlidir. Ama tedarik zincirindeki paydaşlar, bu kompleks ilişkilerin yaratabileceği sonuçları kestirememektedir. Literatürde, ISO/IEC 25010 ve ISO/IEC 25012 standartlarındaki kalite karakteristiklerini kullanıp, bunların aralarındaki ilişkileri inceleyen bir BBH yöntemi bulunmamaktadır. Bu çalışmada aynı zamanda kurumların Blokzinciri seçim sürecine destek olabilecek Blokzinciri karakteristikleri de detaylı bir şekilde özetlenmiştir. Ayrıca, bir teknoloji tasarımının mimari özelliklerini değerlendirirken oluşabilecek ödünleşmeleri değerlendirmek önemli olduğundan, BBH metodu kullanarak Blokzinciri tasarım özellikleri arasındaki ödünleşmeleri de değerlendirdik. Literatürde Blokzinciri seçimi yapan çalışmalar ya tedarik zinciri odaklı ya da çok teknik yazılımsal konular içermektedir. Bu çalışmada uygulanan Bulanık KFY, tedarik zinciri ve yazılımla alakalı problemleri birlikte değerlendirme fırsatı sunmuştur. Son olarak, TOPSIS yöntemini kullanarak uygun bir blokzinciri alternatifi seçtik. Literatürde, entegre Bulanık BBH-KFY-TOPSIS yöntemi kullanılarak kurumlar için Blokzinciri seçimi yapan, ve özellikle Blokzinciri özellikleri arasındaki ödünleşmeleri inceleyen bir çalışma yoktur. Bu çalışmada kullanılan standart model ve süreç tanımları, tedarik zincirinde olması gerekli durumları destekler niteliktedir. Kalite özelliklerinde ve performans boyutlarında standart bir dil kullanılması, Blokzinciri teknolojisini daha anlaşılır kılmıştır; literatürde bu tarz çalışmalar da çok mevcut değildir. Ayrıca senaryo bazlı olarak uyguladığımız BBH yöntemi, bize farklı senaryolarda ortaya çıkabilecek sonuçları göstermesi bakımından fayda sağlamıştır. Farklı senaryolar, ortaya çıkması muhtemel olan sonuçları göstermiştir.

Anahtar sözcükler: Satınalma süreci, blokzinciri teknolojisi, BBH, Bulanık KFY, Bulanık TOPSIS

1. INTRODUCTION

As Hammer stated: 'Every good process eventually becomes a bad process' unless adapted and developed continuously to keep pace with the constantly changing customer requirements, technology, and competition (Dumas et al., 2018). The design and performance of the processes affect both the efficiency of services and customers' perceived quality of service (Dumas et al., 2018). Supply chains are supposed to modify their services to meet their customers' needs, which necessitates the coordination of participants in supply chains, covering processes like design, manufacturing, logistics, marketing, etc. (Hwang et al., 2008). Among the organizations with similar types of services, an organization with better processes can perform better than the others (Dumas et al., 2018). This is valid for customer-oriented external processes and internal processes like the procure-to-pay process to meet an internal requirement (Dumas et al., 2018). In this study, we primarily focus on a company's procurement process with problematic sub-processes that will be tackled in the application part of this study.

Success of an enterprise can be understood from economic, technological, and social perspectives (Komatina et al., 2019). Technology, particularly Information Technology (IT), is a principal instrument to advance business processes (Bashir, 2017). As a brand new technology, blockchain technology will change the way we handle transactions, and also the way business processes are managed by organizations (Mendling et al., 2018). Blockchain can eliminate intermediaries from transactions as buyers and suppliers can trade directly on this technology (Zhu & Kouhizadeh, 2019). This reduces costs and time in supply chains. If business processes are redesigned considering the potential benefits of blockchain technology, efficiency can be achieved (Milani & Garcia-Banuelos, 2018). Although bitcoin spread globally, cryptocurrency is not the only domain in this technology (Morabito, 2017). Therefore, the researchers have to explore the characteristics of blockchain technology that meet the needs of specific business processes (Mendling et al., 2018).

This study aims to support the blockchain technology selection decision of a supply chain in line with the requirements of its stakeholders, specifically focusing on the procurement process. We made a case study application considering the problematic supply chain metrics and software-related characteristics of the case supply chain using an integrated Cognitive Map-QFD-TOPSIS methodology to select an appropriate enterprise blockchain alternative. To the best of our knowledge, in literature, there is no QFD-Cognitive Map-TOPSIS integrated study on enterprise blockchain selection, specifically inspecting the trade-offs between blockchain characteristics. We used fuzzy logic throughout our study to address the vagueness of stakeholders' judgments.

Imprecise process and metric definitions, together with imprecise quality descriptions, can hurt the technology selection decision, and these definitions should be evaluated systematically. Technology selection requires the inspection of the entire supply chain, not just focusing on one process or its related activities. Since blockchains are suitable for systems that necessitate multiple participants, a process identification process should cover the requirements of both known and unknown organizations (Mendling et al., 2018) when selecting a suitable blockchain alternative for an existing system. A complete understanding of a business process is a prerequisite to performing process analysis, redesign, or automation (Dumas et al., 2018). As a basic modelling tool does not meet all criteria required for a good process description (Aoulaid, 2016), we produced an as-is process model for the case supply chain using the SCOR model and Business Process Modeling and Notation (BPMN) language better to understand business processes of the supply chain in detail; before making decisions about blockchain technology selection.

In this work, we focused on using standardized process, metric and quality definitions. Specifically, we used SCOR (Supply Chain Operations Reference) modelling since the case company has a vague and imprecise process and metric definitions. One of the open issues of procurement processes is the ambiguity in the relationships between

KPIs (Key Performance Indicators) of the procurement process (Abolbashari et al., 2018). SCOR ensures methodology, diagnostic and benchmarking instruments that support businesses to make striking and fast developments in supply chain processes (APICS, 2015). However, SCOR KPIs are complicated to manage without a systematic approach. There is not enough methodology to manage SCOR KPIs in literature, which is one of the most significant trouble in supply chain management (Akkawuttiwanich & Yenradee, 2018; Estampe et al., 2013). A company cannot satisfy all of its metrics, so they have to trade-off among the KPIs (Akkawuttiwanich & Yenradee, 2018). A trade-off is a property that impacts more than one attribute. In order to prioritize and eliminate SCOR metrics for the case company, we used Fuzzy Cognitive Map since there are positive and negative relationships between the SCOR metrics, and there is also a lack of crisp data.

The case supply chain processes are nearly automated, so more attention should be given to the software side to explore supply chain-related problems in detail. In addition, existing software characteristics and metrics are not understandable by the supply chain participants who have similar software systems. Hence, there is a significant need to examine software-specific problems and metrics systematically. In literature, blockchain technology studies in supply chains are either too supply chain-specific or too technical in software topics. However, supply chain and software perspectives need to be systematically linked to each other for the selection of a suitable blockchain alternative. In this study, we had an opportunity to meet supply chain topics with the software issues with the help of the Fuzzy QFD methodology. Software product quality indicates how much the critical needs (e.g., software purpose, performance, the usability of a product, and ease of maintainability) are satisfied (Nakai, 2016). If the quality is insufficient, the software product could cause high development or maintenance costs and violations of user needs (Nakai, 2016). More than 70% of companies apply quality models to their development processes (Nakai, 2016). However, organization-specific non-standard quality frameworks, metrics, and models are hard to compare since they focus on only the quality characteristics of interest (Nakai, 2016). The International Organization for Standardization (ISO) and the International Electro-technical Commission (IEC) established information technology guidelines for global standardization. In this study, ISO/IEC 25010 (ISO/IEC 25010, 2011) and ISO/IEC 25012 (ISO/IEC 25012) standard quality characteristics (product quality, quality in use, and data quality characteristics) were benefited, which enabled us to quickly determine problematic software quality characteristics of the case supply chain using a standardized language. Considering the problematic metrics of related product quality, quality in use, and data quality characteristics, problematic characteristics were chosen considering the metrics' gaps from the targets.

We followed a different approach for blockchain technology selection since it is not suitable to follow a standardized language considering the broader concept of the blockchain (Nanayakkara et al., 2021). Existing software selection procedures are either technology-based or domain-specific (Nanayakkara et al., 2021). Technology-based procedures deal with data structures, programming procedures, functionality, etc., while domain specifics handle selection processes for business domain needs (Nanayakkara et al., 2021). Hence, it is not appropriate to trace conventional software selection processes since blockchain has many different perspectives (Nanayakkara et al., 2021). After inspecting all blockchain features from the literature, we summarized blockchain characteristics to support blockchain selection decisions of enterprises. The summarized characteristics can also evaluate blockchains from a broader perspective, including their architectural characteristics, consensus mechanism, governance-dependent, business-related features, open-source, implementation-related, domain-specific features, and other features, including licensing and popularity. Therefore, the summarized characteristics are suitable to be customized for blockchain selection decisions of organizations. Considering the highly significant positive and negative relationships between ISO and blockchain characteristics separately, we used Fuzzy Cognitive Maps to determine these relationships and focus on the most significant ISO software and blockchain characteristics.

The cross-functional and multi-staged focus of QFD enabled us to reflect different functionalities' perspectives (from supply chain-related tasks to software-specific jobs) to the blockchain technology selection process. To specify product quality, quality in use, and data quality in the software architectural design, we used ISO quality characteristics in the design requirements part of QFD. In literature, there is limited study on the selection of blockchain alternatives. Choosing a feasible blockchain alternative may help to re-organize or re-design business processes to make them perform better. Hence, we used Fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal solution) methodology to select an appropriate blockchain alternative. In literature, there is not a QFD-Cognitive Map-TOPSIS integrated study on enterprise blockchain selection, primarily focusing on the trade-off analysis of blockchain characteristics. For a technology like a blockchain that is not yet mature, it is necessary to determine which standardized quality characteristics can be satisfied with which blockchain features. Using a standardized language in quality characteristics and performance dimensions (SCOR, ISO, etc.), blockchain became more understandable, also limited in the literature. Besides, blockchain characteristics were evaluated in detail to be able to support blockchain selection decisions.

In the environment of brand new technologies, there is uncertainty about how the future will be realized (Zhang & Jetter, 2018). Instead of handling these uncertainties, opinions about the future can be explored using scenario analysis, and different scenarios can be created (Zhang & Jetter, 2018). It is imperative to determine the complex relationships between performance criteria, considering their contribution to the result. However, stakeholders in the case supply chain cannot easily predict the complex relationships between performance metrics. In this study, various scenario analyses using Fuzzy Cognitive Map enabled us to consider different effects of different scenarios in our study. As blockchain has not been widely adopted yet, working on possible scenarios by emphasizing its various characteristics will help to understand and use it. SCOR metrics, ISO characteristics, blockchain design requirements, and enterprise blockchains' selection enabled us to support to-be processes of the existing supply chain.

The rest of this thesis is organized as follows. Section 2 provides the procurement process in supply chains. Section 3 outlines the blockchain concept. Section 4 explains the methodology, section 5 gives the application procedure and then a numerical example. Conclusions and future research directions are delineated in section 6.

2. PROCUREMENT PROCESS IN SUPPLY CHAINS

2.1 Supply Management Terminology

Managers responsible for supply chain processes have to obtain materials, services, and pieces of equipment in the right quantities, at the correct prices, at the right time, and the right quality (Leenders, 2006). The varying number of supplies with redundancy and deficiency cycles, changing prices, and delivery times cause difficulties for organizations who want to take advantage of competitive advantages (Leenders, 2006). Moreover, security, environmental and financial regulatory needs could cause significant complications for the organizations (Leenders, 2006). A typical purchasing process model and relevant concepts can be seen in Figure 2.1,

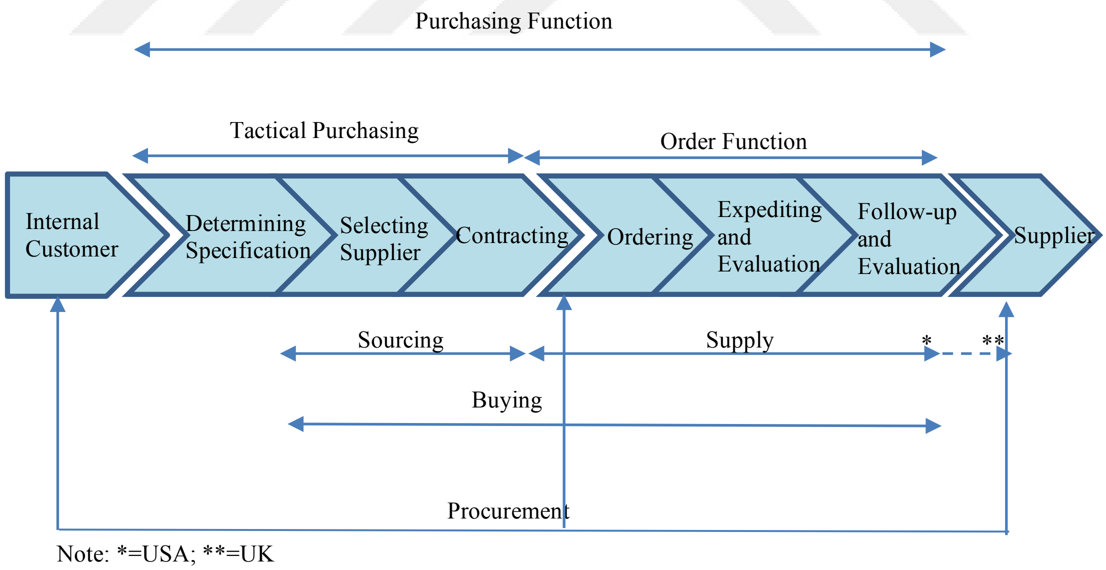

Figure 2.1: Purchasing process model and relevant concepts (Leenders, 2006)

Figure 2.1 shows the major activities in the purchasing function, and it is called as purchasing process model (Van Weele, 2009). It indicates the relations of these activities (Van Weele, 2009). The purchasing function does not cover the liabilities for deficiency planning of items, the timing of items, stock management, and quality control (Van Weele, 2009). However, purchasing must be firmly connected to materials activities (Van Weele, 2009). It also involves tasks between organizations, trade regulations, short-term personnel recruitment from external organizations, etc. (Van Weele, 2009). Therefore, the extent of the purchasing function is generally more extensive than the purchasing department (Van Weele, 2009).

'Ordering' means placing purchase orders under predetermined circumstances (Van Weele, 2009). This term is utilized when purchase orders are taken immediately by suppliers. Ordering can be regarded as a component of the purchasing process, and it also connects to the last three stages of the purchasing process (Van Weele, 2009). Tactical purchasing covers the first three stages of the purchasing process (Van Weele, 2009). However, it is hard to observe an explanation of buying in literature (Van Weele, 2009). It is distinct from the purchasing, as it does not cover the first step of the purchasing (Van Weele, 2009). This is compatible with trade-in retail organizations (Van Weele, 2009). Buying is about collecting bids from a finite number of suppliers and contracting for the lowest bid (Van Weele, 2009). Purchasing is distinct from buying and ordering in one significant way (Van Weele, 2009). There are certain specifications in ordering and buying, while the situation is different in purchasing. Whether the specifications comply with the objective or not is debatable (Van Weele, 2009). Procurement is a term that covers a slightly larger area, as shown in Figure 2.1 (Van Weele, 2009). It involves all operations necessary for supplying and delivering products to customers (Van Weele, 2009).

'Supply' is among the generally utilized statements for materials (Van Weele, 2009). However, it is hard to understand it since there seem to be variances between North America and Europe (Van Weele, 2009). In the United States, it covers the store function of items like cleaning items (Van Weele, 2009). 'Supply' in the United Kingdom and Europe appears to mirror an extensive definition that involves purchasing, stores, and receiving (Van Weele, 2009). Another popular term in materials is 'sourcing' that concerns the advancement of a proper supplier strategy for a specific product (Van Weele, 2009).

Purchasing means to do five rights: ensuring the right quality, quantity, time and price, and from the right source (Trent & Monczka, 1998). Purchasing and procurement can be used interchangeably (Trent & Monczka, 1998). Conceptually, supply management is broader than procurement (Trent & Monczka, 1998). Supply management is a developing approach to handle supply base that differs from conventional approaches (Trent & Monczka, 1998). It necessitates procurement experts to work with suppliers who can provide high performance and benefits to the purchaser (Trent & Monczka, 1998). Supply management can be considered an advanced type of basic procurement (Trent & Monczka, 1998). Thinking of supply chains as a set of organized processes makes sense. Processes often move between functional borders that are compatible with a supply management and supply chain orientation.

2.2 Why Procurement Is Important?

As the desire for novel goods rose in the 1980s, companies were pushed to be resilient and sensible to change their products or services (Trent & Monczka, 1998). As organizational skills developed throughout the 1990s, executives discovered that suppliers considerably influenced their power to satisfy customer requirements (Trent & Monczka, 1998). This led to the center of the interest on the supply base and procurement liabilities (Trent & Monczka, 1998).

As the enabler of obtaining products and services, Procurement is unquestionably a mandatory department of any working environment (Abolbashari et al., 2018). In addition, procurement operations have become more complicated with the properties it provides, so procurement necessitates the collaboration of various departments to reach its ultimate target (Abolbashari et al., 2018). Efficiently managed supply chains ensure competitive benefits, and procurement is crucial to gaining such a benefit (Gustin et al., 1997). Ellram and Carr, 1994; Carr and Pearson, 1999; and Abdollahi et al., 2015 clarify the significance of procurement as an assistance activity and as a strategic instrument for the performance of a business. While the present theoretical frameworks about procurement will stay in their primary functional point of view, the procurement function will turn into a more strategic and innovative character **(**Bienhaus & Haddud, 2018). Procurement covers the whole management liabilities that procurement administrators should focus on involving sourcing, accessing, and directing resources outside the organization. Furthermore, it is required to accomplish strategic purposes to aid companies in obtaining significant business value (Jahani et al., 2021). As a strategic network node within the supply chain ecosystem, procurement facilitates companies to manage their data and connect various procurement functions to distinct companies to form an intelligent master supply chain environment (Bienhaus & Haddud, 2018).

It is not hard to understand why procurement is an important area for cost savings (Trent & Monczka, 1998). Savings can be in varied forms (Trent & Monczka, 1998). Playing a communicative role between engineers and suppliers, procurement can help develop product and process design (Trent & Monczka, 1998). In the production sector, the ratio of purchases to sales is 55% on average, which means that more than half returns to suppliers for each dollar of income from selling the goods and services. In more improved companies, various spend categories such as energy, IT, logistics, etc., are among the procurement responsibilities (Leenders, 2006). Procurement especially has an extensive effect on health-related decisions, and it has a significant task (Miller et al., 2019). Health-related expenses circulate between purchasing offices (Miller et al., 2019). The importance of procurement's task has stimulated improved inspection, with increasing invitations for "evidence-based" and "value-based" frameworks and large cooperation with health technology assessment (HTA) (Miller et al., 2019).

Today, considering digital technology, procurement has switched from a conventional to an electronic form, which can be defined as an extensive ICT process to install agreements (Xu et al., 2021). This electronic form can handle specific drawbacks of conventional procurement systems like low transaction security, lack of trust, repeated verifications, and payment delays (Xu et al., 2021). In addition, the fourth industrial revolution has remarkably altered the conventional style of supply chain management (Jahani et al., 2021). The Industry 4.0 (I4.0) technologies like the Internet of Things (IoT) and Artificial Intelligence (AI) in various processes of supply chains have supported organizations to develop their performance (Jahani et al., 2021). In literature, highly used I4.0 implementations are cloud computing, data mining, big data analytics, artificial intelligence, internet of things, cloud robotics, cloud manufacturing, blockchain, cyber-physical system, simulation, robotics, etc. (Jahani et al., 2021). These novel I4.0 technologies have a high potential to decrease the drawbacks and complications in procurement processes, which should be carefully evaluated.

2.3 Supply Chain Performance Measurement

In literature, only one component of Supply Chain Performance Measurement Systems (SCPMSs) is generally addressed at a time, depending on the internal or external content of SCPMS metrics (Maestrini et al., 2017). Internal SCPMS deals with monitoring and control of the processes that occur in the company's borders as stated by Chen (2015), while external SCPMS focuses on intercompany processes that include supplier and customer performance measurement systems as stated by Falagario et al. (2012), Blome et al. (2014) and Lima-Junior & Carpinetti (2016).

There are different approaches in the literature for SCPMS frameworks. The Balanced Scorecard (BSC) and SCOR models are among the well-known approaches. BSC, developed by Kaplan and Norton (1992), has four views: financials, customer, learning and growth, internal processes (Maestrini et al., 2017). The BSC aims to design a strategy compatible with the company strategy, involving critical success factors in these four views (Maestrini et al., 2017). In this approach, a general balance is desired between short and long term, internal and external focus, the four BSC views, and different stakeholders' views (Akyuz & Erkan, 2010). However, methods and metrics of measurement are not entirely described in the Balanced Scorecard model (Komatina et al., 2019). SCOR was first introduced in 1996 and updated regularly to keep pace with the modifications in business practices of supply chains (APICS, 2015). To achieve the business goals, the output of the supply chain process should be measured and checked against a set of standards (Akkawuttiwanich & Yenradee, 2018). SCOR can be implemented to all businesses of industry and service sector, at tactical and operational levels to apply decisions regarding the company's strategic planning (Estampe et al., 2013).

The SCOR model is widely applied to different performance measurement issues (Akkawuttiwanich & Yenradee, 2018). For example, Hwang et al. (2008) analysed the SCOR sourcing processes and their related metrics for Taiwan's thin-film transistor-liquid crystal display (TFT-LCD) industry. In literature, several frameworks cover internal supply chain operations and external metrics that cross the company's borders within the source and delivery processes, like the SCOR model (Maestrini et al., 2017).

To manage the supply chain performance, it is necessary to align performance metrics with the company's fundamental aim and significant problems (Chand et al., 2020). Supply chain performance management is inherently dynamic because of the increased complications created by components such as global sourcing, mass customization, decreased product life cycle, and technological corruption (Chand et al., 2020). In most applications, once the performance measurement process is designed, they stay unmodified for a long time, and the measurement process is assumed as static (Sokar et al., 2011). However, the measurement process is dynamic; particularly, the KPIs can become outdated because the business atmosphere modifies fast (Sokar et al., 2011). Hence, it is significant for the company to repeatedly update and modify its strategic targets to keep pace with the changing business atmosphere (Sokar et al., 2011). To be able to trace and assess the objectives at the project outcome level, steps that should be followed to convert objectives into performance metrics are: analyzing the objective, metric design and choosing, consideration of data to define metrics, identification of baseline data, and objective values for the metrics (ADB, 2012). In this study, we inspected KPIs considering the overall projects of the case company. However, it is recommended to update and change KPIs as the business atmosphere changes dynamically.

2.4 Performance measurement in procurement

The advantages of a good supply performance evaluation are: ensuring data for corrective activities, improving relationships, emphasizing staff requirements, documenting the probable requirements of supplementary resources like information technology, ensuring information to directors, and developing motivation with the help of rewards (Leenders, 2006). Therefore, performance evaluation of suppliers and performance evaluation of supply management are the two essential fields for a world-class supply company, which are connected since suppliers' participation is vital (Leenders, 2006).

In literature, there are different procurement measurement practices in different topics such as procurement performance measurement (Kumar & Ozdamar, 2005), (Chen, 2015), (Saad et al., 2016), procurement management (Abolbashari et al., 2018), contract management (Rendon, 2008), sustainable procurement (Walker & Brammer, 2012), internal control of procurement circulation (Chen, 2015), supplier evaluation and selection (Falagario et al., 2012), (Lima-Junior & Carpinetti, 2016) and green procurement and green supplier development (Blome et al., 2014). Procurement measurement practices can be seen in Table 2.1,

Table 2.1: Procurement measurement practices in literature

Focus Area	**List of works**
Make or buy	(Arya et al., 2014), (Moschuris, 2015), (Pakir Mohamed & Kamarudin, 2013), (Rolstadås et al., 2012)
Supplier selection	(Fonseca & Lima, 2015) , (Mak & Nebebe, 2016) , (Kisly et al., 2016) , (Neumüller, 2016)
Supplier management	(Sharples & Domingue, 2015), (Carboni, 2015), (Fonseca & Lima, 2015), (Zimmer et al. 2016)
Supplier performance evaluation	(Shen et al., 2013), (Dey et al., 2015), (Malik et al., 2016)
Sustainable procurement	(Brammer & Walker, 2011), (Venkatesh & Luthra, 2016)
Supplier development	(Awasthi & Kannan, 2016), (Dou et al., 2014), (Sarang et al., 2016),
Contract Management	(Rendon, 2008)

To understand the significance of procurement in forming the relations between distinct sides of supply chains, it is necessary to determine how the procurement function is measured and perform the development programs accordingly (Abolbashari et al., 2018). In literature, there are different approaches, particularly on procurement performance, which can be categorized considering their focus fields. Some of these works emphasize the development of procurement metrics (Abolbashari et al., 2018). For instance, Kestenbaum and Straight (1995) propose some KPIs to measure procurement quality, effectiveness, and efficiency in the United States of America government. Caniato et al. (2014) define widely accepted metrics and main items in purchasing performance within distinct industries via a case-based exploration. Kakwezi and Nyeko (2019) investigate financial and non-financial factors that influence procurement performance in their government. Some of these works are concerned with measuring and developing procurement performance (Abolbashari et al., 2018). For example, Kerkfeld and Hartmann (2012) use a Fuzzy AHP (Analytic Hierarchy Process) to rank procurement evaluation criteria in the automotive industry. Rendon (2008) provides a contract management maturity model to evaluate, measure, and develop procurement performance. Lastly, the remaining works emphasize the design of a procurement performance measurement framework. In literature, procurement performance measurement practices are not much concerned with the strategic idea of procurement that overlaps with different disciplines or departments (Abolbashari et al., 2018). Instead, these practices measure the effectiveness of procurement by evaluating it as a stand-alone function focused on a sole department (Abolbashari et al., 2018).

Various types of approaches have been utilized for procurement performance measurement and management, such as multiple regression (Walker & Brammer, 2012), Bayesian network (Abolbashari et al., 2018), Data Envelopment Analysis (Falagario et al., 2012), multiple case study analysis (Chen, 2015), structural equation modelling (Blome et al., 2014), Fuzzy TOPSIS (Lima-Junior & Carpinetti, 2016), Fuzzy AHP (Saad et al., 2016) and hybrid dynamic MCDM (Chen, 2015). These approaches may be advantageous or disadvantageous depending on the situation. For example, Data Envelopment Analysis considers only efficiency and not necessarily effectiveness (Abolbashari et al., 2018). Furthermore, there is not a standard model to measure the performance of an enterprise or business process, so the selection of an optimal model depends on several aspects: the aim of the model, the complexity, the KPIs, the organizational level, etc. (Komatina et al., 2019). When it comes to methods, AHP can be time-consuming when there are many alternatives (Abolbashari et al., 2018). On the other hand, DEMATEL, ANP (Analytic Network Process), and Bayesian Network approaches are advantageous when interdependencies between evaluation criteria. Some studies have used the terms effectiveness and efficiency (Abolbashari et al., 2018; Saad et al., 2016; Kumar & Ozdamar, 2005). Effectiveness is about whether the primary aims of procurement are satisfied or not, while efficiency means whether the secondary aims are satisfied (Abolbashari et al., 2018). Kumar and Ozdamar (2005) defined purchasing efficiency using purchasing materials costs/prices, quality of purchased materials, and purchasing logistics. They defined purchasing efficiency using purchasing organizations that include personnel, management, procedures, policies, and information system.

In literature, procurement performance measurement practices focus on only one side of procurement that considers it a sole discipline, such as contract management or supplier management. Focus areas vary from the healthcare industry to the automotive industry as a framework, theory, and survey practices. Only a few of these practices use various KPIs; they generally focus on only one dimension like cost. Moreover, these practices do not focus on fuzziness in their evaluations. Procurement performance measurement practics can be seen in Table 2.2,

Table 2.2: Procurement performance measurement practices

Topic	Focus Area	Methodology	Different KPIs	Fuzzy Numbers	F/T	Survey
Procurement Performance Measurement (Kumar & Ozdamar, 2005), (Pohl & Förstl, 2011), (Saad et al., 2016)	Healthcare Industry (Kumar & Ozdamar, 2005)	Balanced Scorecard	*		*	*
	Automotive Industry (Saad et al., 2016)	Fuzzy AHP	*	*		*
	Purchasing Competence (Pohl & Förstl, 2011)	Multiple Case Study Analysis	*			*
Supplier Selection, Supplier Evaluation, and Management (Falagario et al., 2012), (Blome et al., 2014), (Lima-Junior & Carpinetti, 2016)	Public Procurement (Falagario et al, 2012)	Data Envelopment Analysis			*	*
	Green Procurement (Blome et al., 2014)	Structural Equation Modelling	*			*
	Supplier Development (Lima-Junior &	Fuzzy TOPSIS, SCOR	*	*		*

	Carpinetti, 2016)					
Procurement Management (Abolbashari et al., 2018)	KPIs	Bayesian Network	*		*	*
Procurement circulation (Chen, 2015)	Internal Control	DEMATEL, DANP, VIKOR				*
Contract Management (Rendon, 2008)	Public Procurement	Contract Management Maturity Model	*		*	
Sustainable Procurement (Walker & Brammer, 2012)	E-procurement	Multiple Regression			*	*

F/T: Framework/Theory

There should be more study on procurement performance measurement considering procurement as a comprehensive function since it is a strategic discipline when considering various topics such as supplier development and contract management. In addition, using different kinds of KPIs in evaluations can satisfy multiple-sided characteristics of procurement in nature. Besides, procurement is a highly complex function, and this complexity generally creates fuzziness in evaluations. Hence, also using fuzzy numbers in evaluations can eliminate vagueness in procurement-related decisions. In this study, the Fuzzy QFD method enabled us to consider different KPIs in a fuzzy environment. Besides, Fuzzy Cognitive Map enabled us to discover the relationships between these KPIs in detail.

2.5 The Challenges in Procurement Performance Measurement

An old proverb says, "If you do not measure it, you cannot manage it," which is still valid today (Leenders, 2006). Managers are aware of the necessity of performance evaluation and the difficulties in advancing expressive supply metrics and assessment procedures (Leenders, 2006). Procurement performance is highly significant for purchasing departments that handle products, services, and other various solutions, consistently among the fundamental principles of industries and organization-related trade (Chavan et al., 2020). Weak procurement management applications can cause unfavourable effects in the procurement network (Sayyed et al., 2021). Hence, the chosen procedure and the criteria to determine procurement strategy are highly significant for a company (Sayyed et al., 2021). Moreover, some analysts even evaluate a firm's procurement management as one of the critical elements affecting its innovation behaviour (Sayyed et al., 2021).

In literature, procurement performance frameworks are mostly suggested for production companies; however, Chavan et al. (2020) focused on this point and evaluated the factors that affect the performance of engineering, procurement, and construction (EPC) organizations. The authors intend to empirically confirm an integrated framework, integrating fuzzy AHP and QFD that is utilized to establish a procurement performance matrix for engineering, procurement, and construction organizations; which is original and distinctive since procurement performance frameworks of engineering, procurement, and construction companies do not have been studied extensively and also empirically in literature. In another study, Sayyed et al. (2021) aim to explore the impact of innovation level on a particular project performance while evaluating the impact of a collaborative procurement management scheme. Besides, the authors improve the viewpoints of construction management about making plans to facilitate the application of innovative products, services, processes, and procedures to develop the entire firm's performance. In another study, Gnoffo (2021) aims to establish causal relationships between deterioration in public procurement and regional administrations' performance. In the construction industry, procurement management is often project-based, and subcontractors lack trust and cooperation (Sayyed et al., 2021). The average time and expenditure excess is mainly linked to different project features such as project place, project type, industry, and project period (Habibi et al., 2019). Therefore, it is significant to determine the main reasons for weak performance and reduce the potential threats to accomplish massive performance alterations (Habibi et al., 2019).

There are challenges to procurement performance measurement and management topics, and some issues are controversial. First of all, in literature, existing approaches evaluate the effectiveness of purchasing, defining it as a sole operation that emphasizes only one department (Abolbashari et al., 2018). For instance, studies in the literature have developed procurement applications such as make-or-buy options (Puranam et al., 2013), supplier selection (Yadav & Sharma, 2016), and supplier evaluation (Bruno et al., 2012). These procedures generally focus on separate roles of the purchasing function, and they do not determine all procurement operations as a system for strategic activity (Abolbashari et al., 2018). Moreover, it is necessary to have an exact definition of a procurement requirement in organizations, whether it is a material or a service (Leenders, 2006). Besides, there is a lack of a decision-making mechanism in contradictory situations (Abolbashari et al., 2018). Multiple aims like cost and environment in procurement processes can be conflicting. There are not enough studies on multi-objective structured cases (Abolbashari et al., 2018). Additionally, a small number of organizations utilize formalized evaluation frameworks to assess the performance of procurement functions. However, these frameworks are significant for B2B marketing and supply chain management, valid for engineering, procurement, and construction projects (Chavan et al., 2020).

2.6 Metric Determination

Supply chain performance metrics aim to symbolize the whole supply chain strategy of the company (Chand et al., 2020). Therefore, an apparent interrelationship between the metrics can be explored; metrics can represent even more than one fundamental characteristic (Chand et al., 2020). One of the open issues in procurement is the ambiguity in the relationships between the KPIs of the procurement process (Abolbashari et al., 2018). Although all KPIs should be determined to accomplish an optimum output for the procurement process, determining relationships is still a significant problem (Abolbashari et al., 2018). For supply chain performance assessment, measurement models (i.e., extended BSC and SCOR) have limitations (Cai et al., 2009). There are many different measures utilized in the supply chain context (Cai et al., 2009). Although these measures present beneficial information for decision-making, choosing and trading-off so many measures to get efficient and significant development strategies is a challenging mission for distinct supply chain members. This study evaluated SCOR performance metrics using the Fuzzy Cognitive Map, determining both positive and negative relationships between these metrics.

Most of the KPIs in supply chains are correlated and have complex cause and effect interactions in practice (Cai et al., 2009). This means that KPI achievement is highly iterative and interactive (Cai et al., 2009). It is a widespread achievement of one KPI to cause additional cost or struggle for other KPIs, because of different reasons such as incomplete data, limited resources, or communication obstacles (Cai et al., 2009). To demonstrate these relationships, KPI pairs that have high correlations with each other have to be defined (Cai et al., 2009). The nature of such pair-wise relationships can be categorized into three parts: parallel, sequential, and coupled (Cai et al., 2009). In a parallel relationship, two KPIs are independent of each other, i.e., the attempts of achieving these two KPIs are not related (Cai et al., 2009). A sequential relationship generally means a simple cause-effect relationship (Cai et al., 2009). An attempt to achieve a KPI causes the extra cost to another (Cai et al., 2009). For instance, attempts to achieve the goal for ‘production costs’ KPI will usually cause additional efforts and/or cost for achieving ‘customer satisfaction’ KPI, though the opposite dependence does not usually hold.

KPI relationships can also be examined using the techniques like AHP and ANP (Abolbashari et al., 2018). AHP merely specifies the “weight” or relative significance of individual KPIs; it does not determine the relationships between KPIs and their role in achieving attempts which are very significant for continuous supply chain performance development in a dynamic atmosphere (Cai et al., 2009). Ahi and Searcy (2015) proposed a conceptual study for supply chain performance measurement and focused on prioritizing particular metrics suitable for the companies’ situations. Maestrini et al. (2017) inspected the supply chain performance measurement frameworks. They focused on the necessity for integrating different types of metrics indicating different parts of the supply chain rather than an individual examination of metrics.

Every company does not need to consider all of these KPIs (Abolbashari et al., 2018). The choice of KPIs to determine in the model is up to the company being evaluated (Abolbashari et al., 2018). Celik and Akyuz (2018) used AHP and TOPSIS to choose a suitable ship-loader type in maritime transportation, including sensitivity analysis to explore the influence of different KPIs under various situations. Chand et al. (2020)

used the Delphi method to determine critical SCP metrics, and then they applied DEMATEL to determine relationships between SCP metrics. The authors selected the top ten metrics from the importance of cumulative representation for further evaluation using DEMATEL. Gonçalves et al. (2015) proposed a new framework for choosing maintenance KPIs using the ELECTRE method. They determined a set of criteria for maintenance KPI evaluation: maintenance quality, maintenance objectives, KPI influence, and understanding and interpretation of KPI.

The excess number of criteria causes expensive computations and comparisons, particularly in subjective factor prioritization procedures (Altay & Kayakutlu, 2011). Decreased number of criteria produces deviations in computations and causes loss of information (Altay & Kayakutlu, 2011). Hence, factor elimination must remove an insignificant amount of information without causing the judgment to go beyond the sensitivity limits of the problem (Altay & Kayakutlu, 2011). Qualitative and quantitative procedures are available for criteria elimination, but quantitative procedures are more reliable and robust (Altay & Kayakutlu, 2011). Cognitive maps are broadly adopted as instruments for criteria evaluation, prioritizing, and elimination (Altay & Kayakutlu, 2011). Altay and Kayakutlu (2011) eliminated the last ten criteria from evaluations using Cognitive Map, which have a total weight of 10% and are insignificant for evaluations. They stated that a threshold for the centrality value could be determined to eliminate the criteria. Sokar et al. (2011) made goal arrangements using trade-off analysis in Fuzzy Cognitive Maps. One of the fundamental advantages of using Fuzzy Cognitive Maps is that it has an if-then scenario analysis, including a change of one KPI. Its impacts can be explored before the KPI modification is applied in a real-world application (Sokar et al., 2011).

Regarding the techniques used for metric selection, specifically MCDM methodologies, there is no standard approach to eliminate KPIs, mainly focusing on KPIs' importance degree. In this study, we followed a common approach to focus on important KPIs focusing on their importance degrees above the average. However, the scenario-based Fuzzy Cognitive Map enabled us to consider the other probable metrics in our evaluations.

2.7 Systems Generally Used in Procurement Processes

2.7.1 Supply Chain Technologies and Firm Performance

In many companies, determining and simplifying business processes for cost reduction, revenue increase, and asset management seems advantageous (Leenders, 2006). Managing business processes, exploring efficient processes, and exploring the interactions between processes and activities are crucial for successful performance in companies (Leenders, 2006). However, knowing how and when to implement information technology solutions continues to be challenging. (Leenders, 2006). The first thing to evaluate is the decision of the process that will be worth an efficient solution.

The procurement process is nearly linked to whole other business processes, causing a requirement for a mature information system and cross-functional cooperation (Leenders, 2006). Procurement should work with engineering to assign specifications and should also work with operations to assign production schedules and finance to coordinate payments (Leenders, 2006). Over the past 30 years, there have been notable developments in information technology utilized to record, transfer, and analyse information in companies and related supply chains (Leenders, 2006). Procurement managers should keep up with technological improvements and evaluate the suitability of new tools to the company’s aims. Another significant decision focuses on what information systems should be used to activate efficient business processes.

Supply Chain Management coordinates business functions, such as forecasting, manufacturing, procurement, logistics, distribution, marketing, and sales (Vijayasarathy, 2010). Effective coordination of these functions often requires the use of new processes and/or reengineering of existing processes to enable the efficient and effective flows of products and information among supply chain parties (Vijayasarathy, 2010). A supply chain transformation can be in two categories. The first category tries to improve supply chain strategy and operation. In contrast, the second category is more IT-oriented and focuses on either the new IT frameworks or upgrading current IT systems like ERP (Dong et al., 2006). The IT-oriented category focuses on supply chain visibility and operational efficiency using advanced IT systems (Dong et al., 2006).

Earlier technologies, such as Electronic Data Interchange (EDI), have enabled data exchange between two sides for high-volume transactions involving purchase orders and invoices between a supplier and manufacturer (Anderson et al., 2017). However, as this process extends to multi-party transactions, it becomes unsuitable and inefficient (Anderson et al., 2017). The more parties included and the greater the requirement for speed, the higher the risk of data being lost along the process (Anderson et al., 2017). In literature, a limited number of studies focused on new technologies for performance improvements in supply chains. One of these technologies is cloud technology; a virtualized IT resource that can be scaled considering the type of service, payment alternatives, and privatization (Schniederjans & Hales, 2016). A growing trust in the utilization of Internet-of-things (IoT) implementations is among the trends that will influence supply chain management (Kshetri, 2018). Using the IoT (Internet of Things), Radio-frequency Identification (RFID) tags, sensors, barcodes, GPS (Global Positioning System) tags, and chips, the locations of products, packages, and shipping containers can be traced in real-time (Kshetri, 2018).

Big data and data analytics have caused significant modifications and advancements in organization management and decision making (Yadegaridehkordi et al., 2018). Yadegaridehkordi et al. (2018) inspected the effect of big data adoption on firms' performance using an integrated DEMATEL-ANFIS methodology. Verboeket and Krikke (2019) inspected the influence of Additive Manufacturing (AM) on supply chain design using the SCOR model. The authors found that AM mainly affected supply chain cost and responsiveness. Gunasekaran et al. (2001) focused on the requirement for performance measurement and metrics concerning the technological investments along the supply chain. In literature, there is not much work on evaluating performance measures to help understand new technologies.

2.7.2 Traditional Relational Database Management Systems (RDBMS)

Conventionally, software systems keep data in Relational Database Management Systems (RDBMS) and sometimes use other data storage methods such as File systems to store documents (Rath, 2019). Administrators employed by the database owners use these systems. They are responsible for maintaining the database, providing data integrity, and ensuring secure access to users according to their roles (Rath, 2019). In addition, this centralized authority maintains the database and provides administrative tasks such as making backups (Rath, 2019).

However, distributed ledger technologies, also known as blockchains, are getting more recognized with decentralized data stores than conventional data storage systems (Rath, 2019). Blockchain has distinctive features like consensus mechanism, decentralization, built-in trust, and low entry barriers to joining the network, attracting many different areas to adopt blockchain (Rath, 2019). Furthermore, the cost model of data storage on the blockchain is different from traditional data storage (Xu, 2017). Even though it may seem more costly, storing data on blockchain offers a one-time cost for permanent storage (Xu, 2017). Nevertheless, to safely develop an enterprise application using a distributed ledger as its primary database, we must ensure that all necessary services assisted by existing systems (firstly RDBMSs) can be efficiently provided through distributed ledgers (Rath, 2019).

With the use of traditional RDBMS, the following limitations emerged: (Rath, 2019)

1. Transparency: When data in the RDBMS is updated or altered, the modifications are not visible to users (Rath, 2019).
2. Immutability: Once the data is added to the RDBMS, it can be modified at any time (Rath, 2019).
3. Openness: The RDBMS is not mostly open since enterprises own them (Rath, 2019).
4. Data Formats: Before storing the data in RDBMS, it should be engineered (normalized and interlinked with foreign keys) (Rath, 2019). This situation decreases flexibility; different data sources with distinct data formats cannot use RDBMSs to store data (Rath, 2019).

Conventional shared data stores have consensus protocols to synchronize replicas in a wholly trusted condition, such as 2-Phase Commit and Paxos (Xu et al., 2016). However, blockchain consensus protocol aims to tolerate Byzantine Generals' problem, in which system components intend to achieve an agreement to handle correct transactions despite a faulty component (Xu et al., 2016).

2.7.3 Centralized, Decentralized, and Distributed Systems

The 21st century's significant Internet architectural movement is the rise of cloud computing. Businesses like Google, Amazon, Apple, Microsoft, and Facebook now operate big data centres that function as platforms for network activity (Werbach, 2018). Cloud computing shows vast progress in the capability and scalability of services transferred to users and companies (Werbach, 2018). However, just a few businesses have the resources and specialty to compete (Werbach, 2018). Moreover, with the expanding strength of cloud super-giants and the revelations about broad government surveillance over online activity, an increasing number of technologists and entrepreneurs are speaking about decentralizing the Internet (Werbach, 2018).

Many people are familiar with "application" since it relates to software (Raval, 2016). A software application is a software that describes a specific purpose (Raval, 2016). There are many software applications are recently available, and the more significant part of web software applications use a centralized server-client framework (Raval, 2016). Some software applications are distributed, and several new ones are decentralized (Raval, 2016). Distributed computation is extended across various nodes instead of only one (Raval, 2016). Decentralized is a node that can't instruct other nodes on what to do (Raval, 2016). The three different types of software applications can be seen in Figure 2.2,

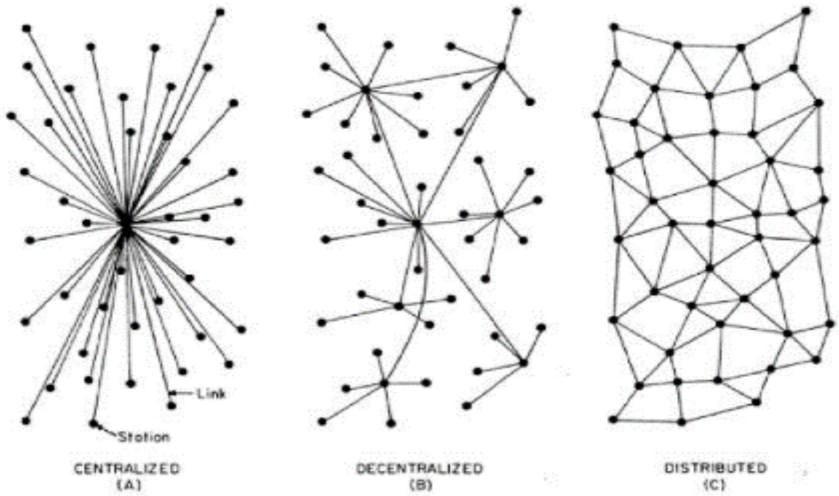

Figure 2.2: The three types of software applications (Raval, 2016)

Centralized systems are nowadays the most widespread systems for software applications (Raval, 2016). Centralized models directly control the flow of information from a single point (Raval, 2016). Facebook, Amazon, Google, and every other established service we use on the internet employs this model (Wu, 2017). These giant services can be called 'Stacks' (Raval, 2016). The Stacks are beneficial services since they ensure good services, but they have massive failures (Raval, 2016).

Every network architecture has its advantages and trade-offs (Amazon AWS). For instance, decentralized blockchains, unlike distributed systems, prioritize security over performance (Amazon AWS). Hence, when a blockchain system scales up or out, the system becomes more secure, but it slows down as every node must validate all the data joined to the blockchain (Amazon AWS). Adding nodes to a decentralized architecture can make it secure, but it does not always make it faster (Amazon AWS). Comparison of centralized, distributed, and decentralized systems can be seen in Table 2.3,

Table 2.3: Centralized, distributed, decentralized systems (Amazon AWS)

	Centralized	Distributed	Decentralized
Network/hardware resources	Maintained & controlled by a single entity in a centralized location	Spread across multiple data centres & geographies; owned by the network provider	Resources are owned & shared by network members; hard to maintain as no one has it
Solution components	Maintained &	Maintained &	Each member has the

	controlled by a central entity	controlled by the solution provider	exact copy of the distributed ledger
Data	Maintained & controlled by a central entity	Typically owned & managed by customer	Only added through group consensus
Control	Controlled by a central entity	Typically, a shared responsibility between network provider, solution provider & customer	No one owns the data & everyone owns the data
Single Point of Failure	Yes	No	No
Fault tolerance	Low	High	Extremely high
Performance	Maintained & controlled by a central entity	Increases as network/hardware resources scale up and out	Decreases as # of network members increase
Example	ERP system	Cloud computing	Blockchain

In centralized systems, network and hardware resources are maintained and controlled by a single entity, while in distributed systems, these resources spread across data centres and geographies (Amazon AWS). In decentralized systems, resources are owned and shared by network members (Amazon AWS). Solution components in centralized systems are maintained and controlled by a central entity, while in distributed they are maintained and controlled by solution providers (Amazon AWS). In decentralized systems, each member has an identical copy of the distributed ledger. Centralized systems have a single point of failure. Decentralized systems have extremely high fault tolerance. ERP systems, cloud computing, and blockchain are such systems.

Although there is not much work to compare different technologies to the blockchain, the decentralization trilemma may help understand the difference. The decentralization trilemma specifies that a system can just have two of security, scalability, and decentralization, but not all the three simultaneously. In this regard, a system can be secure and scalable, but it can’t be decentralized (Halpin, 2020). According to Halpin (2020), Google and other cloud-based frameworks are suitable for this category. A system may be decentralized and scalable, but it may not satisfy security like Bittorrent technology (Halpin, 2020). Finally, a system may satisfy decentralization and security, but it may not satisfy scalability; blockchains are suitable for this group (Halpin, 2020).

2.7.3.1 Cloud Technology

The main advantage of using one of cloud alternatives is to be able to digitize and scale your work in a way which is more time and cost effective (Rabit Software, 2019). Properties like elasticity, scalability, universal access, low entrance cost, and flexible billing prompt customers to move their businesses to the cloud (Yimam & Fernandez, 2016). However, this creates security, privacy, and compliance problems (Yimam & Fernandez, 2016). Security characteristic refers to particular security protection against specific attacks (Rath, 2019). In cloud technology, the applications and services are offered thanks to the Internet, so it is vulnerable to different types of external security risks like denial-of-service (DoS) and distributed denial-of-service (DDoS) attacks (Rath, 2019). Besides, trust, confidentiality, and privacy are also significant problems since data is held by the cloud service provider, especially in the public cloud deployment (Rath, 2019). Data loss is possible when it is preferred to trust a cloud service provider (Rabit Software, 2019). For example, if an Infrastructure as a Service (IaaS) provider's system collapses, so will yours (Rabit Software, 2019). Hence, it is necessary to control if they have an extensive recovery design and policy before deciding (Rabit Software, 2019).

Google Cloud Platform, Amazon Web Services, IBM Cloud are IaaS examples (Rabit Software, 2019). Platform as a service (PaaS) ensures a cloud framework delivering customers to develop, run and manage applications (Rabit Software, 2019). PaaS Examples are Heroku, Microsoft Azure, and Google App Engine (Rabit Software, 2019). SaaS has the lowest cost among other cloud services with the highest level of trust in the software provider (Rabit Software, 2019). Everything is operated by a cloud service provider, which may cause problems related to privacy and data security compliance problems (Rabit Software, 2019). SaaS instances are Office 365, Semrush, Asana, Salesforce, Planning Pod, and Dropbox (Rabit Software, 2019).

Seeting up servers internally (on-premise) creates a higher level of security and flexibility than external storage (Rabit Software, 2019). Moreover, not using outsourced suppliers can guarantee compliance with GDPR (General Data Protection Regulation) with much less complexity (Rabit Software, 2019). Select the hybrid choice if it is needed to use data in-house and with outside participants (Rabit Software, 2019).

2.7.3.2 ERP systems

Blockchain integration can make ERP systems more secure (Benjamin, 2020). When it comes to ERP and the way it works, ERP combines the information and procedures of a company into a single system and a single database (Benjamin, 2020). The database has the function to be the centre for sharing and storing information within various functions of the company (Benjamin, 2020). The ERP software contains different integrated modules, which can be customized for the company's needs (Benjamin, 2020). Currently, there are two types of ERP systems in the market,

2.7.3.2.1 On-Premise ERP System

On-premise ERP is the conventional type of ERP (Benjamin, 2020). Here, IT is installed on the client location. On-premise ERPs are customized according to the needs of an organization (Benjamin, 2020). This kind of system is relatively expensive (Benjamin, 2020). The application and training take time mush time up to 36 months. Companies choose on-premise ERPs for the confidentiality of data (Benjamin, 2020). On-premise, ERPs are entirely controlled by the owner of the company (Benjamin, 2020).

2.7.3.2.2 Cloud-Based ERP System

Cloud ERP is a web-based ERP system that enables services to enterprises as a SaaS (Benjamin, 2020). Cloud-based ERPs are relatively inexpensive compared to on-premise ERP systems. Cloud ERP operates on a remote server and can be reached by any user by clicking a button (Benjamin, 2020). In essence, it has all the advantages and disadvantages of the cloud architecture characteristics (Benjamin, 2020). Cloud ERP has many advantages some of which are fast implementation, scalability and accessibility, mobility and usability, lower upfront cost, lower operating cost, cost transparency, and disaster recovery (Benjamin, 2020). However, it has disadvantages which are subscription costs, security risks, performance risks, customization and integration restrictions, service level agreements, etc. (Benjamin, 2020).

2.7.3.2.3 Blockchain and ERP Systems

Blockchain ensures a distributed shared data store and a computational infrastructure (Xu, 2019). In software architecture, blockchain is an architecture component that can be utilized as data storage with a computational ability (Xu, 2019). Blockchain's unique properties make it an excellent recipe for use in ERP system applications (Benjamin, 2020). Decentralization, security, and data management properties of blockchain can help ERPs (Benjamin, 2020). ERP runs on a system of a single variant of data (Benjamin, 2020). In a blockchain, the information is available for every node, and no one can control or modify the information without agreement (Benjamin, 2020). The distributed ledger is the most beneficial feature since the combination of ERP with blockchain can be useful in building trust between distinct companies (Benjamin, 2020). Drifting from blockchain to ERP problems, most of the ERPs are going from conventional ERP to cloud ERP (Benjamin, 2020). In cloud ERP, the ERP modules are accessible on-demand and can be utilized in a plug-and-play manner (Benjamin, 2020). However, traceability and security problems arise with this type of system (Benjamin, 2020). Enterprises are working on frameworks like Hyperledger to trace their entire supply chains using their ERP systems. However, the blockchain will not replace the current ERP systems (Benjamin, 2020).

With the GDPR laws, all owners of e-commerce websites have to be sure that their data is protected (Sloboda). ERP and blockchain technology integration can track who has access to personal data and prevent undesired activities (Sloboda).

2.7.3.2.4 Distributed Ledger Technology

DLT (Distributed Ledger Technology) is similar to WhatsApp communication (Shahaab et al., 2019). When there is a message in the group, the participants witness the ‘what, who, when' details of the message (Shahaab et al., 2019). Distributed ledgers are databases held at distinct nodes rather than a central place (Du et al., 2019). Transactions can be seen directly on the distributed ledger by the users who have their own verified copy of the ledger (Du et al., 2019; Kshetri, 2018).

DLTs can be divided into two types based on their data architecture: blockchain and directed acyclic graphics (DAG) (Fan et al., 2020). In a blockchain, transactions are stored in blocks chained immutably with the hash values, while in DAG, transactions are linked by a reference relation (Fan et al., 2020). Moreover, distributed ledgers have distinctive data architectures like Radix and Corda, which do not fall into any former data architecture types (Fan et al., 2020). Although DAGs are not blockchain, they are broadly utilized in successful cryptocurrencies (Bamakan et al., 2020). In addition, knowing the functions of DAG can support people to figure out better blockchains (Bamakan et al., 2020).

An arbitrary time is required in a blockchain to guarantee that the main chain is valid (Bamakan et al., 2020). In DAGs, nodes can exist in parallel as long as the information is routed in the same way, facilitating faster transaction approval (Bamakan et al., 2020). Thus, a fast, scalable, and fully decentralized network structure can be formed (Bamakan et al., 2020). Categories of DLTs based on data architecture can be seen in Figure 2.3,

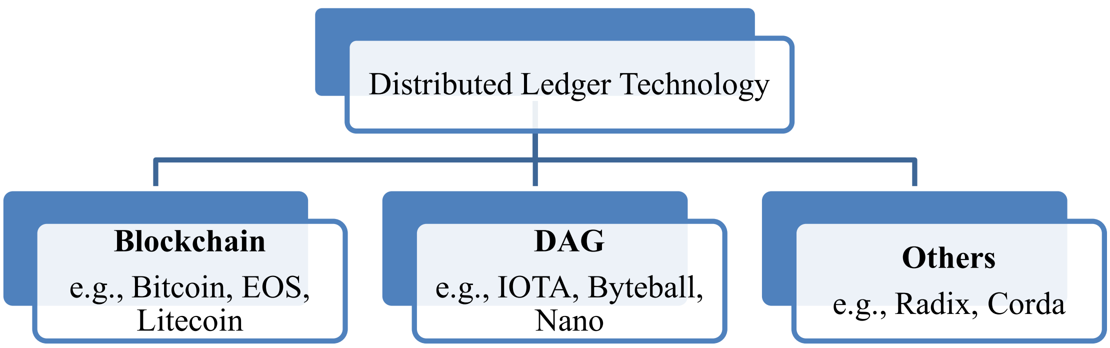

Figure 2.3: Categories of DLTs based on data architecture (Fan et al., 2020)

In this study, we made an application study for an organization (and its supply chain) that already uses ERP software and plan to use the distributed ledger infrastructure.

3. BLOCKCHAIN CONCEPT

3.1 A Brief History of the Blockchain

In 2008, in an article titled ‘Bitcoin: A P2P electronic cash system’ written by the nickname Satoshi Nakamoto put forward ‘chain of blocks’ (Bashir, 2017). The motivation behind Bitcoin's design was to achieve the three objectives of conventional money (Morabito, 2017). These objectives are as follows:

• To facilitate exchange commercially,
• To store value by participants for prospective goals,
• To perform as the central unit to measure the worth of goods and services.

Satoshi’s article identified a decentralized type of electronic currency that will provide online payments from one side to another without using an intermediary corporation (Bahga & Madisetti, 2017). The first implementation of this idea was Bitcoin (Bahga & Madisetti, 2017). On August 18, 2008, the field name ‘bitcoin.org’ was recorded (Bahga & Madisetti, 2017). On October 31, the Bitcoin article was released. On November 9, Bitcoin design was registered at SourceForge.net (Bahga & Madisetti, 2017). On January 3, 2009, Genesis was installed. An open-source program was launched applying the new protocol with the 50 coins in Genesis block (Bahga & Madisetti, 2017). On January 9, Bitcoin version 0.1 was published on the cryptography mailing (Bahga & Madisetti, 2017). On January 12, the first Bitcoin transaction was sent from Satoshi to Hal Finney. Bitcoin's popularity has continued to grow since these days (Bahga & Madisetti, 2017). Nakamoto's (2008) article utilizes the names "block" and "chain" in a separate way (Crosby et al., 2016). By 2014, the word had been combined with a single "Blockchain" (Crosby et al., 2016).

3.2 Blockchain 1.0, 2.0, and 3.0

Different types of blockchain activities are grouped as blockchain 1.0, 2.0, and 3.0. Blockchain 1.0 handles currency, spreading cryptocurrencies in cash-involved applications like money transfer and digital payment mechanisms. On the other hand, blockchain 2.0 handles contracts covering the whole list of economic and market implementations that use blockchain technology. It covers more than basic cash operations, which are stocks, bonds, futures, loans, mortgages, titles, smart property, and smart contracts.

Blockchain 2.0 is the subsequent layer in improving the blockchain industry, which has been a remarkable field of business since autumn 2014 (Swan, 2015). Since the blockchain 2.0 domain is still evolving, many groups, distinctions, and descriptions refer to Blockchain 2.0, such as Bitcoin 2.0 and DAOs (Decentralized Autonomous Organizations) (Swan, 2015). Blockchain 3.0 deals with blockchain applications specifically in general-purpose areas like government, health, science, and culture (Swan, 2015).

3.3 Technical Background of Blockchain Technology

A block includes a header that stores details of the block, a transactions list, a block hash, and the former block's hash (Morabito, 2017). Fundamental Parts of Blockchain can be seen in Figure 3.1,

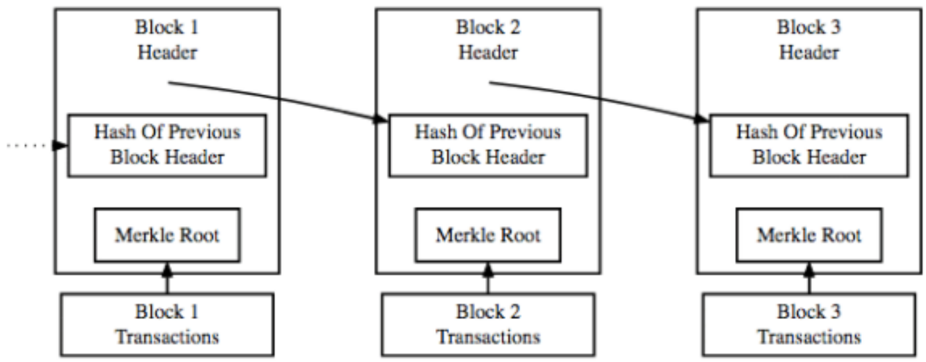

Figure 3.1: Blockchain technology fundamental parts (Blockgeeks, 2020)

Blockchain is a time-stamped, organized, and immutable record of the transactions in the Bitcoin system (Bashir, 2017). Timestamp includes the block generation time in the Unix format, which is the beginning time of hashing (Bashir, 2017). A block can store approximately 500 transactions, each size 250 bytes (Morabito, 2017). The basic structure of the blockchain can be seen in Table 3.1,

Table 3.1: Basic structure of the Blockchain (Morabito, 2017)

Size (bytes)	Name	Description
4	Block size	The size of the block
80	Block header	Information from the block header
1-9	Counter	How many transactions?

In the header part, provided that a change has occurred in the block, all the following block hashes are also modified (Morabito, 2017). This situation necessitates great calculations seeing the immutable nature of blockchain (Morabito, 2017). When new blocks are included in a chain, they cannot be changed easily and are safer (Morabito, 2017). When a block is accommodated next to the prior block, this new block has an upper-level status than the prior block (Morabito, 2017). Each block can be defined using a cryptographic hash or its block height (Morabito, 2017). Block height expresses the quantity of all the transactions inside a block (Morabito, 2017). Although the distinctive characteristic is the hash generated via the SHA256 algorithm, we can describe it via its location or the distance from the first block (Morabito, 2017).

3.4 Blockchain Applications

Blockchain technology has many application areas: financial management, the Internet of things, healthcare management, reputation systems, business, and industry. Blockchain technology application areas can be seen in Table 3.2,

Table 3.2: Blockchain technology application areas

Financial Management	Fintech	(Du et al., 2019)
	Securities, Fiat Money, Derivatives	(Paech, 2017), (Avgouleas & Kiayias, 2019), (Wu &

	Digital Payments Banking Services Cryptocurrency payment	Liang, 2017) (Gao et al., 2018) (Guo & Liang, 2016) (Anderson et al., 2017)
Internet of Things	Smart Home, Smart Agriculture, Smart City, Smart Traveling, Smart Contracts, Data Marketplace	(Dorri et al., 2017), (Lin et al., 2018) (Rahman et al., 2019), (Chen et al., 2018) (Papadodimas et al., 2018) (Özyilmaz et al., 2018)
Healthcare Management	Electronic Health Records	(Hoy, 2017), (Kuo et al., 2017)
Reputation System	Seller/Buyer Reputation Incentive Mechanism	(Khaqqi et al., 2018) (Huang et al., 2019)
Business and Industry	Supply Chain Management	(Kamble et al., 2020), (Wang et al., 2019), (Kshetri, 2018), (Chang et al., 2019)

3.4.1 Financial Management

Financial Technology, briefly FinTech, indicates organizations that utilize new technologies to make financial tasks more effective (Bahga & Madisetti, 2017). Using the new programs and internet technologies, these organizations intend to disturb the traditional applications, processes, business types, and products in the field of finance (Bahga & Madisetti, 2017). As a distributed ledger that any intermediary does not govern, blockchain is beneficial in various aspects for FinTech implementations (Bahga & Madisetti, 2017). Some FinTech areas may profit from the blockchain (Bahga & Madisetti, 2017). These areas are banking, insurance, payments and transactions, trade and investments, P2P loans, and crowd-funding (Bahga & Madisetti, 2017). A FinTech implementation study of blockchain was applied by Du et al. (2019); the authors decreased transaction delays and errors without using paper-based clearance.

The intercontinental financial mechanisms investigate different aspects of blockchain applications on financial properties like securities, fiat money, and derivatives (Paech, 2017). Blockchain proposes effective routes for fulfilling transactions like securities and derivatives (Avgouleas & Kiayias, 2019), (Wu, 2017), digital payments (Gao et al., 2018), loan management designs (Gazali et al., 2017), financial audit (Dai & Vasarhelyi, 2017).

3.4.2 Internet of Things

Today, there are 5 billion IoT appliances. The number of these applications are expected to increase by 2022 and become 29 billion (Panarello et al., 2018). IoT deals with linking intelligent appliances to gather data and make intelligent resolutions (Panarello et al., 2018). However, IoT becomes susceptible to threats due to its security failures (Panarello et al., 2018). The security characteristics in blockchain can support the essential security needs of IoT (Panarello et al., 2018).

Blockchain is beneficial to monitor and manage devices as well (Bahga & Madisetti, 2017). IoT frameworks can benefit from blockchain technology to facilitate device-to-device and consumer-to-device operations (Bahga & Madisetti, 2017). Using blockchain for IoT applications, different decentralized applications can be created to enable customers to negotiate with devices without a reliable middleman (Bahga & Madisetti, 2017). IoT instruments can own smart contracts positioned on the blockchain (Bahga & Madisetti, 2017). Smart devices with blockchain can observe their working situation, recognize troubles, and easily send orders via smart contracts (Bahga & Madisetti, 2017). There are various types of IoT applications that use blockchains, such as smart home application (Dorri et al., 2017), smart agriculture (Lin et al., 2018), smart city (Rahman et al., 2019), smart traveling (Chen et al., 2018), smart contracts (Papadodimas et al., 2018), and data marketplace (Özyilmaz et al., 2018).

3.4.3 Healthcare Management

There are not enough widespread software frameworks and information store configurations for healthcare management. This causes interoperability issues in healthcare organizations and their IT mechanisms (Bahga & Madisetti, 2017). This deficient interoperability brings difficulties for data movement among healthcare organizations (Bahga & Madisetti, 2017). Smart contracts can store different health data like demographic data, input and output data, provided services, etc. (Bahga & Madisetti, 2017). Electronic health records management in hospitals has a high growth rate (Hoy, 2017), (Kuo et al., 2017). Electronic health records include all the information, estimates, and data about a patient's circumstances and a brief health story (Casino et al., 2019).

3.4.4 Reputation system

Reputation is a significant indicator of public trust (Zheng et al., 2018). How broad your reputation is about how reliable you are considered by others (Zheng et al., 2018). The reputation can be measured based on former actions and interactions of an individual with the society (Zheng et al., 2018). In e-commerce, many listed counterfeit customers want to obtain a reputation (Zheng et al., 2018). Blockchain has the potential to find beneficial solutions for this kind of issue and reputation mechanisms as well (Zheng et al., 2018). Reputation is a significant issue also for academics (Zheng et al., 2018). Therefore, the capability of evaluating the reputation of an associate in the web community is crucial (Zheng et al., 2018). Khaqqi et al. (2018) proposed a framework based on blockchain that utilizes seller/buyer reputation in emission trading.

3.4.5 Supply Chain Management

Supply chains need particular attention as they have a significant potential to be transformed by blockchain (Kshetri, 2018). There are not enough decision-making frameworks on the analysis of blockchain performance outcomes for supply chains (Kamble et al., 2020). RFID tags, sensors, barcodes, GPS tags, and chips, the locations of products and shipping containers can be followed with the help of IoT (Kshetri, 2018). Kshetri (2018) examined roles of blockchain in achieving different supply chain management targets. Wang et al. (2019) utilized sense-making theory to investigate how blockchains may change supply chains. They applied cognitive mapping and narrative analysis to improve their understanding and assess people's cognitive complexity in making sense of blockchain.

3.5 Literature Review

3.5.1 Blockchain Technology and Supply Chain Management

Blockchain has the power to revolutionize business models in many fields, particularly in logistics and supply chain management (Kshetri, 2018; Bai & Sarkis, 2020). Blockchain creates trust among business participants through its data immutability and distributed ledger mechanism (Bai & Sarkis, 2020). Blockchain handles many difficulties concerning information sharing and resource integration in conventional enterprise management, and it also creates a new business operation and management model (Kshetri, 2018; Pan et al., 2020). An intermediary third party can be avoided via blockchain technology through its decentralization and encryption mechanism, which means better transaction execution with little cost and time (Pan et al., 2020). For purchasing services, blockchain can provide order management, warehouse, and logistics management (Pan et al., 2020).

Credit scores, risk warnings, and risk control can be provided via risk control services (Pan et al., 2020). Pan et al. (2020) proved that blockchain could increase asset turnover rates and reduce sales expenses, remarkably enhancing enterprise operational capabilities. Furthermore, blockchain implementations improve monitoring and screening of the performance of suppliers and develop verifying the claims of suppliers about their products (Zhu & Kouhizadeh, 2019). In supply chain activities, communication problem is generally intense (Kshetri, 2018). For example, different authorities require multiple approvals, which necessitates efficient communication in the same format (Kshetri, 2018). This is precisely an issue satisfied thanks to blockchain technology in supply chains (Kshetri, 2018).

Blockchain technology has many potential benefits in an informational context like data integrity, higher data quality, reducing the mistakes of humans, fast and easy access to information, privacy, and reliability (Olnes et al., 2017). Blockchain can help simplify business processes by eliminating duplicate efforts in data governance (Dinh et al., 2017). Since information is stored in more than one location, information is reached fast and easily (Olnes et al., 2017). Paper records can be removed via blockchain (Kshetri, 2018). Besides, all the shipment documents can be digitized, and the identities can be validated (Kshetri, 2018). Blockchain also provides better supply chain provenance. Some industries base the value of the goods on provenance. The products can be traced back to their roots in the value chain through the unique fingerprints created by blockchain (Kamble et al., 2020). The three significant advantages of blockchain technology in Business Process Management (BPM) are building trust, reducing costs, and accelerating transactions (Viriyasitavat et al., 2018). The risk of conflict and tampering can be decreased, and trust can be built between parties and devices via blockchain (Viriyasitavat et al., 2018). Besides, the cost can be reduced by eliminating overhead related to the intermediaries, and settlement time can be decreased significantly by accelerating transactions (Viriyasitavat et al., 2018). Blockchain also can automate data analytics like asset tracking and demand forecasting (Wang et al., 2019). Recently, electronic contracts have had a severe effect on business processes, particularly in the context of blockchain technology (Kamble et al., 2020).

There is a lack of studies in the literature that inspect both blockchain and supply chain issues, especially on the blockchain characteristics for particular needs of companies. Viriyasitavat and Hoonsopon (2019) took the first step to describe blockchain, and they explored the characteristics of blockchain-related to business processes. For the innovation of business processes in the blockchain revolution, they proposed a framework using these explored characteristics. Korpela et al. (2017) clarified how supply chain integration via blockchain could reach disruptive transformation in digital supply chains. They used the QFD to turn integration requirements into system functionalities. Finally, Catalini and Gans (2016) utilized a multiple case analysis to advance an illustrative model for the interaction of participants in an operational supply chain, including blockchain. Büyüközkan et al. (2021) evaluated blockchain needs for efficient digital supply chain management using a QFD based methodology.

Mendling et al. (2018) analysed carefully how blockchains could benefit in the context of the BPM lifecycle. They also described the key advantages and disadvantages of blockchain technology for BPM. Viriyasitavat et al. (2018) investigated a framework based on blockchain and BPM for service composition in industry 4.0. With the help of a blockchain-enabled e-commerce framework by Ying et al. (2018), employees had more choices to claim their benefits, and suppliers had an extra channel to market their products. Mingxiao et al. (2017) discussed the technologies of Bitcoin, Ethereum, BlockDS, BigchainDB, Storj, Sia, Hawk, Enigma, and they concluded that these technologies are not adequate to integrate supply chains and blockchains entirely. These technologies individually figured out some integration problems, but none can solve all of these problems themselves (Mingxiao et al., 2017). To ensure a complete supply chain integration, much work is still to be done (Korpela et al., 2017). In this study, thanks to the reviewed blockchain characteristics from literature and evaluation of relationships between these characteristics, it will be easier for supply chains to understand and integrate blockchain technology into their existing systems. Blockchain studies and their value propositions can be seen in Table 3.3,

Table 3.3: Blockchain studies and their value propositions

Authors	Aim	Problems	Materials	Materials' Tools	Materials' Focus	Value Proposition	Type
(Liu & Li, 2020)	Achieving traceable products and transactions in supply chain management	N/A	IPFS (Interplanetary File System)	P2P Technology, off-chain data storage	Large size files	Open and transparent information sharing, Data Security and Privacy	Illustrative Example
			Multi-chain structure, data management model, and block structure model	Blockchain	Blockchain-based system design and data management		
			Key Management Method	Cryptography	Access management of users, hierarchical authority		
			Anti-counterfeiting product traceability tag	Cryptography	Verification of tag source, tag information, and tag ownership		
			IoT				
			Smart Contract				
(Martinez et al., 2019)	Investigates a blockchain-driven customer order management	*Multiple communication channels *Extensive manual work *Incomplete or incorrect information *Multiple rule sets for different customers	Hyperledger Fabric	Back-end Technology		Reduced average time of customer orders, number of operations, and human-processing savings	Case Study
			React Customer Interface	Front-end Technology	Gives a complete overview of order, Collects customer data, Feeds back-end		
			Hyperledger Composer	A set of tools for blockchain applications	Develops a 'business network' archive and components and RESTful APIs that interact with customer applications		
			RESTful API	Web services	Opening order status 'blockchain visibility' to		

					supply chain parts		
(Helo & Hao, 2019)	Investigates a blockchain based logistics monitoring system	N/A	JavaScript-based client software implemented as an HTML web page	User Interface		Security and transparency of the record of all activities	Illustrative Example
			Ethereum	Public Blockchain	Blockchain is implemented on a server computer by using Ethereum Geth		
			Local database	Database	Used to store completed transactions for quick search and retrieval		
			Local webserver software		Communicates with user interface, local database storage, and local blockchain node.		
			A distributed Ethereum network	P2P Network	Conducts verification tasks for each blockchain operation		
(Longo et al., 2019)	To enable the interaction between an enterprise information system to an Ethereum like blockchain	N/A	Ethereum	Decentralized ledger	All the information regarding demand forecasts and inventory levels are stored	Solved collaboration and trust issues in a supply chain, increased supply chain performance, minimized information asymmetry over the supply chain.	Illustrative Example
			Software connector		Links the blockchain with the supply chain simulation model		
			MySQL	Classic Relational Database Management System, Off-chain data storage	Supply chain data are stored off-chain in MySQL databases		
			Ethereum wallet	An address	Represents the supply chain member permitted to publish its data or read the		

					data of other companies, and guarantees data authenticity		
			HTTP-Basic authentication	Authentication	Access to endpoints with largely verified solutions		
			RESTful	Web services	Interoperate enterprise information system with blockchain		
(Westerkamp et al., 2020)	To trace manufacturing processes using blockchain-based token compositions	N/A	Solidity Contracts	Smart contracts for tokenization of goods	Tokens representing physical goods are created using smart contracts	Complete traceability of goods, including the origin of inputs, scalability with the amount of the input and goods tracked	
			Tokens		Represent physical goods. To digitally represent a manufacturing process, several tokens can be changed into a new token.		
			IPFS or SWARM	P2P storage (Off-chain data storage)	Product information is stored, such as product images, expiration dates, disposal instructions, manuals, documentation of defects, and many others		
			Mobile and web application		Discovery of existing goods and the creation of new types of goods. QR code generation		
			ERC721	Interface	A standardized interface for creating and trading discriminable tokens reflecting digital or physical goods.		
Ying et al. (2018)	A blockchain-enabled e-commerce platform to offer employees flexible benefits	Employees did not have benefits options	Benefit Coins	Digital Coin	Carrying out transactions	*Issuing cryptocurrency *Protecting sensitive	Case Study

						information, and *Eliminating institutional intermediaries	
			e-commerce		Employees had more options to claim their benefits, and suppliers also had an additional channel to sell their products using e-commerce		
			JD.com	3rd party E-commerce company	to bring more products from the 3rd party		
(Hyperledger, 2020)	It aims to meet document and data storage security regulations of GDPR and ensure trust	Trust issue for achieving solutions and meeting GDPR law	Hyperledger Fabric			Companies can shift from volume-based document storage to a value-based model	Case Study
			Off-chain data storage				
			Channels		A new channel is initialized when a new company joins.		
(Hyperledger, 2020)	Invoice Management	Invoice disputes	Hyperledger Fabric			Invoice disputes have been eliminated, exceeded payback speed and annual benefits	Case Study
			DL Freight	DLT Labs' configurable enterprise SaaS platform	The module of DL Freight used was DL Asset Track.		
			OIDC protocol		Authentication and authorization for every member of DL Freight		
(Hyperledger, 2019)	To create an amazon-type marketplace for used aircraft parts	Vendors put up the websites.	Hyperledger Fabric			Future boost to anti-counterfeit measures, reduced purchase time	Case Study
			Channels		To preserve data security,		

					the system uses channels and private data collections.		
			GoDirect Trade	B2B marketplace			
(Hyperledger, 2020)	To have an interoperable system that will allow for drug tracing, product verification, and prompt detection and response protocols to handle all suspect medications	An underperforming, old-style, paper-based supply chain	Hyperledger Fabric			BRUINchain met all DSCSA pilot objectives: from reading actual barcodes with a working app to enabling real pharmacists and real doctors to bring life-saving medicines.	
			BRUINchain	A blockchain-based system that meets DSCSA law (Drug Supply Chain Security Act)	It has barcode scanning functionality		
			Oraculous Notification Service	Automated verification system	Serve the role of “blockchain oracle,” allowing interoperability between the Hyperledger Fabric blockchain app and outside manufacturers		

3.6 Architectural Characteristics of Blockchain Technology

After inspecting the literature in detail, blockchain architectural characteristics were summarized as decentralization, immutability, privacy, security, performance & scalability, smart contract functionality, permissioned/permissionless model of blockchain, on-chain/off-chain data transactions, and tokenization; as in Figure 3.2,

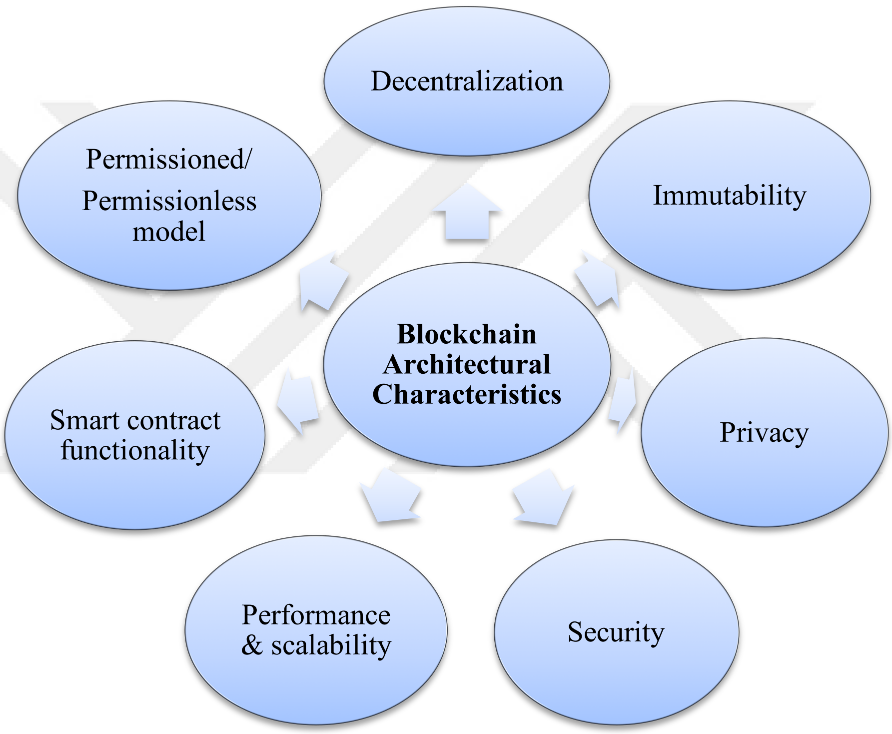

Figure 3.2: Blockchain architectural characteristics

3.6.1 Decentralization

The phenomenon of "trust" that is traditionally established by competent authorities, mediators, and similar third parties leaves its place in decentralized blockchain technology (Çavdar et al., 2019). Blockchains can decrease the trust of third parties since they are P2P networks (Wang et al., 2019). The structure of a standard network is the "client-server" type (Blockgeeks, 2020). Here, the server is centralized (Blockgeeks, 2020). This is quite like how the internet operates (Blockgeeks, 2020). When searching on Google, a query gives you necessary results (Blockgeeks, 2020). The server must be operating all the time since everything depends on this server. In addition, there are security concerns as well (Blockgeeks, 2020). Since there is a centralized network, the server itself copes with many sensitive data of its clients (Blockgeeks, 2020). Moreover, there is a censorship problem (Blockgeeks, 2020). What if the server determines that a specific item like a movie or a song is not appropriate, and decides not to spread it in their network? (Blockgeeks, 2020). Client-server and P2P network model can be seen in Figure 3.3,

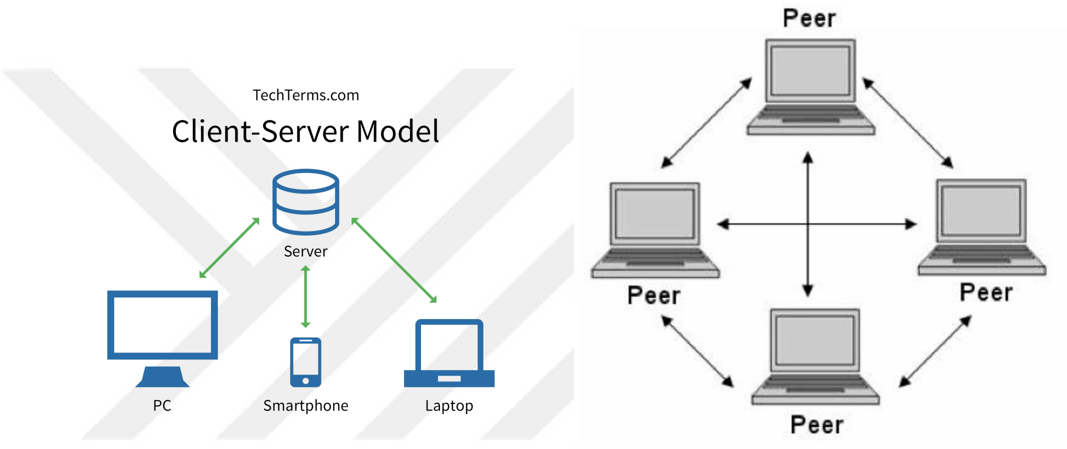

Figure 3.3: Client-server and P2P network model (Blockgeeks, 2020)

Thus, to solve all these problems, a different network structure arose (Blockgeeks, 2020). It is a network which divides all workload among equally privileged participants, called as “peers” (Blockgeeks, 2020). Blockchains can lead to disintermediation with its P2P network, although intermediation is quite common in verifying asset ownership and transaction processing (Catalini & Gans, 2016; Wang et al., 2019). Intermediaries charge a fee which either the costs buyers or sellers have to pay when all transaction attributes cannot be verified effectively (Catalini & Gans, 2016). Moreover, additional costs may arise due to intermediaries having access to private transaction data (Catalini & Gans, 2016). Decentralization is one of the significant characteristics of the blockchain (Bellini et al., 2020). Blockchain facilitates decentralization as new distributed software architectures in which agreements can be achieved on the shared system states without trusting a central integration point (Xu, 2019).

In centralized networks, transaction replacements are validated and confirmed by trusted third-party organizations (Bellini et al., 2020). However, in blockchain networks, two parties can take action to keep records or authorize without the trust of a central organization (Bellini et al., 2020). Compared to traditional and centralized alternatives, blockchain owns some essential benefits such as immutability, increased security, fault tolerance, and transparency (Fan et al., 2020). However, the decentralized characteristic of blockchain significantly limits its performance concerning throughput and latency (Fan et al., 2020).

As reviewed by Bamakan et al. (2020), three main criteria that affect the decentralization of blockchain are permission, trust, and blockchain governance. Over the past decade, the enormous growth of the web was combined with increased centralization (Zyskind et al., 2015). Few large firms now have significant junctures of the web, and therefore they have lots of the data produced on the web (Zyskind et al., 2015). The shortage of transparency and control over these firms shows the negative sights of centralization: manipulation, surveillance, and frequent data breaches (Zyskind et al., 2015).

3.6.2 Immutability

‘Cryptography + Blockchain Hashing Process = Immutability.’

Immutability means that a thing cannot be modified over time or the values may stay the same for a certain amount of time (Morabito, 2017; Kamble et al., 2020). Data written to the blocks cannot be altered even by an administrator (Morabito, 2017). When there is a disagreement about an order, it is unnecessary to review the original order and its waybill messages since blockchain enables an immutable audit trail (Weber et al., 2016). Immutability is one of the main characteristics of the blockchain (Bellini et al., 2020). The specific characteristic that separates blockchain from current technology is its immutability of the stored data (Chowdhury et al., 2018). In a blockchain context, anyone can not modify the data written in the blocks (Morabito, 2017). Blockchain technology can be pretty expensive compared to other persistence mechanisms (e.g., databases) if immutability is not crucial for a system’s architecture

(Scriber, 2018). The connecting blocks in a chain of cryptographic hashes promote a kind of immutability for historical transactions (Lo et al., 2017). The encryption mechanism of the blockchain is formed from public and private keys that are utilized for data encryption and participant authentication, respectively (92; Lo et al., 2017). Encryption keys can help participants be anonymous, and they can help prevent others from seeing their information, and thus privacy can be assured (Olnes et al., 2017).

Cryptography is related to the building of schemes that should resist any abuse (Goldreich, 2009). Such schemes are built to continue the desired functionality, even under malicious efforts targeted at making them leave their functionality (Goldreich, 2009). It is not that sensible to make assumptions concerning the particular strategy that an adversary may utilize (Goldreich, 2009). The only assumption that can be justified is the computational capabilities of the adversary (Goldreich, 2009). A one-way function is a minimum requirement for doing most kinds of cryptography (Goldreich, 2009). A one-way function is easy to compute but difficult to reverse. They are primarily used in order to describe computational difficulty (Goldreich, 2009).

Blockchain's immutability characteristic depends on the cryptographic hash function (Blockgeeks, 2020). Hashing means taking an input string of any length and giving out an output of a fixed length (Blockgeeks, 2020).

SHA-256 is used in calculating the proof of work in Bitcoin mining and Bitcoin address generation processes (Çavdar et al., 2019). Moreover, it is one of the most secure known encryption functions (Çavdar et al., 2019). For example, for the SHA-256 in Figure 3.4, the output will always have a constant 256-bits length, not depending on your input (Blockgeeks, 2020).

INPUT	HASH
Hi	3639EFCD08ABB273B1619E82E78C29A7DF02C1051B1820E99FC395DCAA3326B8
Welcome to blockgeeks. Glad to have you here.	53A53FC9E2A03F9B6E66D84BA701574CD9CF5F01FB498C41731881BCDC68A7C8

Figure 3.4: An example length of SHA-256 (Blockgeeks, 2020)

There are specific characteristics for a cryptographic hash function to be considered as secure (Blockgeeks, 2020). For instance, one property is named “Avalanche Effect.” (Blockgeeks, 2020) In this property, even if you make a slight modification in your input, the modifications mirrored in the hash will be giant (Blockgeeks, 2020). It can be tested using SHA-256, as can be seen in Figure 3.5,

INPUT	HASH
This is a test	C7BE1ED902FB8DD4D48997C6452F5D7E509FBCDBE2808B16BCF4EDCE4C07D14E
this is a test	2E99758548972A8E8822AD47FA1017FF72F06F3FF6A016851F45C398732BC50C

Figure 3.5: Modification impact of SHA-256 (Blockgeeks, 2020)

However, troubles may appear in real-world blockchain frameworks such as debated transactions, wrong addresses, revelation or loss of private keys, data-entry faults, and unforeseen modifications of assets tokenized on the blockchain. Even a court can command an illegal content to be taken out from the blockchain (Lo et al., 2017). Therefore, the worries about the historical transactions need to be considered during the design of blockchain systems (Lo et al., 2017).

3.6.3 Privacy

Privacy is a significant characteristic of any system (Wüst & Gervais, 2018). There is an inherent trade-off between privacy and transparency (Wüst & Gervais, 2018). An utterly private system does not have any transparency (Wüst & Gervais, 2018). Several innovative improvements in cryptography and computer science make it possible to operate applications on data while ensuring data encryption (Lyons & Courcelas, 2020). These procedures are zero-knowledge proofs, homomorphic encryption, secure multiparty computation, and trusted execution environments (Lyons & Courcelas, 2020). These technologies are frequently connected with blockchain-based use cases, where blockchain is operated to ensure an audit trail of the transactions between users (Lyons & Courcelas, 2020). Zero-knowledge proof is a consensus decision-making protocol in which one side proves that information is correct (Wang & Kogan, 2018).

Here, the "prover" does not show any information (Wang & Kogan, 2018). This can be done using complex cryptographic techniques (Wang & Kogan, 2018).

Zero-knowledge proof, newly presented into blockchain frameworks using zk-snarks, has been offered to improve privacy in blockchains (Wang & Kogan, 2018). To protect the decentralized blockchain while decreasing transparency, zero-knowledge proofs show nothing about a transaction except that it is valid (Wang & Kogan, 2018). As another techniques, ring signatures can be utilized. They are digital signatures that can be performed by any member of users who have some keys (Farshidi et al., 2020). Ring signatures have two necessary features. There is no way to destroy the anonymity of a specific signature, and any group of users can be employed as a group without additional setup (Farshidi et al., 2020). Therefore, zero-knowledge-proof, ring signatures, and zk-snarks cryptographic tools can be searched in these platforms to evaluate the privacy of blockchain alternatives.

Businesses may not want to share data on public ledgers, or specific data may not be allowed to be made publicly available because of the GDPR protections (Hunhevicz & Hall, 2020). When doing business with customers and their sensitive information, businesses need to comply with the GDPR (Anwar, 2019). Moreover, you should guarantee that all of your customers' information remains private, and third parties can't use that information for market analysis (Anwar, 2019). With the help of blockchain, you can securely store all the customers' information (Anwar, 2019). You can also be completely GDPR compliant and, at the same time, provide complete transparency in dealing with customers (Anwar, 2019).

3.6.4 Security

Another architectural characteristic of blockchain is security. P2P networks are not new; Distributed Hash Tables (DHTs) like BitTorrent were designed before the blockchain. What makes the blockchain original is that it solves the main security problem of DHTs (Raval, 2016). Blockchain is the first decentralized database that is highly tamper-resistant (Raval, 2016). The security of the blockchain was a dominant design target

(Raval, 2016). Handling the Byzantine General problem and obtaining fault tolerance are at the centre of any distributed ledger (Shahaab et al., 2019). Blockchain can endure various faults, and it is designed to work in extreme byzantine environments (Shahaab et al., 2019). Most of the prior consensus protocols assumed that the replication environments were trusted and did not have adversaries (Shahaab et al., 2019). However, DLT necessitates the network to reach a consensus without intermediaries and in a byzantine atmosphere (Shahaab et al., 2019).

One of the reasons blockchain is used in ERP systems is that it provides low risk in digital transactions (Anwar, 2019). ERP systems can also provide transactions, but they are not that secure for now (Anwar, 2019). Besides, security vulnerabilities allow hackers to attack central servers and hack a transaction (Anwar, 2019). The centralized system of ERPs is highly vulnerable and prone to errors (Anwar, 2019). An employee can easily manipulate the data in ERP systems and take advantage of it (Anwar, 2019). An example of Byzantine Generals problem in which commander is loyal, but lieutenant 2 is a traitor, can be seen in Figure 3.6,

The Problem of the Byzantine Generals

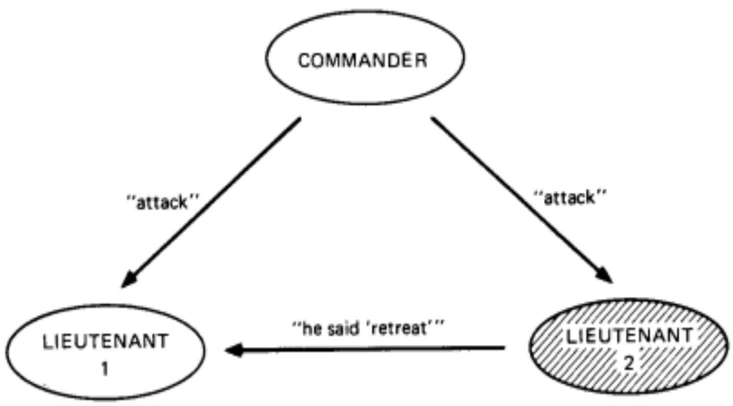

Figure 3.6: Byzantine Generals Problem-Lieutenant 2 a traitor (Lamport et al., 2019)

Trustworthy computer frameworks must cope with faulty components that give contradictory information to distinct parts of the framework (Lamport et al., 2019). This can be explained abstractly through a group of generals of the Byzantine military camped with their soldiers around an enemy town (Lamport et al., 2019). Speaking only by messengers, the Byzantine generals must adopt an agreed battle plan. However, one or more generals may be traitors who will confuse the other generals (Lamport et al., 2019). The issue is exploring an algorithm to ensure that the loyal generals agree (Lamport et al., 2019). The problem of handling this kind of failure is explained abstractly as the Byzantine Generals problem (Lamport et al., 2019). The Byzantine generals must have an algorithm to make sure that (Lamport et al., 2019);

1. All faithful generals agree upon the same action plan.

2. A small number of traitors cannot provoke the faithful generals to accept a bad plan.

Immutability, non-repudiation, integrity, transparency, and equal rights are the fundamental features supported in existing blockchains (Xu, 2017). In general, high fundamental features cause more secure and trustworthy systems (Hunhevicz & Hall, 2020). Indeed, this security comes at a price (Hunhevicz & Hall, 2020). Furthermore, there is a trade-off between performance (transaction speed and system overhead) and the principal features (Hunhevicz & Hall, 2020). From a software architecture viewpoint, every design decision of a system is a trade-off among various characteristics (Paik et al., 2019).

Similarly, performance and confidentiality are the two principal criticisms emerging from the blockchain design (Paik et al., 2019). As two main architectural concerns, the security and performance of blockchain need to be handled appropriately by designers (Zou et al., 2018). In the design of bitcoin, Nakamoto prefers security rather than performance since security is vital for a cryptocurrency implementation (Zou et al., 2018) when many "altcoins" designers change the parameters of bitcoin's proof of work or use a consensus protocol with better performance like proof of stake instead of proof of work, the trade-off security for performance (Zou et al., 2018).

Hard fork resistance means preventing hard forks (Farshidi et al., 2020). A hard fork is a severe change to the protocol that turns formerly invalid blocks and transactions into a valid situation (or vice-versa) (Farshidi et al., 2020). This requires whole nodes or users to upgrade to the newest model of the software protocol (Farshidi et al., 2020). Spam attack resistance means preventing spam attacks (Farshidi et al., 2020). A spam attack happens in the shape of empty invocations, admitting a remarkable number of transactions to be submitted without real funds transfer. In a sybil attack, the attacker tries to dominate a network by forming several fake participants in the blockchain (Bamakan et al., 2020). Sybil attack resistance means preventing Sybil attacks (Farshidi et al., 2020). Sybil attack occurs in P2P networks in which a node in the network operates many identities simultaneously and threatens the authority and power in blockchains (Farshidi et al., 2020). Finally, quantum attack resistance means cryptographic algorithms that are thought to be preserved against an attack by a quantum computer (Farshidi et al., 2020). To evaluate the security of blockchain platforms, hard fork resistance, spam attack resistance, quantum attack resistance, and Sybil attack resistance of these platforms can be evaluated.

3.6.5 Performance & Scalability

There are scalability limits on (i) the size of the data on a blockchain, (ii) the transaction processing rate, and (iii) the latency of data transmission (Xu, 2017). When struggling with scalability, there are various alternatives one can benefit from or develop to make a quicker solution (Lyons et al., 2019). These solutions include four distinct groups: Layer -1, Layer 0, Layer 1, and Layer 2 solutions.

3.6.5.1 Layer -1 Solutions: Hardware Layer

The hardware layer refers to the machines utilized to operate the blockchain client (software) (Lyons et al., 2019). Operating better machines can be interpreted as better performance in transaction throughput since the fundamental computations like verifications and state changes can be fulfilled faster (Lyons et al., 2019). It is significant to focus on that all machines on the network must be upgraded to truly achieve performance developments (Lyons et al., 2019). With the help of this layer, up to 5 to 10 times more, throughput can be gained (Lyons et al., 2019). As the limitation of this solution, this alternative cannot be benefited with ease for extensive networks since machines are heterogeneous in performance. The older nodes may not maintain if the settings make it too difficult to keep up with (Lyons et al., 2019). Minimum needs could be considered for machines to operate a client, but this refers to a finite number of participants who may afford the required hardware, resulting in a smaller decentralized network (Lyons et al., 2019).

3.6.5.2 Layer 0 Solutions: Network Layer

Layer 0 means the network layer involving all communications between nodes (Lyons et al., 2019). A significant notion of remembering is network propagation, which defines how quickly a specific percentage of the network will take the recent bits of information in the final block (Lyons et al., 2019). There are physical drawbacks to how quickly information can move all over the world. Central factors will also affect propagation regarding what data is sent, how much it is sent, and which transmission procedure is used (Lyons et al., 2019). With the help of this layer, up to 5 times more, throughput can be gained (Lyons et al., 2019).

3.6.5.3 Layer 1 Solutions: Blockchain Layer

There are many studies in the development society to develop the blockchain's performance, also called Layer 1 (Lyons et al., 2019). Protocol improvements can guide networks to be quicker or more efficient, for example, using less energy. In a blockchain, blocks contain a certain number of transactions, and each block is added to the blockchain by connecting to the previous block (Çavdar et al., 2019). Layer 1 alternative solutions can be small changes, for instance, modifying the block size or the block interval time (Lyons et al., 2019). There can also be significant alterations like sharding, an overall process in traditional database technology (Lyons et al., 2019). You can divide the data into distinct fragments and validate the individual fragments with sharding, enabling parallel working. Another viewpoint is the replacement of the consensus mechanism (Lyons et al., 2019). The proof-of-work consensus is slow and pricy (Lyons et al., 2019). Preference of a consensus protocol influences the blockchain features such as scalability, energy expenditure, and strength to failures and malicious attacks (Lyons et al., 2019). Each protocol has its advantages and disadvantages, and some will be preferred in certain situations (Lyons et al., 2019). With the help of this layer, up to 10 to 20 times more throughput can be gained. However, there are limitations for this layer. It is important to remember that different consensus protocols have different trust, security, and governance features. Therefore, they cannot be compared using transactions per second or other performance features (Lyons et al., 2019).

3.6.5.4 Layer 2 Solutions: Application Layer

Another direction to develop performance is to move essential components of the computation - the work of directing and verifying transactions - off the chain into more traditional, and therefore more performing frameworks (Lyons et al., 2019). These solutions are usually called Layer 2 solutions. A characteristic Layer 2 solution is a payment channel (Lyons et al., 2019). In this situation, two sides open a channel and then realize their transactions. These payment channels can widely enhance blockchain performance. However, the channels also mean distinct trust assumptions, and they can produce problems. With the help of this layer, up to 10,000 to 100,000 times more, throughput can be gained (Lyons et al., 2019). Layer 2 solution is the most favourable one when considering scalability (Lyons et al., 2019). It also presents attractive tools for privacy. However, there are limitations to these solutions (Lyons et al., 2019). This solution strongly depends on interoperable instruments in order to function well. When blockchain becomes completely mature, layer 2 solutions will be ready to combine multiple blockchains seamlessly (Lyons et al., 2019). As blockchain has developed to gain more interest, performance problems such as low throughput and high latency have become crucial (Fan et al., 2020).

3.6.6 Smart Contract Functionality

An asset or a currency is digitally transferred into a blockchain implementation in a smart contract form (Kamble et al., 2020). Smart contracts can be used in a business process which can be encoded into smart contract transactions to attain blockchain advantages for process executions (Viriyasitavat & Hoonsopon, 2019). In addition, automatically processed smart contracts transactions can eliminate costly manual efforts prone to delays and errors (Anderson et al., 2017).

The primary purpose of the blockchain was to promote a decentralized and electronic payment system based on cryptography instead of trust as in Bitcoin (Garriga et al., 2021). However, the scripting language of Bitcoin is not Turing-complete, so it cannot handle complex functions (Liu et al., 2020). Over time, the idea of implementing blockchain to other concepts like decentralized applications arose (Garriga et al., 2021). Functionality and extensibility mean the capability of promoting a complex attitude by a blockchain application either as built-in functionality or as extension mechanisms to develop applications beyond their original purpose (Garriga et al., 2021). This can be accomplished thanks to smart contract support (Garriga et al., 2021). Some applications promote Turing-complete smart contracts utilizing ad-hoc languages (Solidity in Ethereum, Plutus in Cardano). In contrast, others promote conventional languages that are then compiled/transpiled to a bytecode (Garriga et al., 2021). However, the second-mentioned are not entirely supported in any available blockchain applications (Garriga et al., 2021).

3.6.6.1 Smart Contract Potentials for Supply Chains

Smart contract design has the aim of meeting general contractual conditions (such as payment terms, liens, confidentiality, and even enforcement), decrease malicious and accidental anomalies, and reduce the requirement for trusted intermediaries (Tapscott & Tapscott, 2016).

3.6.6.1.1 Depository of Data

A smart contract can act as a depository of data (Milani & Garcia-Banuelos, 2018). Here, contracts must be able to create, read, update but perhaps not delete data.

3.6.6.1.2 Automated execution of business rules

Transfer of the various types of ownership of assets, property, and value can be automated by smart contracts (Chang et al., 2019). As blockchains can automate messages by ‘smart contracts’, the speed of payment is improved.

3.6.6.1.3 Identity Management

Smart contracts can be used for identity validation. They allow access to only authorized stakeholders (Milani & Garcia-Banuelos, 2018).

3.6.6.1.4 Distributed Database

Smart contracts employ the use of a distributed database so that members can verify that there is an existence of a digital event without requiring any third parties (Morabito, 2017).

3.6.6.1.5 Contract Language

Smart contracts suggest an essential benefit to existing contractual applications by removing the inherent uncertainty of natural language (Morabito, 2017). While words can be evaluated in different conditions, smart contracts fight this uncertainty by including legal rules into the source code (Morabito, 2017).

3.6.7 Permissioned/Permissionless Model of Blockchain

The permissionless blockchain is also known as a public blockchain as there is often a blockchain network model on a global scale subject to public administration (Xiao et al., 2020). A permissioned blockchain requires authorized participants to participate in network operations with their revealed identity (Xiao et al., 2020). Permissioned blockchains’ identity-revealing features and more efficient network management structure make them perfect for business or multi-participant practices, compared to permissionless ones (Xiao et al., 2020). Comparison of permissionless and permissioned blockchain can be seen in Table 3.3,

Table 3.3: Comparison of permissionless and permissioned blockchain (Xiao et al., 2020)

	Permissionless Blockchain	**Permissioned Blockchain**
Governance	Public	Private/Consortium
Participation	Free join and leave	Authorized
Transparency	Open	Closed/Open
Network Size	Large (thousands or more)	Small (tens-hundreds)
Transaction capacity	Low (sub-ten-tens)	High (thousands)

Permissioned blockchains are faster, more energy-efficient, and this type of blockchains can be applied effortlessly compared to permissionless ones, but they provide a certain level of centralization.

3.6.8 On-chain/off-chain Data Transactions

Another design decision deals with which data and computation should be kept on-chain and placed off-chain (Xu et al., 2016). Many current blockchain applications demonstrate low throughput, low scalability, and high latency (Paik et al., 2019). However, properly assessing a blockchain implementation's on-chain/off-chain data architectural options can help eliminate some of these problems (Paik et al., 2019). In the on-chain alternative, verification of computational results can be provided (Xu et al., 2016). However, on-chain options have limited computation capacity and data storage. One of its examples is keeping metadata (Xu et al., 2016).

The off-chain data storage can be a private cloud on the customer's infrastructure or public storage provided by a third party or network (Xu, 2017). In off-chain frameworks, there are more computation power and data storage and also less costly. However, off-chain options necessitate additional trust. One of its examples is keeping raw personal data (Xu et al., 2016). By keeping very sensitive, real-time data in off-chain storage, privacy, and better scalability could be provided while still realizing the immutability of blockchain (Paik et al., 2019). Furthermore, the hash of the data would be utilized to verify the integrity of the off-chain data (Paik et al., 2019). Even though off-chain storage reduces the scalability and privacy problems to a certain degree, it brings new problems such as data aggregation and integration (Paik et al., 2019).

For on-chain computation, different blockchains propose various levels of expressiveness (Xu, 2017). For instance, bitcoin merely allows basic scripts and conditions that must be met to transfer bitcoin payments (Xu, 2017). Ethereum provides more general (Turing-complete) programs, which can fulfil conditional payments and make changes to the operational data in smart contract variables (Xu, 2017). Most blockchain-based applications with high throughput and storage needs may consider a hybrid on-chain/off-chain solution since on-chain alternatives may be limited in performance and storage capacity (Paik et al., 2019). Off-chaining data has been an issue for Ethereum specialists for a long time (Collins et al., 2019). Smart contracts seem that they cannot do more interesting than token transfers (Collins et al., 2019). Off-chaining does not allow Ethereum to do what it was fundamentally designed to do; creating smart contracts (Collins et al., 2019). The reason is that off-chain data in Ethereum does not work in a deterministic framework (Collins et al., 2019).

3.6.9 Tokenization

Cryptographic tokens are programmable assets or access rights operated by a smart contract and an underlying distributed ledger (Voshmgir, 2019). They can only be reached by a private key for that address, and they can only be signed by this private key (Voshmgir, 2019). The first blockchain tokens were the native tokens of public and permissionless blockchains such as Bitcoin and Ethereum (Voshmgir, 2019). Ethereum advanced a standardized smart contract, the ERC-20 standard, which identifies a list of rules for Ethereum tokens, involving how the tokens are delivered from one Ethereum address to another and how data within each token is reached (Voshmgir, 2019). These relatively basic smart contracts operate the logic and keep a list of all issued tokens and can represent any asset that has characteristics of a fungible commodity (Voshmgir, 2019). Besides, more complex token standards have arisen to represent any asset or access rights with unique features. For example, ERC-721 presented a free and open standard that defines how to construct non-fungible tokens on the Ethereum (Voshmgir, 2019).

There is no united categorization for tokens (IOscoring, 2018). However, there are movements to solve this issue from the Securities and Exchange Commission in the United States of America and Switzerland's Swiss Financial Market Supervisory Authority (IOscoring, 2018). These organizations separate tokens into two classes: security tokens that are similar to securities and utility tokens that give their owners access to the services of the project (IOscoring, 2018). Another class is cryptocurrency or payment tokens frequently determined as payment (IOscoring, 2018). Hyperledger does not promote native-tokens, so it is not an appropriate blockchain for token-based implementations (Farshidi et al., 2020).

3.7 Consensus Mechanism

Unlike conventional distributed computing which has a clear client-server framework, a blockchain network gives the opportunity to each participant to be both a client (to issue transactions) and a server (to validate and finalize transactions) (Xiao et al., 2020). The underlying ledger data form, blockchain, contains chronologically ordered and hash-chained blocks (Xiao et al., 2020). A blockchain is frequently connected with a financial application and is responsible for transaction processing and clearing (Xiao et al., 2020). Consequently, a blockchain consensus protocol has more responsibility than conventional distributed consensus protocols (Xiao et al., 2020). The consensus mechanism provides that information is modified only when related participants agree (Olnes et al., 2017).

A consensus algorithm is described as an operation to agree on the value of data among many nodes in the distributed frameworks (Bamakan et al., 2020). Three requirements for a practical consensus concept are mutual acceptance of laws and rules; mutual acceptance of nodes, procedures, and stakeholders that implement the laws and rules; a feeling of the identity that will make all participants feel equal according to the laws

(Morabito, 2017). In these frameworks, to make the network reliable and secure, the miners/validators are required to spend some computational power, stake, or hard disk space in order to confirm the transactions and join new blocks to the blockchain in exchange for some rewards (Bamakan et al., 2020). These rewards are an incentive for miners to participate in the transaction validation operation (Bamakan et al., 2020). Depending on the nature of the consensus algorithms, mining or validation rewards will differ based on distinct blockchains (Bamakan et al., 2020).

The transaction fee is paid to the miners with the aim of verifying the block on the network (Bamakan et al., 2020). Transaction fees and transaction speed are closely related to each other (Bamakan et al., 2020). High-value transactions are usually the fastest (Bamakan et al., 2020). Fees usually rise concerning cryptocurrency networks' increasing use and popularity (Bamakan et al., 2020). However, some cryptocurrencies have indicated that the transaction fee is not essential, and they use other convincing methods for the attendance of miners in the block creation process (Bamakan et al., 2020). These blockchains utilize procedures to remove transaction fees and ensure an accessible user experience (Bamakan et al., 2020).

3.7.1 Components of Blockchain Consensus Protocol

Blockchain consensus mechanism has five main components (Xiao et al., 2020):

- Block proposal: Creating blocks and attaching generation proofs.
- Information propagation: Spreading blocks and transactions across the network.
- Block validation**:** Examining blocks for the generation of proofs and transaction validity.
- Block finalization: Achieving agreement on the admission of validated blocks.
- Incentive mechanism: Encouraging honest participation and forming network tokens.

The fact that only blockchain consensus has an incentive mechanism is worth paying attention. This is not similar to conventional state machine replication consensus mechanisms (Xiao et al., 2020). This is because conventional state machine replication mechanisms are only designed for transaction processing and serialization in a preexisting network of participants who are supposed to be honest (Xiao et al., 2020). Therefore, a fair and universal incentive mechanism is required to promote honest attendance to maintain the system's reliable processing (Xiao et al., 2020).

Although a new blockchain consensus protocol may not contain all five components, these are critical for a successful blockchain consensus (Xiao et al., 2020). For instance, while the incentive mechanism is inevitable for permissionless blockchains, particularly those carrying a financial liability, it is not a must for permissioned blockchains in which attendance is approved as a privilege (Xiao et al., 2020). Many recent public blockchain attempts focused solely on block proposal, while taking other four components from the Nakamoto consensus of Bitcoin (Xiao et al., 2020). This is because the majority criticized Bitcoin's proof of work-based block proposal for its limited scalability and wasteful energy usage (Xiao et al., 2020). Performance evaluation criteria in blockchain consensus literature are as follows;

- Transaction Per Second (TPS) (Mingxiao et al., 2017), (Tang et al., 2019)
- Block Time/Block Creation/Latency/Block Creation Speed: (Xu et al., 2018), (Alsunaidi & Alhaidari, 2019)
- Scalability: (Mingxiao et al., 2017), (Alsunaidi & Alhaidari, 2019)
- Adversary Tolerance (Fault tolerance) (Mingxiao et al., 2017), (Xu et al., 2018), (Alsunaidi & Alhaidari, 2019)
- Verification speed/Block Verification Time (Mingxiao et al., 2017), (Alsunaidi & Alhaidari, 2019)
- Double spending (Alsunaidi & Alhaidari, 2019)
- Throughput (Mingxiao et al., 2017), (Xu et al., 2018), (Alsunaidi & Alhaidari, 2019)

TPS is mainly used for cryptocurrencies (Bamakan et al., 2020). It is described as the number of transactions fulfilled per second (Bamakan et al., 2020). TPS is used to define the speed of the platform or network in achieving transactions (Bamakan et al., 2020). Block time or latency delays the approval of transactions and places them in a block (Bamakan et al., 2020). The block is then joined into the blockchain and linked to the existing chain (Bamakan et al., 2020). When a certain amount of money is attempted to be spent, a double-spending attack happens (Bamakan et al., 2020).

3.8 Blockchain Architectural Trade-offs

A trade-off is a feature that influences more than one attribute (Kazman et al., 2000). For example, replacing the encryption level could significantly influence security and performance (Kazman et al., 2000). On the other hand, improving encryption develops security but necessitates more processing time (Kazman et al., 2000). Trade-offs are the most crucial decisions that must be made in an architectural evaluation, so trade-offs should be evaluated meticulously (Kazman et al., 2000). Every blockchain technology application has significant trade-offs on specific usage scenarios (Garriga et al., 2021). For example, improving privacy on one application may require additional controls at the cost of its performance (Garriga et al., 2021). Given these trade-offs between blockchain architecture characteristics, software architects and developers should be careful about prioritizing their architecture characteristics (Garriga et al., 2021).

3.9 Total Cost of Ownership for Blockchain Solutions

Four inputs mostly affect the costs of public and private blockchain solutions. They entirely depend on the use case and target an organization aims to achieve (Broady et al., 2019). There are some other inputs to consider but for the purposes of simplicity and standardization, the most influential of these are discussed, which are: transaction volume, transaction size, node hosting method, and consensus protocol (Broady et al., 2019).

Transaction volume is about the amount of activity performed on a blockchain (Broady et al., 2019). Transaction size means storage requirements for one unit of value transacted on the network (Broady et al., 2019). The input not only depends on the amount and complexity of data that is needed for each transaction but also on-chain and off-chain data storage practices (Broady et al., 2019). For example, applications requiring use of smart contracts to complete agreements have larger transaction sizes than applications facilitating the transfer of value, such as payments or securities (Broady et al., 2019). The node hosting method is the selected method for storing a blockchain platform and all of its assistant technological needs (Broady et al., 2019). The most common methods are on-premises (new systems), on-premises (existing technology), and cloud-based (Broady et al., 2019). The type of consensus protocol chosen depends on a company's situation and aims (Broady et al., 2019).

3.10 Blockchain Technology Challenges

3.10.1 Government Regulation

The development of government regulations can be determinant in indicating whether the blockchain will develop in a fully developed financial industry or not (Swan, 2015). In the United States of America, federal and principality-based regulations can exist. New York Bitlicense could determine the form of legislation around the world (Swan, 2015).

Governments have made different attempts globally to investigate and offer regulations (Bashir, 2017). While governments have tried to tax Bitcoin, nowadays, Bitcoin is entirely unsteady (Bashir, 2017). Governments manage currencies, and for broadly adopting blockchain, governments must achieve an agreement for the utilization of blockchain, or else its situation stays unstable (Morabito, 2017).

3.10.2 Security Challenges

3.10.2.1 51% Vulnerability

Blockchain is grounded on a distributed consensus mechanism to constitute trust (Li et al., 2020). However, the consensus mechanism has a 51% vulnerability which can be used by attackers to operate the whole chain (Li et al., 2020). Obviously, in proof of work-based blockchains, 51% attack can be initiated when the hash force of an individual miner is responsible for more than 50% of the overall hash force of blockchain (Li et al., 2020).

3.10.2.2 Double Spending

Double spending may occur when there is a conflicting node (Morabito, 2017). Double spending is when nodes try to form various operations on the identical output or credit, which may happen unintended or purposeful (Morabito, 2017). When more than one node has the same credit, only one operation can be available for that credit (Morabito, 2017). A node considers that the first operation is valid when two contradictory operations are observed (Morabito, 2017). However, the diffusion order of operations may not be identical for full nodes (Morabito, 2017). Hence, a dispute resolution procedure is admitted (Morabito, 2017). Even though a consensus mechanism can confirm operations, it is still unlikely to be protected from double-spending (Swan, 2015).

3.10.3 Technical Challenges

3.10.3.1 Latency

Many cryptocurrencies have a low transaction ratio (Casino et al., 2019). Bitcoin mechanism cannot be compared to the mechanisms like VISA's network which operates thousands of transactions (Casino et al., 2019). With the broad adoption of cryptocurrencies, latency problems should be discussed (Casino et al., 2019). Currently, the time to operate a bitcoin block is 10 minutes, so 10 minutes is required for your transaction approval (Swan, 2015). In addition, you need to wait around an hour for adequate security. This time may be longer for larger amounts when there is damage to a possible double-spending attack (Swan, 2015).

3.10.3.2 Throughput

The throughput of bitcoin is problematic since it operates only one TPS, with a theoretical current maximum of 7 TPS (Swan, 2015). Bitcoin can operate higher throughput through the larger block, but this can cause other problems regarding the size and bloat (Swan, 2015). For example, VISA has 2,000 TPS typical and 10,000 TPS peak in transaction operations (Swan, 2015).

3.10.4 GDPR Law and Blockchain

General Data Protection Regulation (GDPR) in the European Union and the Personal Data Protection Law (KVKK) in Turkey forms the most progressive regulations of the rights acquired by real persons on their data (Atmaca, 2018). With these regulations, the owners of personal information gained comprehensive and highly applicable rights. The most critical expression covering all of these rights is that people can make decisions about their data (Atmaca, 2018). The law aims to impose the rights of individuals on technology instead of complying with technology. In this respect, today, all data technologies in practice need to be designed to fulfil these rights (Atmaca, 2018). Therefore, compliance with personal data protection legislation is not related to the technology; it is about its use. (Çavdar et al., 2019).

Efficient and fast integration of blockchain into business life is possible with technical developments and a legal infrastructure that considers the features of the blockchain (Çavdar et al., 2019). Blockchain is essentially a data storage method, and there is no doubt that GDPR legislation is one of the most critical legislation in terms of its compatibility with the blockchain (Çavdar et al., 2019). It would not be wrong to say that if blockchain technology and the legislation in this branch of law are not compatible, this incompatibility will interrupt the spread of blockchain (Çavdar et al., 2019).

Legal regulations on personal data protection have been created assuming that at least one natural or legal data controller is responsible for carrying out personal data processing activities according to the obligations specified in the relevant legislation (Çavdar et al., 2019). Therefore, these regulations are built on a centralized structure (Çavdar et al., 2019). However, thanks to the distributed network structure of blockchain, which is among the essential elements of it, the records of all transactions are distributed to each participant on a network instead of being kept in a single-centre, which eliminates intermediate actors like data controllers (Çavdar et al., 2019). In other words, the technology in question is built on a decentralized structure (Çavdar et al., 2019). This contradiction raises the tension between blockchain technology and regulations on protecting personal data (Çavdar et al., 2019).

Public keys, transactional data, and reversibly encrypted data are often considered personal data. If they are used in the blockchain network, they must be processed per the provisions of the KVKK and GDPR (Çavdar et al., 2019). In transactional data, information is directly derived as a consequence of transactions (Technopedia). Unlike being the object of transactions like the product being procured or the identity of the customer, it is more of a reference data defining the time, place, prices, payment procedures, discount values, and quantities related to that specific transaction; generally, at the point of sale (Technopedia).

Within the scope of having the right to correction, people have the right to request from the data controller to correct inaccurate personal data without delay (Çavdar et al., 2019). Due to the immutable nature of the blockchain, a significant problem arises between the GDPR with blockchain as to how to implement the correction right in blockchain (Çavdar et al., 2019). When a person submits his request to correct incorrect or incomplete data to the data controller, the data controller must correct this data (Çavdar et al., 2019). However, the core of blockchain security is its immutability (Çavdar et al., 2019). What data can and should be stored on the blockchain should be carefully evaluated because of the regulatory and performance-related issues.

3.10.4.1 Technical Solutions for Protection of Personal Data in Blockchain

3.10.4.1.1 Not Storing Personal Data on Blockchain-Keeping Only Anonymous Data

Some developers have started developing different methods to ensure GDPR compliance (Çavdar et al., 2019). One view suggests using a personal address that relies on one-time keys and performs a one-time transaction (Çavdar et al., 2019). For example, Monero has managed to hide the transaction recipient by creating a new private address and a "secret key" (Çavdar et al., 2019).

3.10.4.1.2 Off-chain Data Storage

In the current situation of blockchain, it is hard to provide mentioned rights without disrupting the integrity of the technology, so personal data is stored in a private and confidential network outside the blockchain network, that is "off-chain," and only the proof of the off-chain data (for example, cryptographic summarized data related to encryption) kept on the blockchain (Çavdar et al., 2019). With this method, personal data are saved on the referenced, encrypted, and changeable database, not on the blockchain (Çavdar et al., 2019).

If it is necessary to process personal data during blockchain technology, processing and storing it outside the blockchain may be a solution for data protection regulations and the relevant person's rights (Çavdar et al., 2019). However, using off-chain storage methods can reduce the trust in DLTs since these methods require the participation of a trusted third party. Furthermore, these methods will lead to ignoring the decentralized and intermediary-removing characteristics of blockchain technology (Çavdar et al., 2019). It is impossible to use the right to correct or delete data on the blockchain network (Çavdar et al., 2019). When personal data are kept out of the chain and the personal rights are requested to be used by the person concerned, the data controller can perform the relevant correction or deletion process outside the chain (Çavdar et al., 2019). In this case, the problem of storing personal data on the blockchain network as long as the network is alive will be solved (Çavdar et al., 2019).

3.10.4.1.3 Adding Error Record to Chain

When the data correction request is sent to the data controller by the relevant person, a record is added to the chain stating that the data subject to the request has been corrected (Çavdar et al., 2019). This record notifies that previous data has been deleted, erroneous, and/or corrected (Çavdar et al., 2019). Although the relevant data has been changed in the chain, this method is criticized as inaccurate data still appears.

3.11 Blockchain Technology Features, Enablers, and Selection Criteria

In literature, blockchain features generally focus on quality features formed in line with the companies' requirements. Unfortunately, blockchain technology selection criteria are not studied from a standardized perspective. There are more studies on blockchain enablers and the features that motivate people to employ blockchain technology. For a technology like a blockchain that is not yet mature, it is necessary to determine which standardized quality features can be satisfied with which blockchain features. The studies mainly focusing on blockchain technology features, enablers, and selection criteria can be seen in Table 3.4,

Table 3.4: Blockchain technology features, enablers, and selection criteria

	Blockchain Characteristics (Features/Enablers/Selection Criteria)	Technique	Quality Attributes	Characteristics' Relations	Alternative Selection	Area	Supply Chain Performance
(Kshetri, 2018)	N/A	Case Studies	N/A	N/A	N/A	Supply Chains	Cost, Speed, Dependability, Risk Reduction, Sustainability, Flexibility
(Kamble et al., 2020)	**Enablers:** Anonymity and privacy, Auditability, Decentralized database, Transparency, Traceability, Smart Contract, Shared Database, Secured Database, Reduced Settlement lead times, reduced transaction costs, provenance, improved risk management, Immutability	Interpretive Structural Modelling (ISM)/DEMATEL	N/A	Available	N/A	Agriculture Supply Chain	N/A
(Tang et al., 2019)	**Selection:** Basic Technology, Applicability, Transaction per Second, Market Capitalization, The fork in Github, The total commits in Github, The star in Github, The number of followers on Twitter, Google search heat, The number of commits in Github in the previous month, the Turnover rate in the previous month	Entropy/TOPSIS	Domain-Specific	N/A	Three public blockchains	N/A	N/A
(Dinh et al., 2017)	**Selection:** Throughput, Latency, Scalability, and Fault-tolerance	Benchmarking	Domain-Specific	N/A	Three Private Blockchains	N/A	N/A
(Kuo et al., 2019)	**Selection:** Network Permission, Consensus Protocol, Special Hardware Requirement, Smart Contracts Support, Scripting Language, Software License	Systematic Review	Domain-Specific	N/A	Ten popular blockchains	Healthcare	N/A

(Orji et al., 2020)	**Enablers:** Availability of specific blockchain tools, Infrastructural facility, Complexity, Ease of being tried and observed, Perceived benefits, Compatibility, Security and privacy, Presence of training facilities, Top management support, Firm size, Capability of human resources, Perceived costs of investment, Organizational culture, Government policy and support, Competitive pressure, Institutional based trust, Market turbulence, Stakeholders pressure	ANP	N/A	Available	N/A	Freight logistics industry	N/A
(Zarour et al., 2020)	**Selection:** Authentication, Authorization, Information Privacy, Data Management, Synchronization, Control, Hashing, Cryptography, Proof-of-stake, proof-of-work, Performance, Convenience, Demand	Fuzzy ANP/TOPSIS	Domain-Specific	Available	Blockchain Models	Healthcare	N/A
(Farshidi et al., 2020)	**Selection:** Enterprise system integration, On-chain transactions, Delegated Byzantine Fault Tolerance, Permissioned, Resilience Technologies, Sybil Attack Resistant, Directed Acyclic Graph, Privacy Technologies, Technology Maturity, SNARKS, proof-of-work, Smart contracts, transaction speed, Zero-knowledge proof, Golang, Network Layer, etc.	MCDM, DSS	ISO/IEC 25010, EXT. ISO/IEC 9126	Available	28 Blockchain Platform	Software Producing	N/A
(Stranieri et al., 2021)	N/A	Case Study	N/A	N/A	N/A	Agri-food supply chain	Efficiency, Flexibility, Responsiveness, Food Quality, Transparency
Maden & Alptekin (2020)	**Enablers:** P2P Network, Immutability, Consensus Mechanism, Permanent Availability of Data, Chronological order of data, Open source mechanism, Cryptocurrency creation, Encryption mechanism, Smart contract enablement, Instant money transfer, Privacy, Real-time processing, Security, Authentication, Transparency, Traceability, Distributed Ledger, Reduced delays	Fuzzy DEMATEL	N/A	Available	N/A	Logistics Company	N/A

The techniques widely used in studies primarily focusing on blockchain technology features, enablers, and selection criteria are ISM, DEMATEL, Entropy, TOPSIS, Benchmarking, ANP, Systematic Review, and Case Studies. Focus areas of these studies are supply chains, logistics, agri-food supply chain, healthcare, agriculture supply chain, and software producing. There are limited studies on blockchain technology dealing with supply chain performance dimensions, which is vital for the broad adoption of blockchain for supply chains. Relations between blockchain characteristics are also fundamental, and they should be evaluated before making decisions about blockchain technology. Studies on the selection of blockchain technology have focused on either the supply chains or software issues.

Kshetri (2018) inspected different mechanisms by which blockchain technology support to reach supply chain objectives. They primarily focused on the roles of the IoT in blockchain-based solutions and the degree of blockchain deployment to validate identities of individuals and assets. The authors inspected how blockchain is likely to influence primary supply chain management objectives such as cost, quality, speed, dependability, risk reduction, sustainability, and flexibility. Kamble et al. (2020) identified blockchain technology enablers that lead companies to apply blockchain in their supply chains. After identifying these enablers, they implemented an integrated ISM and DEMATEL methodology. Dinh et al. (2017) proposed BLOCKBENCH, the first evaluation architecture to evaluate private blockchains. BLOCKBENCH serves as a fair means of comparison for various platforms, and it facilitates a deeper understanding of different design options (Dinh et al., 2017). This architecture measures comprehensive and component-wise performance using throughput, latency, scalability, and fault tolerance. Finally, they used BLOCKBENCH to evaluate three significant private blockchains: Ethereum, Parity, and Hyperledger Fabric. The outcomes showed that these private blockchains are still far from replacing existing database systems in conventional data processing workloads. Maden and Alptekin (2020) used Fuzzy DEMATEL to define and assess the critical factors to encourage blockchain adoption based on the case company’s needs. In literature, a relatively small number of papers investigated the relations of factors affecting the decision to adopt blockchain. According to the authors, factors affecting the decision to adopt blockchain technology were, in order of priority: cryptocurrency, instant money transfer, privacy, real-time processing, smart contract, security, authentication, transparency, immutability, traceability, distributed ledger, reduced delays, and peer-to-peer networks.

Different supply chain aims such as cost, time, quality, flexibility, sustainability, and risk management are developed by Kshetri (2018) with blockchain-based supply chain cases of Maersk, Provenance, Alibaba, and Walmart. Bai and Sarkis (2020) proposed a blockchain technology performance measurement framework for sustainable supply chain transparency using hesitant fuzzy sets and regret theory. In literature, blockchain was evaluated using different metrics, such as throughput (Dinh et al., 2017; Bai & Sarkis, 2020), latency (Dinh et al., 2017), fault tolerance (Dinh et al., 2017), cost (Kshetri, 2018; Bai & Sarkis, 2020) and scalability (Bai & Sarkis, 2020; Dinh et al., 2017).

In literature, blockchain selection studies are either too supply chain-specific or too technical in software issues. Moreover, there is almost no study describing its complex structure by simplifying it, especially for blockchain alternative selection decisions. In this study, we had an opportunity to meet supply chain topics with the software issues with the help of the QFD. Conventional software selection procedures are either technology-based or domain-specific (Nanayakkara et al., 2021). Technology-based procedures deal with data structures, programming procedures, functionality, etc., while domain specifics handle selection processes for business domain needs (Nanayakkara et al., 2021). Hence, tracing these conventional software selection procedures is not appropriate since blockchain technology selection has a broader perspective (Nanayakkara et al., 2021). In this study, we made a case study to satisfy the problems in supply chain metrics and software-related characteristics of a selected supply chain using an integrated Cognitive Map-QFD-TOPSIS methodology.

3.12 Enterprise Blockchain Alternatives

This study used a classical internet search engine to select popular blockchain alternatives to evaluate since it is simple and easy to search. With the help of the technology articles like Gartner Peer Insights (Gartner Peer Insights) and Hacker Noon (Hacker Noon), the newest blockchain alternatives can also be reached for detailed evaluations. Ethereum, Hyperledger, Corda, and Ripple are among the most popular enterprise blockchain alternatives. Some of them are regarded as distributed ledgers, but they are widely used today as blockchain. Although some are only heard as cryptocurrencies, they are considered among the enterprise blockchain because of their wide use.

Ripple was initially released in 2012 (Ripple, 2021). Ripple has broad adoption in finance (Ripple, 2021). However, speculators can influence the cryptocurrency side. It does not have smart contract functionality (Gord & Holek, 2019). It has % 33 providers with experience based on the response from 15 blockchain providers (Fersht, 2018). It is moderate in size of the developer team (50+ contributors on Github). It has large partnerships and alliances, having multiple large banks involving 11 of the world’s top 100 banks (Gord & Holek, 2019). The governance of Ripple is through its Ripple Labs (Gord & Holek, 2019). Validator nodes confirm and validate transactions in security model of Ripple. As validators become more trusted in the network, it becomes more difficult to control and change the ledger as an outside attack (Gord & Holek, 2019). Its consensus algorithm is Ripple Protocol Consensus Algorithm (Ripple, 2021). Cost to use Ripple depends on the value of XRP yet all services do not depend on cryptocurrency (Gord & Holek, 2019). The development environment of Ripple is in C/C++, Java, node.js, Go languages (Ripple, 2021).

Hyperledger is a modular blockchain platform architecture allowing plug-and-play implementations of various functions (Hyperledger, 2021). It hosts any mainstream language for smart contract development (Hyperledger, 2021). Hyperledger is an open-source collaborative effort to progress cross-industry Blockchain (Hyperledger, 2021). Hyperledger Fabric is Hyperledger’s most active project to date. The Fabric project was initiated by IBM (Hyperledger, 2021). It is designed as a base for improving blockchain distributed ledger implementations with a modular structure. It supports components, such as consensus and membership services, to be pluggable (Hyperledger, 2021). Hyperledger is built for enterprise implementations and can support effective private networks (Hyperledger, 2021). Besides, it has strong professional backing of contributors (Hyperledger, 2021). However, hyperledger is still relatively young in development, and its support is dependent on IBM's help center. Another disadvantage is that its only centralized aspect is the Certificate Authority (CA), which issues certificates to eligible parties.

Ethereum is a distributed computing platform which is generic, open-source and blockchain-based and it is for applications to be built upon (Gord & Holek, 2019). Ethereum has a large development community, and it is quick to develop applications on it. In addition, it has a wide array of use cases (Gord & Holek, 2019). However, it creates security concerns since it has a public side. As another disadvantage of Ethereum, it uses cryptocurrency as fuel for transactions (Gord & Holek, 2019). Besides, forks can cause problems in Ethereum. In Ethereum, Ether (gas) is used to pay for transactions (Gord & Holek, 2019). Based on the response from 15 important blockchain providers, it has % 93 providers with experience (Fersht, 2018). When it comes to the size of the developer team, it has one of the most active development communities (Gord & Holek, 2019). Updates' frequency of Ethereum is high; it is open-source with a large community for updates. Ethereum platform development is governed by Ethereum developers (Gord & Holek, 2019). In addition, its enterprise focus is moderate. Its Enterprise focus is through forks, Quorum, and Enterprise Ethereum Alliance (EEA). The first important breakthrough for Enterprises happened in October 2016. Quorum was made public by JP Morgan Chase as an effort to broaden blockchain with Enterprise abilities (Gord & Holek, 2019).

It should be stressed that R3 Corda is not a blockchain, but it uses the same underlying fundamentals of DLT to provide a very similar environment that operates differently (Gord & Holek, 2019). It has significant financial institutional backing, and it is built specifically for enterprise use. However, it has fewer use cases than its alternatives.

Besides, it has a smaller developer community (slower updates) and does not have much developer expertise compared to the competition. Corda has no cryptocurrency to operate (Gord & Holek, 2019). Corda has %60 providers with experience (Fersht, 2018). Enterprise blockchain alternatives can be seen in Table 3.5,

Table 3.5: Enterprise blockchain alternatives

		Ethereum	Hyperledger Fabric	Corda	Ripple
	Purpose	Running smart contracts on EVM for the mass consumption of decentralized applications.	Creation of cross-industry Blockchain tools and applications	Recording and enforcing business agreements between trading partners	Fintech, Enterprise blockchain for global payments
Maturity/Popularity	**Coin Market Cap.**	$44,853,349,857	N/A	N/A	$11,305,560,418
	Genesis Block	July 30, 2015	N/A	N/A	February 2, 2013
	Google Search (Year)	732	2817	4148	1971
	Governance	Ethereum Developers	Linux Foundation	R3 Consortium	Ripple Labs
Architecture Features	**Data Structure**	Blockchain	Blockchain	Distributed Ledger	Interledger Protocol
	Permission Model	Permissionless	Permissioned	Permissioned	Permissioned
	Scalability	Highly scalable	Highly scalable	Highly scalable	Highly scalable
	Smart Contract Functionality	Yes	Yes	Yes	Very Limited
	Cryptocurrency	Ether (ETH)	None; Can be built using chain codes	None	Ripple (XRP)
	Industry Focus	Cross-Industry	Cross-Industry	Financial Services	Financial Services
	Privacy	zk-SNARKs, ZKP	Private channels, ZKP	ZKP	ZKP
	Modularity	Generic, with DApp and smart contract support for broader applications	Modular architecture	Less focus on modularity	Fully supported
	Open Source	Yes	Yes	Yes	Yes
	Security	Spam attack, Sybil attack resistant	Spam attack, Sybil attack resistant	Hard fork, Spam attack, Sybil attack resistant	Sybil attack resistant
	On-chain transactions	Available	Available	N/A	Available

	Off-chain transactions	N/A	Available	Available	Available
Consensus Mechanism	**Consensus Algorithm**	PoW	Pluggable Framework	Pluggable Framework	Ripple Protocol Consensus
	Algorithm	Ethash (KECCAK256)	SHA 2 family	SHA 256	N/A
	TPS	200	>2000	170	>1500
Integration	**Licensing**	*Go-Ethereum: Lesser General Public License (LGPL) v3.0 *CPP-Ethereum: General Public License (GPL) v3.0 *Py-Ethereum: MIT License EthereumJ: General Public License (GPL) v3.0 *Parity: General Public License (GPL) v3.0	Various, for example, Apache License v2.0 for Fabric, Copyright by Intel Corporation for Sawtooth	Limited-Apache 2.0	Various Copyright
	Enterprise System Integration	Supported	Supported	Supported	Supported
	Scripting Language	Solidity (similar to C and JavaScript), Serpent similar to Python), LLL (similar to Lisp	Various, for example, Go/node.js for Fabric (Chaincode), C++, Go, Java, JavaScript, Python, Rust, or Solidity (through Seth) for Sawtooth	Kotlin, Java	N/A (Java Script for Codius, abandoned)
TCO	**Cost to Use**	Transactions cost ETH	Free-Only development and maintenance costs	Free-Only development and maintenance costs	Varies-Dependent on the value of XRP, but not all services rely on cryptocurrency
	Requires ongoing support	Yes-As updates are released	Yes-As updates are released	Yes-As updates are released	Low- Ripple has in house support with proficiency in the back end
	Difficult to use	Moderate-Specific use cases require	Low-Moderate; Low	Moderate-Requires knowledge of	Ripple has designed specific

	DApp development	maintenance, but requires some work to set up for specific use case	their platform, which has a smaller support community than the competition	products built on their protocol for different use cases, which aids in the adoption within the enterprise

When considering all of the features of blockchain technology, from consensus mechanism to architectural design, there is almost no study describing its complex structure by simplifying it, especially for alternative blockchain selection decisions. Moreover, there is not even a common consensus or framework on the essential architectural characteristics of blockchain. Hence, we summarized blockchain characteristics related to blockchain architectural design, consensus mechanism, and blockchain-specific characteristics to support enterprise blockchain selection decisions.

After inspecting all blockchain features, we summarized blockchain characteristics to support blockchain technology selection decisions, especially for enterprise systems' blockchain application development decisions. The summarized blockchain characteristics are architectural characteristics (permissioned network, permissionless network, smart contract functionality, privacy, off-chain transactions, on-chain transactions, security, and scalability), consensus mechanism (adversary fault tolerance, verification speed, block time, double spending, and TPS), governance-dependent (governance, network size, transaction capacity, participation), business-related features (cost), open-source (community; which is not available in ISO model), implementation-related (enterprise system integration, ease of use, modularity, APIs support), domain-specific features (blockchain data structure, non-blockchain data structure, cryptocurrency support, tokenization) and other features like licensing and popularity.

In this study, we used Fuzzy TOPSIS to select an appropriate blockchain alternative. Two-staged Fuzzy QFD enabled us to consider supply chain-related business-specific (SCOR) dimensions and technology-specific (ISO) dimensions in the blockchain alternative selection process.

4. METHODOLOGY

This study supports the blockchain technology selection decision of a supply chain in line with the requirements of its stakeholders, explicitly focusing on the procurement process. We made a case study application considering the problematic supply chain metrics and software-related characteristics of the case supply chain using an integrated Cognitive Map-QFD-TOPSIS methodology**.** Firstly, we determined supply chain processes using SCOR and BPMN. Secondly, we determined and focused on important SCOR engineer-to-order performance metrics using Fuzzy Cognitive Map. We preferred the Fuzzy Cognitive Map since it also considers non-negative relationships between the criteria. Finally, FCMapper is used to perform Fuzzy Cognitive Map analysis. FCMapper is an open licensed excel macro (available at http://www.fcmappers.net/joomla/).

We determined and focused on essential quality characteristics from ISO standards using Fuzzy Cognitive Map. After determining essential SCOR performance metrics and software characteristics, we used them in QFD Stage 1. Finally, we calculated QFD Stage 1 correlations and multiplied Fuzzy QFD and Fuzzy Cognitive Map results. As a result, we reached QFD Stage 1 Final HOW weights. In this study, three stakeholders in the system represent the supplier, customer, and procurement staff, and three stakeholders from the software development.

Characteristics of blockchain technology were determined from literature primarily focusing on enterprise use. Then, important blockchain design characteristics using Fuzzy Cognitive Map were focused. Next, QFD Stage 2 correlations were calculated, the results were multiplied with Fuzzy Cognitive Map results, and QFD Stage 2 Final HOW weights was reached. Another step was to select an enterprise blockchain alternative from four popular enterprise blockchains using the final blockchain characteristics' weights in Fuzzy TOPSIS. Finally, we analyzed different scenarios using the Fuzzy Cognitive Map. The methodology of our study can be seen in Figure 4.1.

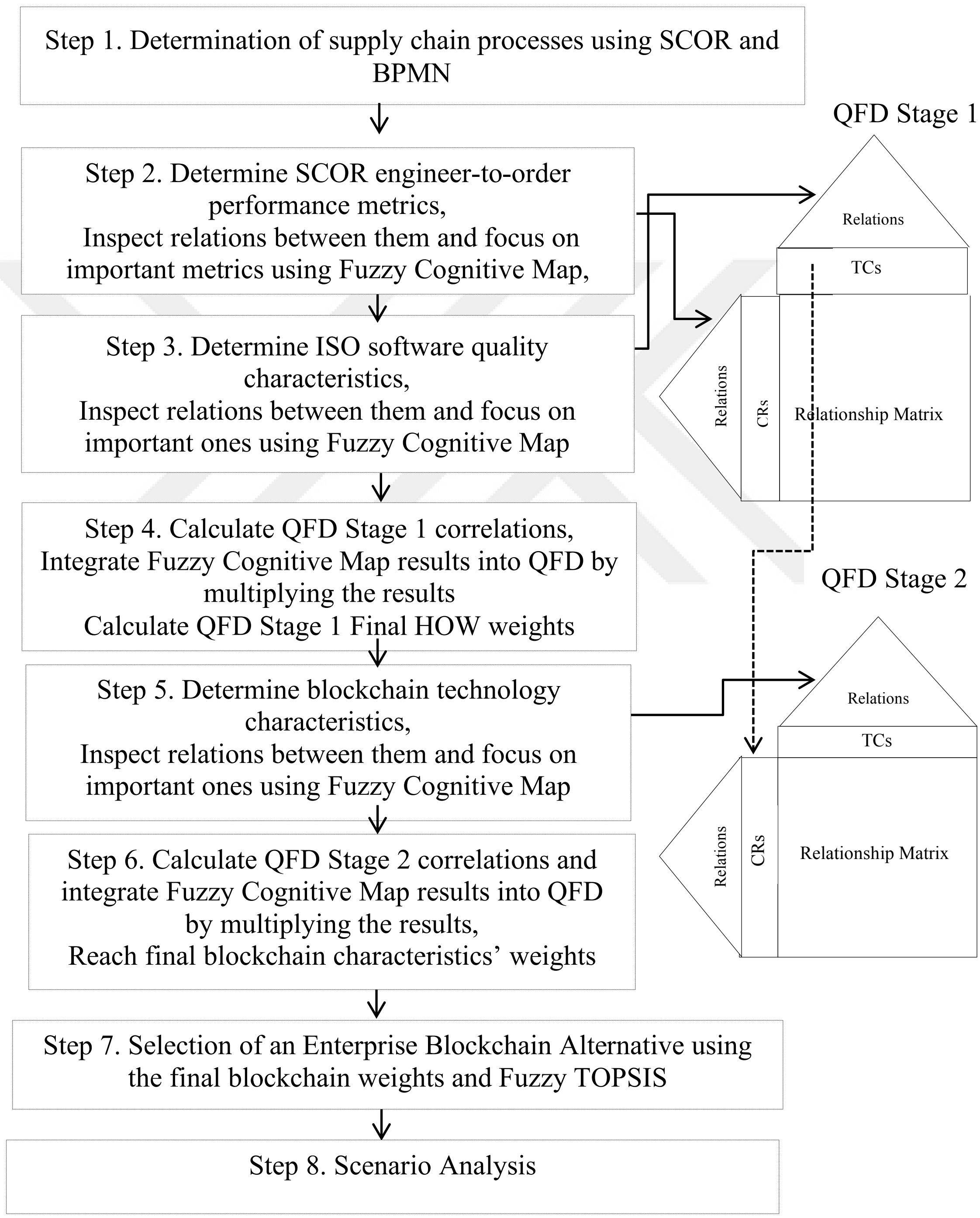

Figure 4.1: Methodology of the study

4.1 Models and Standards Used in the Study

4.1.1 SCOR model

SCOR is a reference model that identifies your business process well for your shareholders (APICS, 2015). Here, the framework touches on the process communication, execution, configuration, and the needs of employees working in the process (APICS, 2015). The SCOR includes four main components: performance, processes, practices, and people (APICS, 2015). The performance involves standard metrics to define process performance and describe strategic aims (APICS, 2015). Processes involve standard definitions of management processes and process connections (APICS, 2015). Practices involve management implementations that increase process efficiency (APICS, 2015). Lastly, the people part involves standard descriptions of abilities required for process performance (APICS, 2015).

The SCOR has been introduced to identify business activities related to all stages of meeting a customer's demand (APICS, 2015). Different industries can be connected to define the depth and width of almost all supply chains (APICS, 2015). The model has efficiently identified and ensured supply chain development for site-specific and universal projects (APICS, 2015).

The process part provides a set of explanations established in advance for activities that organizations carry out to run their supply chains successfully (APICS, 2015). The SCOR is based on six fundamental management processes in supply chains – Plan, Source, Make, Deliver, Return and Enable– to satisfy planned and actual demand (APICS, 2015). However, SCOR does not define business processes like sale process, marketing process, research process, or product development process (Komatina et al., 2019). Instead, the SCOR allows modelling supply chains and relationships gradually and systematically (Cheng et al., 2010). There are four levels of model development in the SCOR (Cheng et al., 2010). Level 1 modelling enables a description of the scope and content for SCOR. The potentials in Level 1 processes are identified by Level 2 (APICS, 2015).

Level 2 divides the six main management processes into process categories, which help businesses define their supply chains configuration (Cheng et al., 2010). For example, essential Level 2 processes include make-to-stock, make-to-order, engineer-to-order for source, make and deliver processes, etc. (APICS, 2015). In addition, level 2 conceptually determines the relationship and interactions between supply chain participants (Cheng et al., 2010).

The conceptual specification can be expanded to define the process workflow using Level 3 (Cheng et al., 2010). Level 3 processes have stages enforced in a specific order to plan supply chain activities (APICS, 2015). Level 3 modelling ensures organizations with the data for detailed planning and setting targets (Cheng et al., 2010). Level 3 processes also ensure the basis for describing the supply chain performance metrics.

SCOR Level 4 models are unique for companies, and the particular elements at this level are not described in the SCOR modelling (Cheng et al., 2010). SCOR can be broadened to take and exemplify complex interactions between supply chain members (Cheng et al., 2010). Fundamental SCOR processes and four levels of model development in the SCOR can be seen in Figure 4.2,

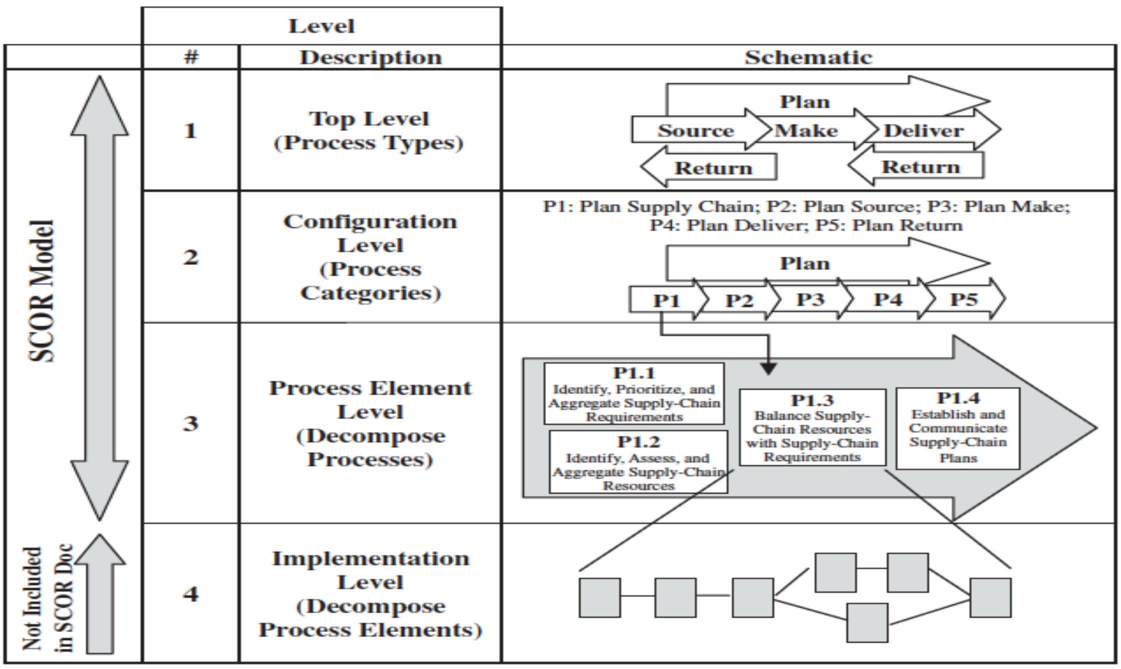

Figure 4.2: Four levels of SCOR business processes (Cheng et al., 2010)

SCOR Level 1 modelling, six main processes of SCOR, can be seen in Figure 4.3,

Figure 4.3: SCOR Level 1 modelling (APICS, 2015)

4.1.1.1 SCOR Performance Metrics

SCOR's performance part includes two components: performance attributes and metrics (APICS, 2015). A performance attribute consists of metrics utilized to explain a strategy (APICS, 2015). For instance: 'The LX product needs to be leading the competition in reliability' and 'The xy-market requires us to be among the top 10 agile producers' APICS. (2015). The main purpose of a lean supply chain strategy is to decrease cost and improve efficiency through elimination of wastes in both inter-organizational and intra-organizational processes (Qi et al., 2009). When the market is more dynamic and turbulent, organizations need to follow an agile supply chain strategy (Qi et al., 2009). An attribute is utilized to describe a strategy, and it is immeasurable (APICS, 2015). SCOR metrics are assembled in one of these attributes, which are: reliability, responsiveness, agility, cost, and assets (APICS, 2015). Reliability defines the capability to fulfill tasks as expected (APICS, 2015). Responsiveness defines the speed at which tasks are performed. Agility defines the capability to respond to external influences, the ability to answer to market modifications to earn or maintain competitive advantage. Cost defines the cost of operating the supply chain processes. Asset management efficiency defines the capability to efficiently use assets. Asset management strategies in a supply chain involve inventory reduction and in-sourcing vs. outsourcing.

Metrics of the SCOR are arranged in order of rank (APICS, 2015). For example, level 1 metrics can help measure a company's accomplishments in satisfying its aims regarding the competitive area (APICS, 2015). SCOR model explains the metrics in varied levels: Level 1, Level 2, and Level 3 (APICS, 2015). These levels have identifiable relations (APICS, 2015). For example, achievements of the Level 2 metrics can clarify performance situations for Level 1 (APICS, 2015). The SCOR Level-1 metrics can be seen in Table 4.1,

Table 4.1 The SCOR Level-1 metrics

Performance Attribute	Level-1 Strategic Metrics
Reliability	Perfect Order Fulfillment (RL.1.1)
Responsiveness	Order Fulfillment Cycle Time (RS.1.1)
Agility	Upside Supply Chain Flexibility (AG.1.1) Upside Supply Chain Adaptability (AG.1.2) Downside Supply Chain Adaptability (AG.1.3) Overall Value At Risk (AG.1.4)
Cost	Total Cost to Serve (CO.1.001)
Asset Management Efficiency	Cash-to-Cash Cycle Time (AM.1.1) Return on Supply Chain Fixed Assets (AM.1.2) Return on Working Capital (AM.1.3)

Level 3 performance metrics are concerned with SCOR Level 3 processes (Cheng et al., 2010). Hence, we can choose the supply chain performance metrics in a process-based approach after the SCOR Level 3 modelling (Cheng et al., 2010). The selection of performance metrics is specific to the characteristics of the project and the requirements of the stakeholders (Cheng et al., 2010). According to the company strategy, this study selected supply chain performance metrics from the Level 3 Source engineer-to-order product process. Then we evaluated and eliminated these metrics using the Fuzzy Cognitive Map since there are trade-offs between these KPIs.

4.1.2 BPMN models

BPMN models have four fundamental concepts, which are flow objects, connecting objects, swim-lanes, and artefacts. Flow objects include three core elements: events, gateways, and activities (Cheng et al., 2010). An event is indicated as a circle, showing something happening (Cheng et al., 2010). A gateway defines forking and merging of paths based on the situations explained (Cheng et al., 2010). Connecting objects show links between flow objects, with sequence flows which link flow objects in the identical pool and message flows which link flow objects in distinct pools (Cheng et al., 2010). Core components in BPMN can be seen in Figure 4.4,

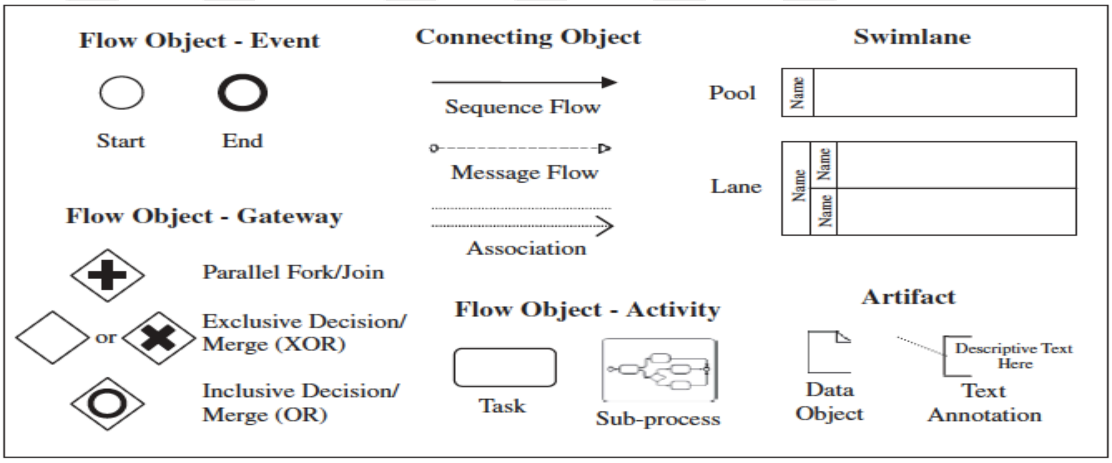

Figure 4.4: Core components in BPMN standard (Cheng et al., 2010)

BPMN is mostly preferred for process definitions in supply chain or software-related tasks. For example, Semerdjieva and Krastev (2012) used BPMN to encode processes to evaluate public procurement works. BPMN enabled them to see the interactions of distinct participants in their system. With the help of a detailed model based on the SCOR and BPMN, Lhassan et al. (2018) map processes of wholesaler-distributors supply chain from a strategic level to operational tasks. This enabled them to see interactions between different participants in the supply chain. López-Pintado et al. (2017) proposed Caterpillar, an open-source Business Process Management System that runs on Ethereum. Caterpillar supports creation of instances of a process model (received in the BPMN) and permits users to trace the state of process instances and execute tasks thereof (López-Pintado et al., 2017). In Caterpillar, the state of each process instance is maintained on Ethereum, and the workflow routing is implemented using smart contracts created by a BPMN-to-Solidity compiler (López-Pintado et al., 2017). To monitor and execute business processes in an untrusted way with the help of blockchain technology, Weber et al. (2016) benefited BPMN 2.0 XML filed and JBoss BPMN2 modeler to describe process specifications. The authors also implemented proof-of-concept prototypes for the translator and the trigger. In the design process, a translator derives from a process specification described in, e.g., BPMN, a smart contract in a scripting language like Solidity (Weber et al., 2016). This study used Camunda Modeler 3.5.0, a process automation tech stack for BPMN workflows and DMN (decision model and notation) decisions, to show supply chain processes.

4.1.3 Software Quality Models

When reviewing the software engineering literature, various quality models can be explored, such as McCall's (McCall et al., 1977), Boehm's (Boehm, 1978), FURPS (Grady, 1992), Dromey's (Dromey, 1996), and ISO 25010 (ISO/IEC 25010, 2011). In addition, there are various procedures and frameworks to assess software architectures that are suitable for specific targets (Moaven & Habibi, 2020). ISO 25010 is the latest software quality model, and it has international views (Haoues et al., 2017).

Miguel et al. (2014) compared the software quality models to be able to assess software products. The authors mainly focused on ISO 25010 model since it has the latest standardized language. They found that ISO 25010 is the most comprehensive model within basic models since it includes the most evaluated characteristics. When considering the whole reviewed procedures to assess software architectures, it can be discovered that there are significant problems such as overlapping or contradicting quality characteristics (Moaven & Habibi, 2020). Software specialists should frequently pay attention to overlapping and conflicting characteristics in software architectures, creating complexity in software selection operations (Moaven & Habibi, 2020). One of the hardships in the ISO quality model is to determine the weights of quality features (Rochimah, 2013). This is because of the interrelations between the quality characteristics in ISO 9126, which impact the characteristics' weights and software quality (Rochimah, 2013). These quality characteristics have the potential to impact or contradict each other (Rochimah, 2013).

In literature, mostly used procedures for open source software quality evaluation, especially for choosing decisions, are data mining methods (Artificial Neural Network, etc.), process-based solutions (a range of actions), tool-based solutions (software tools), model-based solutions (system representation) and framework-based solutions (Adewumi et al., 2016). Although the community separates open-source software from other software products, half of the procedures do not measure community-concerned quality features (Adewumi et al., 2016). An excellent model covering all quality characteristics in an open-source software product has not been identified yet (Miguel et al., 2014). Moreover, considering the comparison results of the available open-source software quality evaluation procedures, it can be concluded that there is no convenient procedure as every procedure has its restrictions (Adewumi et al., 2016). Besides, instead of including all the software attributes in the proposed evaluation procedures, more applications should build procedures that involve solely necessary quality attributes (Adewumi et al., 2016).

Software metrics should be easy to quantify, and they must possess aims connected to software projects (Bukhari et al., 2015). Moreover, these metrics should be strategic to align organizational actions with organizational targets; they should be quantitative to enable exploration of advancement towards the targets; and they should be qualitative to enable exploration as to how the metric is essential (Bukhari et al., 2015).

4.1.3.1 SQuaRE Standards Family

Software quality focuses on removing bugs, developing performance, providing security, preventing the loss or corruption of data, etc. (Enriquez, 2016). The major reason for handling software quality assurance as a component of the software development process is to ensure a final error-free product and to ensure development according to the needs of customers (Enriquez, 2016). As the software quality can be evaluated, a software system's quality characteristic should be determined in order to specify if the implied or stated requirements are satisfied (Enriquez, 2016). Software quality models have been developed to standardize the criteria against which quality is assessed (Enriquez, 2016). SQuaRE is a family of standards divided into five parts (ISO/IEC 25010, 2011). This study focuses on only the Quality Model Division 2501n and the Quality Measurement Division 2502n, specifically in the ISO/IEC 25010 (ISO, 2011(E)), ISO/IEC 25023 (ISO, 2016(E)), ISO/IEC 25024 (ISO, 2015(en)) and ISO/IEC 25022 (ISO, 2016) standards, respectively. The series of standards ISO/IEC 25000 includes five divisions, as can be seen in Figure 4.5,

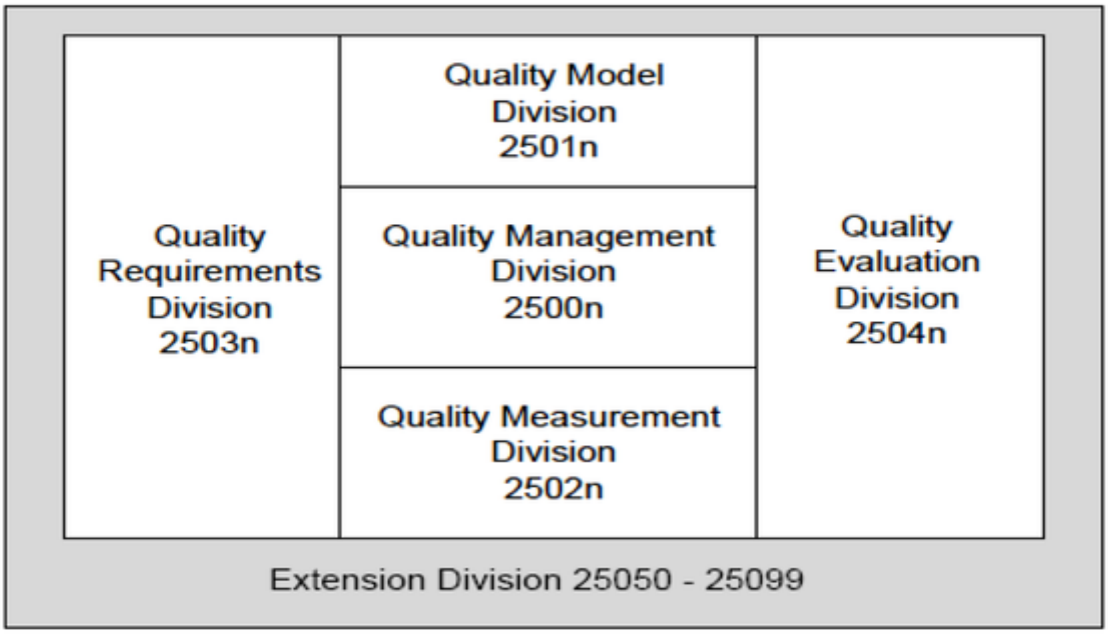

Figure 4.5. Divisions of ISO/IEC 25000 standards (ISO/IEC 25010, 2011)

4.1.3.2 ISO/IEC 25010:2011-Systems and software engineering-System and software quality model

The ISO/IEC 25010 Standard, Systems and Software Quality Requirements and Evaluation (SQuaRE) [ISO/IEC-25010] determined quality in use model and a product quality model to ensure a consistent terminology for specifying, measuring, and evaluating system and software product quality. The quality models in this standard can determine suitable quality characteristics, which can also define needs, their criteria, and related measures (ISO/IEC 25010, 2011). There are three quality models in the SQuaRE: the quality in use model, the product quality model, and the data quality model.

4.1.3.2.1 Product quality model

Realizing targets and aims for individual satisfaction, organization performance, and/or human safety depend on high-quality software and systems (ISO/IEC 25010, 2011). A product quality model comprises eight characteristics divided into sub-characteristics, which are about static features of the software and the dynamic features of the computer system. Software Product Quality Model and its eight characteristics can be seen in Figure 4.6,

4.1.3.2.2 Quality in use model

The quality in use model comprises five characteristics that relate to the result of interaction when a product is utilized in a specific context of usage (ISO/IEC 25010, 2011). Quality in use model is appropriate for the whole human-computer systems, involving both computer systems and software products in use (ISO/IEC 25010, 2011). Software quality in use model and its five characteristics can be seen in Figure 4.7,

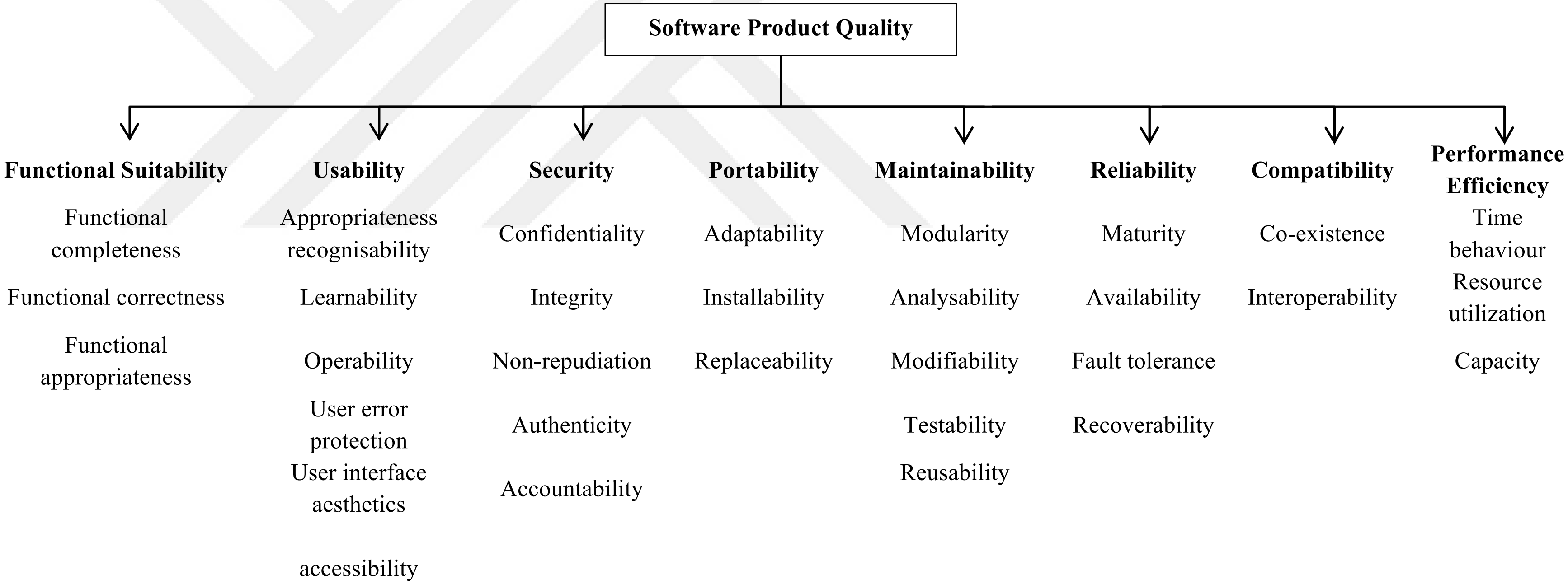

Figure 4.6: Software product quality model (ISO/IEC 25010, 2011)

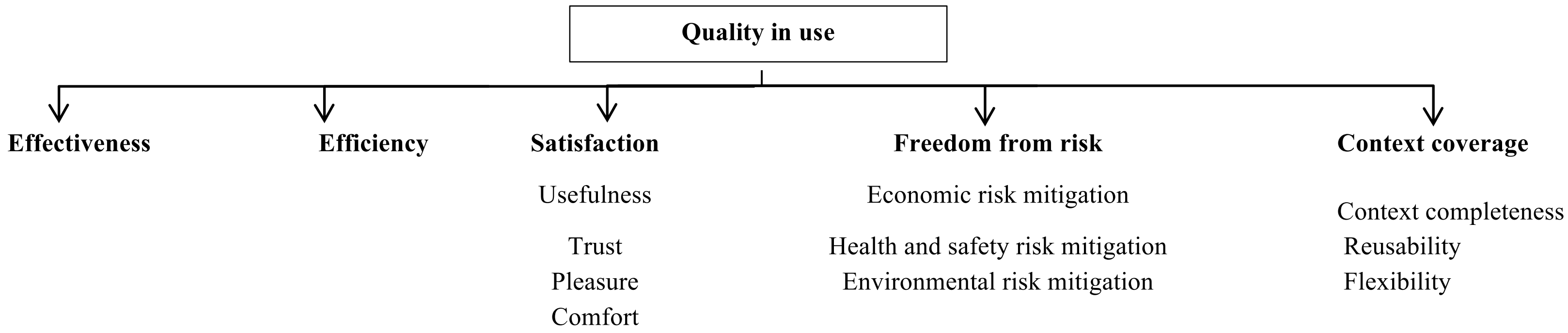

Figure 4.7: Quality in use model (ISO/IEC 25010, 2011)

4.1.3.3 ISO/IEC 25012

In this data quality model, the principal data quality characteristics which should be considered when evaluating the features of the data product are specified (ISO/IEC 25012).

The data product quality is how data meet the needs described by the product-owner company (ISO/IEC 25012). Precisely, those requirements are mirrored in the model thanks to the characteristics: completeness, consistency, accuracy, credibility, currentness, and accessibility, as can be seen in Figure 4.8,

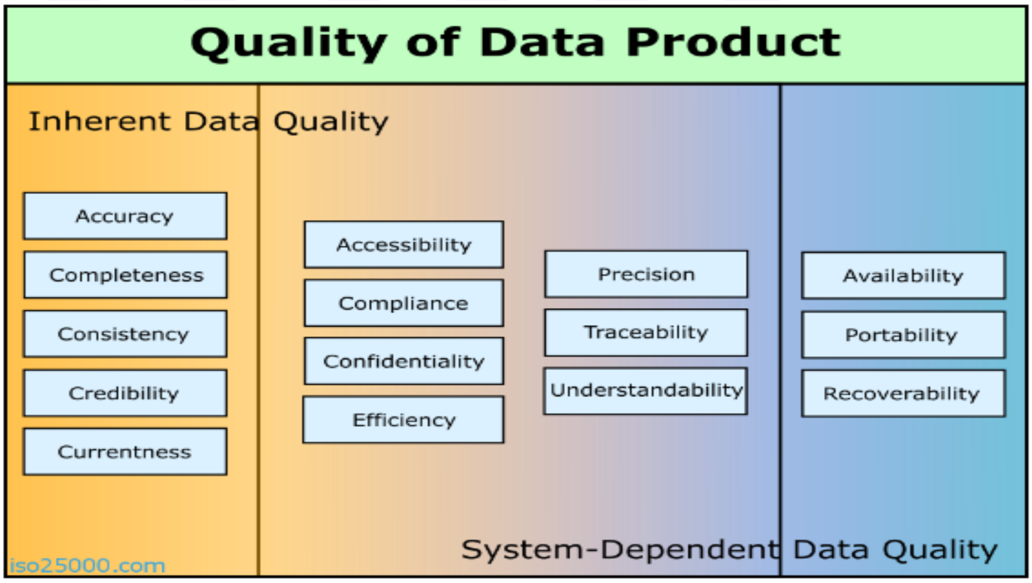

Figure 4.8: Data quality model (ISO/IEC 25012)

The data quality characteristics are categorized into two parts (ISO/IEC 25012):

Inherent data quality: It means the degree of intrinsic potential of data quality characteristics to meet stated and implied requirements when data is utilized under predetermined situations. Data quality can be considered as the data itself, especially:

- Data domain values and possible restrictions,
- Relationships of data values (e.g., consistency),

- Metadata.

System-dependent data quality: It means the degree to which data quality is reached and protected in a computer framework when data is utilized under particular situations (ISO/IEC 25012). Here, data quality depends on the technological domain in which data are utilized; it is accomplished by the abilities of computers' elements such as hardware devices, computer system software, and other software (ISO/IEC 25012).

Pérez et al. (2019) utilized ISO/IEC 25010 to evaluate software usability and its sub-characteristics. They used the Fuzzy Cognitive Map method that enables inspecting relationships between criteria. When considering the software quality needs, Pérez et al. (2018) determined the characteristics and sub-characteristics to be evaluated. Using the ISO/IEC 25010, characteristics determined by the authors are functional adequacy, reliability, efficiency, usability, and portability. To model relationships between the software quality criteria, they used the Fuzzy Cognitive Map method.

Data has an ever-expanding significance and it is generally determined to be an organization's most precious property. Since data is becoming the primary driver of business value, data quality and especially data security are significant to organizations. Different regulations on data cyber-security have been introduced such as the GDPR and the Cyber-security Act which proved the significance of data cyber-security. Verdugo and Rodríguez (2020) proposed a framework to evaluate data cyber-security using the specific characteristics in the ISO/IEC 25012. The authors chose the characteristics for their close relation to security issues. The selected characteristics are compliance, confidentiality, traceability, availability, and recoverability. Madjid et al. (2019) aimed to provide criteria appropriate for Ambient Assisted Living systems using the ISO/IEC 25012 and ISO/IEC 25010 quality standards. They made evaluations using the metrics based on sensors data and fuzzy logic.

In literature, studies evaluating ISO software characteristics do not include characteristics from the SQuaRE's all three quality models (software product quality model, quality in use model, and data product quality model). These studies generally focus on either ISO 25010 software product quality characteristics or ISO 25012 data product quality characteristics, and they do not evaluate quality in a broader perspective. However, when evaluating a software system, software product quality and quality in use should not be evaluated separately. Moreover, when inspecting software quality, data found in the software system is also essential, and data product quality should also be considered in evaluations. In this study, using all three quality models of the SQuaRE, we had an opportunity to evaluate existing software systems of the case supply chain from a broader perspective. In literature, there is not any study evaluating the relationships between characteristics from both ISO/IEC 25010 and ISO/IEC 25012 standards using Fuzzy Cognitive Map. Blockchain is a database technology. When considering data-related issues such as data cyber-security and GDPR data protection law, adding ISO data product quality characteristics in our evaluations is also essential.

4.1.4 Stakeholders

Quality models enable quality characteristics concerned to different stakeholders, such as system integrators, acquirers, software developers, owners, maintainers, contractors, quality assurance and control professionals, and users (ISO/IEC 25010, 2011).

4.1.4.1 Quality from different stakeholders' perspectives

The quality models enable a framework to collect stakeholder requirements (ISO/IEC 25010, 2011). Stakeholders include the following types of users (ISO/IEC 25010, 2011):

1. Primary user: A person who interacts with the system to accomplish the primary targets.

2. Secondary users provide support, for example

- content provider, system manager/administrator, security manager;
- maintainer, analyser, porter, installer.

3. Indirect user: a person who takes output but does not interact with the system. Nonetheless, every type of stakeholder needs to be represented in reviewing and considering the suitability of the quality characteristics in each model before completing the quality characteristics to be utilized in the system (ISO/IEC 25010, 2011).

The quality in using a system defines the effect that the product (system or software product) has on stakeholders (ISO/IEC 25010, 2011). It is defined by the quality of the software, hardware, and operating environment and the characteristics of the users, tasks, and social environment (ISO/IEC 25010, 2011). All these factors have a role in contributing to the quality of use of the system (ISO/IEC 25010, 2011).

4.1.4.2 Selection of Stakeholders

A stakeholder can be an individual, a team, an organization, or classes thereof, having an interest in the realization of the system in system architecture (Rozanski & Woods, 2012). Although a large number of people may have an interest in your system architecture, you may not have time to take into account everyone's concerns (Rozanski & Woods, 2012). Therefore, your first challenge is to study whose opinions and priorities are most significant to consider and focus on (Rozanski & Woods, 2012). Your high-priority stakeholders will fall into one or more of the following groups (Rozanski & Woods, 2012):

- Stakeholders who are influenced mainly by your architectural decisions, for instance, those who have to utilize the system, operate and manage it, or pay for it.
- Stakeholders who impact the shape and final success of the development, for instance, will have to pay for it.
- Stakeholders who have professional knowledge of the business or technology domain and can provide you beneficial advice or even evaluate your architecture.
- Stakeholders who need to be added for organizational or political causes, such as compliance officers, a central architectural governance team, or a respected opinion former in the organization.

The architect must guarantee that there is sufficient stakeholder representation across the board with both non-technology stakeholders (such as acquirers and users) and technology-focused ones (such as developers, system administrators, and maintainers) (Rozanski & Woods, 2012). Selecting one of those is subjective to populate a community of stakeolders (Rozanski & Woods, 2012). The choice of stakeholders to engage is a subjective choice, but generally, the wider the stakeholder community, the better are chances of providing a successful product or system (Rozanski & Woods, 2012). Unfortunately, there are no purely objective criteria for describing whether stakeholders are correctly defined or not (Rozanski & Woods, 2012). Extending your set of stakeholders leads to a trade-off; the larger the group becomes, the harder it is to reach a consensus (Rozanski & Woods, 2012). In this study, both primary users and indirect users (who do not directly use the system like suppliers and customers) are affected mainly by architectural technology decisions in the case study. In the case study, three stakeholders represent suppliers, customers, procurement personnel, and three software developers (who know software product quality, data product quality, and quality in use topics).

4.2 Methods

4.2.1 QFD

QFD is a multidisciplinary process that requires various teams from design engineering, manufacturing engineering, marketing, etc. (Haktanır & Kahraman, 2019). QFD has been commonly implemented in specific sectors like software systems, production, supply chain, service, and communication (Haktanır & Kahraman, 2019; Onar et al., 2016). QFD can be a powerful tool in developing activities, mainly when addressing quality concerns (Erdil & Arani, 2019).

Figure 4.9 demonstrates a standard House of Quality (HOQ) containing various components, referred to as ‘rooms.’ Practitioners integrate the information in these room matrices to generate a final weight for the technical characteristics (Iqbal et al., 2016). HOQ rooms can be seen in Figure 4.9,

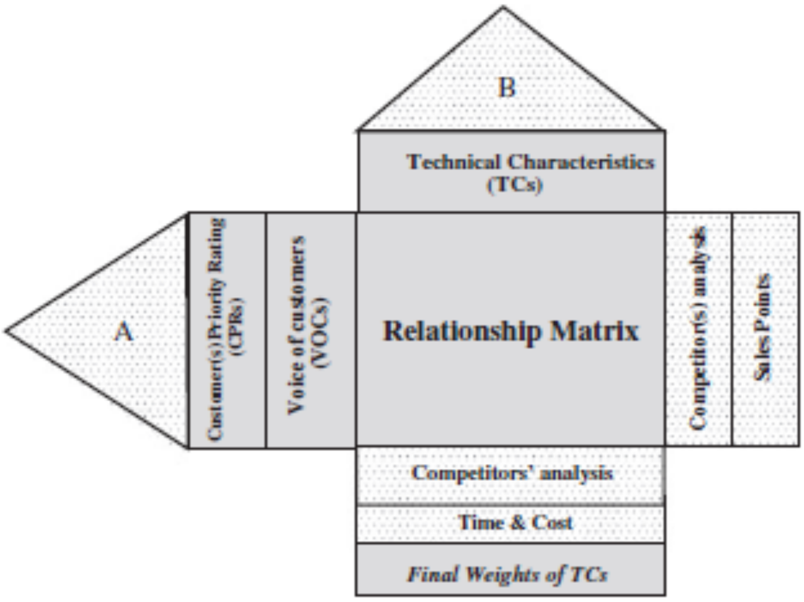

Figure 4.9: House of quality rooms (Iqbal et al., 2016)

The HOQ rooms can be grouped into two main categories, as shown in Figure 4.9: (Iqbal et al., 2016)

- Compulsory: These are the mandatory parts of the QFD, and they are essential in calculating the final weights of the TCs (Iqbal et al., 2016). Compulsory parts are the minimum parts that are necessary to compute final weights, including the voice of customers, customers' priority rating, technical characteristics, and the relationship matrix as seen in solid-shaded parts in Figure 4.9 (Iqbal et al., 2016)
- Optional: These are not mandatory in calculating final weights, but their integration into the QFD arguably advances the calculation of the final weights of technical characteristics (Iqbal et al., 2016). Optional parts are competitor analysis, and sales point data, correlations between technical characteristics, etc. (Iqbal et al., 2016)

Some researchers do not utilize the 'optional' parts when computing final weights of technical characteristics (Iqbal et al., 2016). Probable causes for not utilizing these include cost, time, technical hardships of measuring the attributes data, and absence of techniques to combine with final weights (Iqbal et al., 2016). On the other hand, QFD has advantages like high customer satisfaction, the potential for breakthrough innovation, low manufacture cost, shorter lead times, better communication through cross-functional teamwork, and knowledge preservation (Liu & Wang, 2010).

The overall aim of a HOQ is to acquire the importance weightings of the design requirements specified by the significance ratings of customer needs and the relationships between customer requirements and design requirements (Temponi et al., 1999). However, the conventional QFD utilizes absolute significance degrees. Thus it is hard to diversify the relative significance of distinct attributes (Temponi et al., 1999).

Since QFD is a quality management method, it is subject to continuous challenge, refinement, and development, as other techniques are within the quality management toolkit (Iqbal & Grigg, 2020). QFD focuses on maximizing positive quality by adding customer requirements into product design from the conceptual phase in contrast to conventional quality frameworks that target minimizing negative quality from the product (Erdil & Arani, 2019). The QFD's competitive advantage is its structured implementation of strategic concepts (Brown, 1991). Protecting customers' voices ensure those customer requirements will not be distorted in the development phase (Brown, 1991). Therefore, the voice of the customer is protected in the design features (Brown, 1991). QFD supports a cross-functional team that inputs product realization from all company functions (Brown, 1991). Product is used to represent any process output designed for consumption (Brown, 1991). Thus, it can represent services or goods. Therefore, the interests of marketing, design, deployment, and support functions are prioritized and addressed early in the process (Brown, 1991). The QFD team involves representatives from each of the main functions of a product realization operation (Brown, 1991). Members in the cross-functional team bring particular knowledge to their organizations about their abilities and needs. In QFD, concurrent engineering allows functions to start planning earlier using more correct data, shortening time-to-market (Brown, 1991). The most critical issues with the usage of HOQ are: it is time-consuming, the size of the matrices is massive, it is hard to reach an agreement on contradictory technical needs, and it is hard to translate and classify customers' requirements as well as to prioritize customer needs (Temponi et al., 1999).

A new software package is an instance of a tangible new product which can be defined with the help of QFD (Brown, 1991). In QFD, the customer requirements would be the criteria that the customer cares about the goal of software (Brown, 1991). These criteria may contain tasks that are required to be done, or response time, availability, and so on (Brown, 1991). The design requirements can be mechanisms that satisfy mentioned customer requirements: attributes of architectural components (e.g., modules) for a complex software system or high-level design needs (e.g., algorithms or data structures) for a more detailed package (Brown, 1991). For a more-complex new system, it would be suitable to utilize design requirements as the new customer requirements in the following stage to describe design attributes (Brown, 1991). The staged approach could also be followed to ensure that suitable development processes and resources would be in place and that software production was sufficient (Brown, 1991). For instance, the design attributes might favour an application in an object-oriented programming language (Brown, 1991). The following stages would determine language selection, programming environment, and developer training (Brown, 1991).

4.2.2 Fuzzy QFD

The conventional QFD determines the importance of customer needs without considering their interdependences (Efe, 2019). As a result, the correlation among design requirements is not considered in prioritizing design requirements (Efe, 2019).

It can be argued that among quantitative methods used in Fuzzy QFD, MCDM methods are mainly utilized (Abdolshah & Moradi, 2013). MCDM methods in QFD matrixes (usually HOQ) are used in identifying the significance of parameters (Abdolshah & Moradi, 2013). Fuzzy QFD integrated MCDM studies can be seen in Table 4.2,

Table 4.2: Fuzzy QFD integrated MCDM studies

Methods	**Rooms ~ Methods**
(Büyüközkan et al., 2004) QFD, Fuzzy ANP	Design Requirements ~ ANP
(Kahraman et al., 2006) Fuzzy QFD, Fuzzy ANP	Design Requirements ~ ANP
(Celik et al., 2009) Fuzzy QFD, Fuzzy AHP, Fuzzy Axiomatic Design	Design Requirements ~ AHP Customer Requirements ~ Fuzzy Axiomatic Design

(Zandi & Tavana, 2011) Fuzzy QFD, TOPSIS	Alternatives ~ TOPSIS
(Haq & Boddu, 2017) Fuzzy QFD, TOPSIS, AHP	Customer Requirements ~ TOPSIS, AHP
(Li et al., 2014) QFD, TOPSIS	Alternatives ~ TOPSIS
(Lam, 2015) Fuzzy QFD, Fuzzy VIKOR, Fuzzy Cognitive Mapping	Design Requirements ~ Fuzzy Cognitive Mapping Customer Requirements ~ Fuzzy Cognitive Mapping Alternatives ~ VIKOR
(Efe, 2019) Fuzzy QFD, Fuzzy TOPSIS, Fuzzy AHP	Customer Requirements ~ Fuzzy AHP Alternatives ~ Fuzzy TOPSIS

To assist in evaluating and selecting knowledge management systems, Li et al. (2014) proposed a new MCDM method integrating QFD with TOPSIS and including intuitionistic fuzzy sets. Yu et al. (2018) proposed a framework for ratings of technical attributes in fuzzy QFD using interval-valued intuitionistic fuzzy sets and Choquet integral. For sustainable supplier selection, Liu et al. (2019) proposed a fuzzy three-stage MCDM framework. To overcome the uncertainty in human opinion and to change the customer requirements into engineering specifications, they used interval-valued intuitionistic trapezoidal fuzzy numbers integrated with QFD. However, few studies on managing SCOR KPIs are in the literature (Akkawuttiwanich & Yenradee, 2018). Hence, Akkawuttiwanich and Yenradee (2018) filled this research gap and proposed a fuzzy QFD approach to handle SCOR KPIs, which considers only SCOR make the process and its KPIs. In this study, two-staged Fuzzy QFD enabled us to consider both supply chain-related business-specific (SCOR) dimensions and technology-specific (ISO) dimensions in the selection process.

4.2.2.1 Determination of Customer Requirements

In literature, practitioners use qualitative and quantitative rating scales to explain customer requirements and desires (Iqbal & Grigg, 2020). For example, there are three-point (1–3), four-point (1–4), five-point (1–5), six-point (1–6), seven-point (1–7) scales, etc. where smaller numbers explain low-performance grades while higher numbers indicate high-performance grades (Iqbal & Grigg, 2020). In literature, there are also continuous (Bai & Kwong, 2003), fuzzy (Liu, 2009), percentage-based, and Kano model-based (Garibay et al., 2010) rating scales. The customer requirements of QFD can also be collected from customer-interview information, focus-group information, observations of customer-process satisfiers and dissatisfiers, customer-contact data, and other similar sources (Brown, 1991). Some projects also collect internal customer requirements (e.g., corporate technology goals or quality targets and mandated safety or regulatory needs) (Brown, 1991).

To arrange customer requirements, various techniques can be adopted (Otto, 2003). For grouping requirements, affinity diagrams and customer sort methods can be adopted (Otto, 2003). The product development crew classifies the requirements in an affinity diagram by looking for proximities among the various requirements (Otto, 2003). Each interpreted requirement with its related customer identity is copied on a post-it note (Otto, 2003). One person takes the post-it notes and attaches the first one on a whiteboard (Otto, 2003). Then, the next customer is compared with the first customer (Otto, 2003). If they are not the same, a new column is established on the board (Otto, 2003). If the explanation is the exact requirement, the post-it note is placed under a similar explanation (Otto, 2003). This procedure is repeated for all remaining post-it notes (Otto, 2003). In the customer sort technique, rather than have the design team manage the sorting process, an alternative procedure is to have a few chosen customers sort the requirements (Otto, 2003). This procedure hinders the customer data from being biased by the team (Otto, 2003). With the help of this sorting, a co-occurrence matrix is established (Otto, 2003). In this study, we used affinity grouping to group customer needs.

4.2.3 Fuzzy Cognitive Map (FCM)

The FCMs are robust but straightforward tools that use fuzzy logic for modelling dynamic networks to determine particular areas (Papageorgiou & Iakovidis, 2009). They are helpful in defining hesitancy. The main advantage of FCMs is because of their simple graphical representation (Papageorgiou & Iakovidis, 2009).

In the original cognitive maps, values of the concepts and connection matrices are considered negative, positive, or neutral. Kosko (1986) expanded the former study by using fuzzy causalities in the directed edges and concepts (Baykasoğlu & Gölcük, 2021). Linguistic variables such as low, high, medium, etc., are utilized to define the magnitude of influence between concepts (Baykasoğlu & Gölcük, 2021). Despite the fact that linguistic variables are modelled as fuzzy sets, they are defuzzified to compute output concepts in FCM inference (Baykasoğlu & Gölcük, 2021). In other words, FCMs do not allow the fuzzy character of their parameters and the computations; thus, the exact numeric model is utilized in simulation and inference (Baykasoğlu & Gölcük, 2021). Comparison between possible procedures can be seen in Table 4.3,

Table 4.3: Comparison between possible procedures (Shokouhyar et al., 2019)

Criteria's	ANP	DEMATEL	FCM
Does it show the relationship between concepts?	√	√	√
Does it show the strength of relationships between concepts?	×	√	√
Does it show the causal relationships between the variables?	×	√	√
Does it show the nature of relationships (positive or negative)?	×	×	√
Does it show the feedback between concepts?	×	×	√

ANP, DEMATEL, and FCM have the potential to show relationships between the concepts (Shokouhyar et al., 2019). However, ANP does not show the strength of relationships and causal relationships between the variables (Shokouhyar et al., 2019). Moreover, most of the techniques in the literature, which can model interdependencies between criteria, utilize merely non-negative values such as ANP, DEMATEL, ISM, etc. (Baykasoğlu & Gölcük, 2021). However, FCM shows both positive or negative relationships between criteria. Besides, even feedbacks between concepts can be shown using FCM (Shokouhyar et al., 2019).

The steps of the technique are as follows (Baykasoğlu & Gölcük, 2015),

- Aggregation of fuzzy weights of the attributes. The arithmetic mean of the fuzzy weights taken from decision-makers is computed as (Baykasoğlu & Gölcük, 2015):

$$\widetilde{w}_p = \frac{\sum_i^s \widetilde{w}_{pi}}{s} \qquad p = 1, 2, \ldots, n \tag{4.1}$$

The $\widetilde{w}_{pi}$ values represent the aggregated fuzzy weights (Baykasoğlu & Gölcük, 2015).

- Normalization of the crisp weight vector. Once the aggregated fuzzy weights of the *p*th main attribute are defuzzified using the centroid method (Baykasoğlu & Gölcük, 2015). There are several available defuzzification methods to convert a fuzzy number into a crisp value, such as the Mean Of Maximum (MOM) and centroid method (Center Of Gravity (COG) or Center Of Area (COA) (Hanss, 2005). The centroid method is preferred because of its simplicity. This method is applied using the following formula,

$$\text{Centroid } (\widetilde{A}) = \frac{l+m+u}{3} \tag{4.2}$$

The normalized crisp weight vector, showed by *nwp*, is computed using Eq. (4.3),

$$\mathrm{n}w_p = \frac{w_p}{\sum_{i=1}^{n} w_i}, \tag{4.3}$$

FCMs can be used in scenario analysis and planning (Son et al., 2020). Scenario planning has been used broadly in technology planning and strategic analysis since it can develop the capability to answer to ambiguity and the usefulness of the whole decision-making process using scenarios (Son et al., 2020). FCM-based scenario analysis follows the following steps (Son et al., 2020),

1. Scenario preparation: Identify the targets, time, and bounds of the scenario project.
2. Knowledge capture: Determine relevant concepts and potential scenario drivers from experts and previous studies, and combine mental models of various experts into a final conceptual FCM scenario model.
3. Scenario modeling: Connect causal relationships, measure causal weights,
4. Scenario development: Set various input vectors through plausible combinations of concept nodes. Various scenarios are created based on the concept's state vector.
5. Scenario selection and refinement: Evaluate and develop scenarios by simulation according to the input vectors.
6. Strategic decisions: Strategic decisions for the long-term future are made using

developed scenarios.

FCMs can be changed or enlarged with ease by including new concepts and/or new relationships or replacing the weights of causal linkages (Jetter & Schweinfort, 2011). Although the causal maps of FCMs are considered simple, the FCMs allow fairly extensive interpretations of what the future might hold (Jetter & Schweinfort, 2011). FCMs are especially useful for scenario planning since they are easy to calculate and easily change or expand (Zhang & Jetter, 2018). Performing scenario analyses in FCMs enables monitoring new concept values that vary when the significance level of an element is raised or reduced (Goker & Dursun, 2019). These scenario analyses provide computational effectiveness allowing new concepts' values without necessitating analysis of the entire issue from the start (Goker & Dursun, 2019).

In the atmosphere of new technologies, there is uncertainty about how the future will be realized (Zhang & Jetter, 2018). Instead of tackling these uncertainties, opinions about the future can be explored using scenario analysis, and different scenarios can be created (Zhang & Jetter, 2018). Scenario analysis can be utilized for strategic decision-making in technology and urban planning, transportation, and business (Zhang & Jetter, 2018). Lee et al. (2004) used FCMs to assess EDI performance. They concluded that achievement in EDI performance assessment is related to how a range of EDI performance attributes is causally related to generating strategic performance. Goker and Dursun (2019) suggested a scenario-based framework using FCMs to investigate neuromarketing technology assessment dimensions. Zhang and Jetter (2018) proposed a framework for handling scenario analysis in emerging technologies. In process-based construction projects, construction directors want to manage projects, control budget, prevent excess cost, and they also want to provide that different construction phases are finished in a timely and effortless manner (Dissanayake & AbouRizk, 2007). To reach these targets, directors investigate various what-if scenarios at the planning phase of the projects to explore scenarios' potential effects on performance in advance (Dissanayake & AbouRizk, 2007).

In literature, there are several studies regarding the Cognitive Map model reduction. Complexity is an unwanted property of Fuzzy Cognitive Maps (Homenda et al., 2015). Bigger maps are tough to interpret and utilize (Homenda et al., 2015). Alizadeh et al. (2008) suggested forming Fuzzy Cognitive Maps by using historical data and then creating clusters of concepts. Nápoles et al. (2014) utilized Fuzzy Cognitive Maps to predict and discover the HIV-1 drug resistance. They proposed the protease protein with a Fuzzy Cognitive Map, and they estimated the causality between sequence positions with the help of Particle Swarm Optimization. Homenda et al. (2015) examined the impact of a posteriori removal of weak relations or concepts. First, the concepts were taken out together with their relations. Then, the weak relations were removed by zeroing their weights. After these alterations, the simplified models were tested with famous time series to control whether they were still able to forecast future states with an appropriate error or not. FCM models can be simplified to make them more usable (Homenda et al., 2015). The map can be pruned successively by removing the weights that are weaker than threshold 0,2, 0,4, and 0,6 values; the weights can be evaluated as insignificant below that threshold value, and their values can be set as 0 which shows that no relations exist (Homenda et al., 2015). In this study, we pruned the maps by removing weaker weights than the threshold 0,5 value.

4.2.3.1 Establishing FCM Structure

1. Initial concept values are set up. The normalized weight vector is determined as the initial concept values, as in Eq. (4.4) (Baykasoğlu & Gölcük, 2015):

$$((C_{MA_1}^{t=0} \quad \dots \quad C_{MA_p}^{t=0} \quad \dots \quad C_{MA_n}^{t=0}) = (\mathrm{n}w_1 \quad \dots \quad \mathrm{n}w_p \quad \dots \quad \mathrm{n}w_n) \tag{4.4}$$

where $C_{MA_i}^{t=0}$ is the concept value of the ith main attribute when t = 0 (Baykasoğlu & Gölcük, 2015).

2. Fuzzy influence matrices are elicited (Baykasoğlu & Gölcük, 2015). The degree of causal dependency between attributes is taken from decision-makers by filling out fuzzy influence matrices (Baykasoğlu & Gölcük, 2015). Each influence matrix is shown by

$\tilde{e}_{jiu}^{MA}$, which reflects the influence matrix of the main attributes taken from the *u*th decision-maker (Baykasoğlu & Gölcük, 2015).

3. Fuzzy influence matrices are aggregated (Baykasoğlu & Gölcük, 2015). Fuzzy influence matrices, which are taken from a group of decision-makers are aggregated by utilizing Eq. (4.5) (Baykasoğlu & Gölcük, 2015):

$$\tilde{e}_{ji}^{MA} = \frac{\sum_{u=1}^{S} \tilde{e}_{jiu}^{MA}}{S} \tag{4.5}$$

where $\tilde{e}_{ji}^{MA}$ shows the aggregated fuzzy influence matrix of the main attributes (Baykasoğlu & Gölcük, 2015).

4. Aggregated fuzzy weights are defuzzified (Baykasoğlu & Gölcük, 2015). Finally, the aggregated crisp influence matrix e_{ji}^{MA} is achieved (Baykasoğlu & Gölcük, 2015).

4.2.3.2 Simulating FCMs and Obtaining the Final Weights

After establishing the FCM structure, steps of the FCMs to obtain final weights in the methodology can be followed as,

1. Specifying the parameters of the activation function (Baykasoğlu & Gölcük, 2015). Different activation (threshold) functions can be utilized in FCMs. Trivalent (f(x) = -1, 0, 1), bivalent (f(x) =0,1), hyperbolic tangent function (tanh(x)) or unipolar sigmoid functions (f(x) = 1/(1+e$^{-\lambda}$) are instances of the mostly utilized activation functions in FCMs (Baykasoğlu & Gölcük, 2015). Here, parameters of the activation functions, like λ, specifying the slope of the function to get a proper shape, are determined (Baykasoğlu & Gölcük, 2015).

2. Running of FCMs (Baykasoğlu & Gölcük, 2015). To inspect the long-term influences between the main attributes, FCMs are simulated with a suitable threshold function to

discover the long-term influences (Baykasoğlu & Gölcük, 2015). FCM simulation is conducted to obtain dynamic behavior based upon the equation (4.6):

$$C_{MA_i}^{t+1} = \mathrm{f}\,(C_{MA_i}^{t} + \sum_{\substack{j=1 \\ j=1}}^{n} e_{ji}^{MA} \times C_{MA_j}^{t}) \tag{4.6}$$

where $\mathrm{C}_{\mathrm{MA_i}}^{\mathrm{t}}$ is the concept value of the *i*th main attribute at time *t* (Baykasoğlu & Gölcük, 2015).

3. Normalizing the steady state weights (Baykasoğlu & Gölcük, 2015). The steady-state concept values are normalized, and the final steady-state weights of the primary attributes are determined (Baykasoğlu & Gölcük, 2015):

$$w_i = \frac{c_{MA_i}}{\sum_{i=1}^{n} c_{MA_i}}, \tag{4.7}$$

The final crisp weights are represented by (Baykasoğlu & Gölcük, 2015):
$\mathrm{I_{MA}}$ = ($MA_1\ MA_2$ ... MA_n), (w_1 w_2 ... w_n), where $\sum_{i=1}^{n} w_i = 1$.

In this method, we preferred the sigmoidal FCMs. The sigmoidal FCMs with a proper selection of λ parameter have advantages as follows (Baykasoğlu & Gölcük, 2021):

1. The outcome of concept values ranges between 0 and 1 so that it is appropriate to utilize them as criteria weights without any transformation.
2. The FCM simulation results yield steady-state concept values.
3. The produced steady-state concept values are unique.
4. The produced steady-state concept values are independent of the initial concept values.

Parameter λ specifies the slope of the function in the vicinity of zero, and its value is specified according to the nature of the problem (Najafi et al., 2017). Generally, a small λ is appropriate for nonlinear systems (Najafi et al., 2017). After reviewing the conditions in this study, a sigmoid function with $\lambda = 1$ has been chosen to reach the best solutions (Najafi et al., 2017).

In this paper, we preferred Triangular Fuzzy Numbers (TFN). TFN is more convenient in application due to its simple calculation, and it is beneficial in improving representation and information processing in a fuzzy environment (Li et al., 2020). In addition, TFN is most appropriate for stakeholders' linguistic assessment, and it is broadly used in fuzzy MCDM studies (Li et al., 2020).

TFN is the most popular one because of its simple membership function of the linear type, and it is easy to utilize (Elomda et al., 2014). It can be represented by three points, such as A= (I, m, u) (Elomda et al., 2014). In this paper, the centroid method is utilized for defuzzification as it is simple and widely used. We used three decision-makers' evaluation values in QFD calculations. The relationships between concepts are described using linguistic values by TFN as in Table 4.4,

Table 4.4: Linguistic values for casual relationships

Linguistic values	**TFN**
Negatively Full influence (NF)	(-1; -1; -1)
Negatively Extremely High (NEH)	(-1, -0,9, -0,8)
Negatively Very High (NVH)	(-0,9, -0,8, -0,7)
Negatively High (NH)	(-0,8, -0,7, -0,6)
Negatively Medium High (NMH)	(-0,7, -0,6, -0,5)
Negatively Medium (NM)	(-0,6, -0,5, -0,4)
Negatively Medium Low (NML)	(-0,5, -0,4, -0,3)
Negatively Low (NL)	(-0,4, -0,3, -0,2)
Negatively Very Low (NVL)	(-0,3, -0,2, -0,1)
Negatively Extremely Low (NEL)	(-0,2, -0,1, 0)
NO influence (N)	(0; 0; 0)
Positively Extremely Low (PEL)	(0; 0,1; 0,2)
Positively Very Low (PVL)	(0,1; 0,2; 0,3)
Positively Low (PL)	(0,2; 0,3; 0,4)
Positively Medium Low (PML)	(0,3; 0,4; 0,5)
Positively Medium (PM)	(0,4; 0,5; 0,6)
Positively Medium High (PMH)	(0,5; 0,6; 0,7)

Positively High (PH)	(0,6; 0,7; 0,8)
Positively Very High (PVH)	(0,7; 0,8; 0,9)
Positively Extremely High (PER)	(0,8; 0,9; 1)
Positively Full influence (PF)	(1; 1; 1)

FCMapper is used in this study to perform the Fuzzy Cognitive Map analysis. Developed by Michael Bachhofer and Martin Wildenberg, FCMapper is an open licensed excel macro (FCMapper). The aggregated fuzzy influence matrix is copied and pasted into the matrix sheet of the FCMapper tool (FCMapper) to run the model. The check matrix button performs a check of the general characteristics of the normalized matrix for the values to be in the range [0,1]. FCM Analysis section runs the simulation and applies Eq. (4.6) to the data using the sigmoidal function. FCM_Scenarios screen allows simulating different scenarios. The GUI interface of the FCMapper excel tool can be seen in Figure 4.10,

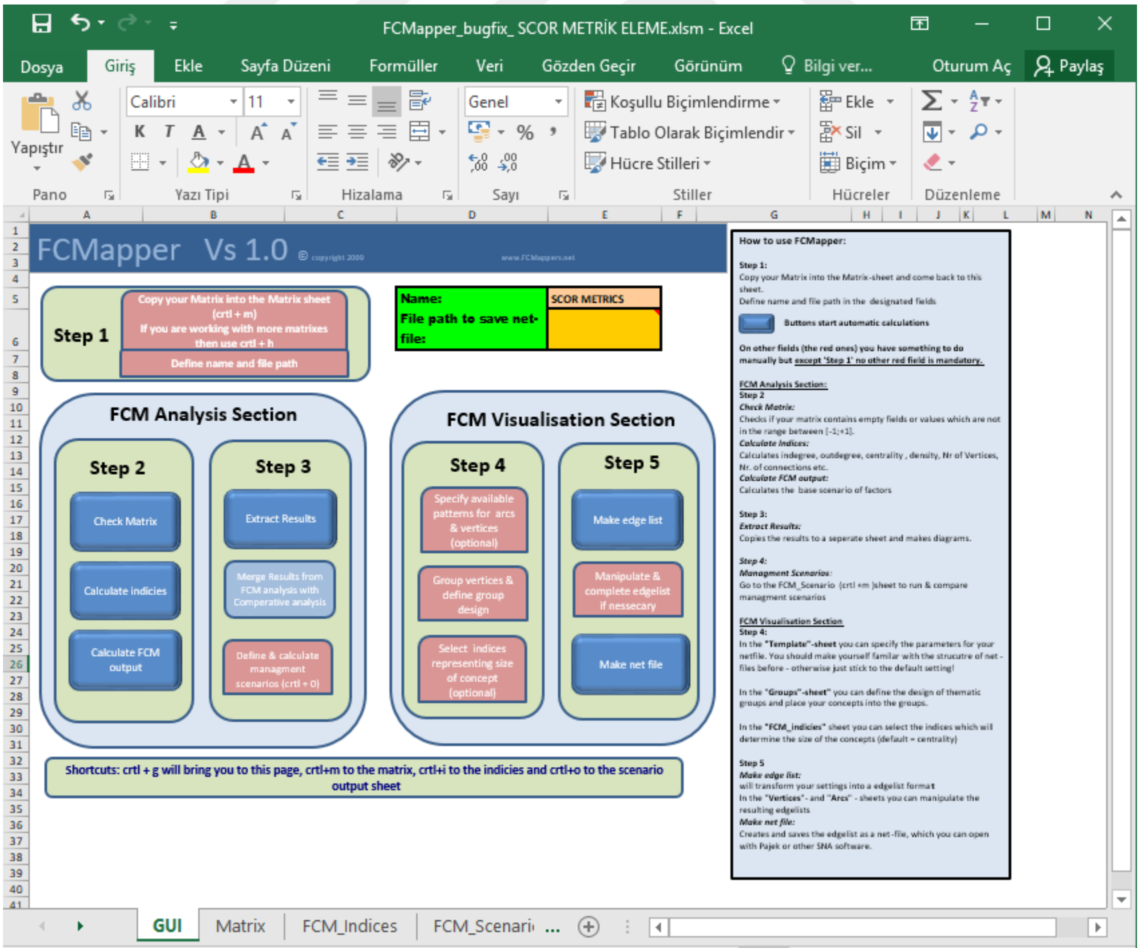

Figure 4.10: GUI interface of the FCMapper (http://www.fcmappers.net/joomla/)

4.2.4 Fuzzy TOPSIS

Fuzzy TOPSIS is appropriate for solving group decision-making problems under a fuzzy environment (Chen, 2000). Here, it is proposed that the decision-makers utilize the linguistic variables to assess the significance of the criteria and the ratings of alternatives considering different criteria (Chen, 2000).

Supposing that a decision group has K persons, and then the significance of the criteria and the rating of alternatives according to each criterion can be computed as,

$$\tilde{x}_{ij} = \frac{1}{\mathrm{K}}\left[\tilde{x}_{ij}^{1}(+)\tilde{x}_{ij}^{2}(+)\ldots(+)\tilde{x}_{ij}^{K}\right] \tag{4.8}$$

$$\widetilde{w}_{j} = \frac{1}{\mathrm{K}}\left[\widetilde{w}_{j}^{1}(+)\widetilde{w}_{j}^{2}(+)\ldots(+)\widetilde{w}_{j}^{K}\right] \tag{4.9}$$

where $\tilde{x}_{ij}^{K}$ and $\widetilde{w}_{j}^{K}$ are the rating and the significance weight of the Kth decision-maker.

To avoid the complex normalization procedure used in traditional TOPSIS, the linear scale transformation is utilized here to change the various criteria scales into a comparable scale (Chen, 2000). Hence, we can reach the normalized fuzzy decision matrix shown by $\tilde{R}$.

$$\tilde{R} = [\tilde{r}_{ij}]_{m\times n} \ , \tag{4.10}$$

where B and C are the set of benefit criteria and cost criteria, respectively, and

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), \ j\in B; \tag{4.11}$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), \ j\in C; \tag{4.12}$$

$$c_j^* = max_i \ c_j^* \quad \text{if} \quad j\in B\,; \tag{4.13}$$

$$a_j^- = min_i \ a_{ij} \ \text{ if } \ j \in C. \tag{4.14}$$

The normalization method mentioned above preserves the range of normalized triangular fuzzy numbers [0; 1] (Chen, 2000).

Using the distinct significance of each criterion, the weighted normalized fuzzy decision matrix is obtained as,

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n}, \quad i = 1, 2\ldots, m, \ j = 1, 2,\ldots, n, \tag{4.15}$$

where $\tilde{v}_{ij} = \tilde{r}_{ij}(\bullet)\tilde{w}_{ij}$.

Considering the weighted normalized fuzzy decision matrix, it is clear that the elements $\tilde{v}_{ij}$, ∀ *i,j* are normalized positive triangular fuzzy numbers, and their ranges belong to the interval [0; 1]. Then, the fuzzy positive-ideal solution (FPIS, A^*) and fuzzy negative-ideal solution (FNIS, A^-) can be determined as (Chen, 2000),

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \ldots.., \tilde{v}_n^*), \tag{4.16}$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \ldots.., \tilde{v}_n^-), \tag{4.17}$$

where $\tilde{v}_j^* = (1, 1, 1)$ and $\tilde{v}_j^- = (0, 0, 0)$, $j=1,2,\ldots,n$.

The distance of each alternative from A^* and A^- can be computed as

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*), \quad i = 1, 2\ldots, m, \tag{4.18}$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-), \quad i = 1, 2\ldots, m, \tag{4.19}$$

where d(• ; •) is the distance measurement between two fuzzy numbers.

A closeness coefficient (CC) is determined to specify the ranking order of all alternatives once the d_i^* and d_i^- of each alternative A_i (i=1,2,…., m) has been computed. The CC of each alternative is computed as

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, \quad i = 1, 2\ldots, m. \tag{4.20}$$

An alternative A_i is closer to the FPIS (A^*) but it further from FNIS (A^-) as CC_i approaches 1. Hence, seeing the CC, we can define the ranking order of all alternatives and choose the best one from the alternatives (Chen, 2000).

Everthing considered, an algorithm of the multi-person MCDM with a fuzzy set approach is given in the following (Chen, 2000).

Step 1: Set a group of decision-makers, and then determine the evaluation criteria.
Step 2: Select the relevant linguistic variables for the significance weight of the criteria and the linguistic ratings for alternatives concerning the criteria.
Step 3: Aggregate the weight of criteria to obtain the aggregated fuzzy weight $\widetilde{w}_j$ of criterion C_j, and pool the decision makers' ideas to obtain the aggregated fuzzy rating $\tilde{x}_{ij}$ of alternative A_i under criterion C_j.
Step 4: Establish both the fuzzy decision matrix and the normalized fuzzy decision matrix.
Step 5: Form the weighted normalized fuzzy decision matrix.
Step 6: Find both FPIS and FNIS.
Step 7: Compute the distance of each alternative from FPIS and FNIS, respectively.
Step 8: Compute the CC value of the alternatives.
Step 9: Using the CC, the ranking of all alternatives can be specified.

TOPSIS method is unique among the most cited multi-criteria group decision methods as it handles the selection problem (Bottani & Rizzi, 2006). It is intuitive, simple to figure out and to apply (Bottani & Rizzi, 2006). It enables the straight linguistic description of weights and ratings under each criterion, without the requirement of heavy pairwise comparisons and the possibility of inconsistencies (Bottani & Rizzi, 2006). Performance of the TOPSIS method is slightly influenced by the number of alternatives and rank differences are increased to a smaller extent for increasing values of the number of alternatives and the criteria (Bottani & Rizzi, 2006). TOPSIS method has been proved to be one of the best methods in handling rank reversal problem, which is variation in the ranking of alternatives when a non-optimal alternative is presented (Bottani & Rizzi, 2006). This consistency characteristic is strongly valued in practical implementations. The rank reversal problem of the TOPSIS method has been verified to be insensitive to the number of alternatives, and it has its worst performance only in the event of very finite number of criteria (Bottani & Rizzi, 2006).

Advantages of the TOPSIS method are (Shih et al., 2007) (i) a strong rationality that represents the logic of human selection; (ii) a quantitative value that considers both the best and worst options at the same time; (iii) an easy calculation process that can be effortlessly programmed into a spreadsheet; and (iv) the performance measures of all options on features can be visualized on a polyhedron, at least for any two dimensions. These superiorities make TOPSIS method a primary multi-attribute decision making method as compared with other related methods such as AHP and ELECTRE (Shih et al., 2007). TOPSIS reduces the need of paired comparisons, and the capacity restrictions may not remarkably dominate the process. TOPSIS method is appropriate for situations where a large number of attributes and alternatives are required (Shih et al., 2007). ELECTRE (ÉLimination et Choix Traduisant la REalité) method also has the potential to select a suitable alternative. It compares the criterion values of the candidates and it evaluates by comparing whether the values are greater than or equal to the concordance threshold and whether they are less than the discordance threshold (Şenel et al., 2018). ELECTRE does not do anything concerning how large the values are from each other (Şenel et al., 2018).

The primary distinction between TOPSIS and VIKOR emerges in the aggregation procedures (Opricovic & Tzeng, 2004). The VIKOR method has an aggregating function indicating the distance from the ideal solution (Opricovic & Tzeng, 2004). This ranking index is an aggregation of all criteria, the relative significance of the criteria, and a balance between total and individual satisfaction (Opricovic & Tzeng, 2004). The TOPSIS introduces the ranking index, including the distances from the ideal point and from the negative-ideal (nadir) point (Opricovic & Tzeng, 2004). Distances from the ideal point and negative-ideal point in TOPSIS method are just summed without concerning their relative significance (Opricovic & Tzeng, 2004). In some situations, the fuzzy VIKOR method gives a set of compromise solutions rather than a single solution (Jaini & Utyuzhnikov, 2018). In that case, decision maker still has to select one single solution from the compromise set obtained through the fuzzy VIKOR (Jaini & Utyuzhnikov, 2018).

This study used Supply Chain Operations Reference (SCOR) modeling, and Business Process Modelling and Notation (BPMN) language since the case company has a vague and imprecise process and metric definitions. SCOR enabled us to determine problematic metrics of the case company. To eliminate SCOR metrics, we used Fuzzy Cognitive Maps since there are trade-offs between SCOR performance metrics. In this study, ISO standard quality characteristics were used to focus on problematic software characteristics of the case company. Using all three quality models of the SQuaRE (software product quality model, quality in use model, and data product quality model), we evaluated the existing software systems of the case supply chain in a broader perspective. To eliminate ISO standard quality characteristics, we used Fuzzy Cognitive Maps since there are also trade-offs between ISO quality characteristics. To eliminate and reflect relationships blockchain characteristics, we used Fuzzy Cognitive Maps since there are also trade-offs between blockchain characteristics. After the elimination processes of the metrics and characteristics, we again used Fuzzy Cognitive Map to weight these eliminated metrics and characteristics. The cross-functional and multi-staged focus of QFD (two-staged QFD) enabled us to consider both supply chain-related business-specific (SCOR) dimensions and technology-specific (ISO) dimensions in the enterprise blockchain platform selection process. We used QFD Stage 2 HOW weights and Fuzzy TOPSIS methodology to select an appropriate blockchain technology alternative.

5. APPLICATION PROCEDURE

Our case company supports mechanical, and plant engineering works worldwide with its cutting-edge technology and industry knowledge. Its customer-specific integrated automation solutions and systems offer all kinds of products and services that the industry needs. In addition, company experts advise various projects using unique services and resources throughout the project processing, from design to the realization of the project.

The company aims to offer customer-specific products at the right time, in the right quality and quantity. Its priority is to work at a low cost. Since customers' demands are very diverse, diversity must be provided in all circumstances. Hence, the strategy of the company is based on reliability, responsiveness, cost, and agility. Unfortunately, the company did not achieve its performance targets in procurement processes where the problems were quite intense.

The procurement process starts when a customer sends a purchase request for a product, and ends with delivery of the product and the corresponding payment. The buyer is the centralized evaluator of the quotes who reaches every detail of the quotes from different organizations. Here, scalability rises as a problem since a single buyer runs all the quality controls and quotes evaluation. Processes of the supply chain are nearly automated, thus to be able to explore supply chain-related problems in detail, more importance should put on its software side.

When it comes to the software side, to keep the price quotes up-to-date, SAP systems of the case supply chain must be constantly updated. Sometimes incorrect data is entered into their SAP systems. Once, SAP enabled an environment to be used by customers; so that customers followed up orders to a certain point. Nevertheless, customers cracked the passwords and reached critical pricing information about purchasing. Many companies determine quotes as being highly ‘secret.’ Besides, the property of the technical drawings sent by the suppliers in their quotes belongs to these companies. These technical drawings cannot be given to third parties and cannot be used other than contractual works. There can be problems when more stakeholders are involved in their software systems. Proper authorization was also a huge problem considering the faulty entries. Moreover, there is a high proportion of modifications which cause degragation in quality in their software systems. The degree to which data comply with regulations and standards was another important topic for them. Problems specific to supply chain and problems related to software will be discussed in detail in the subsequent steps.

With the help of a cross-functional team, problems generally encountered in most of the projects of the case company were grouped using the Affinity Grouping which includes scalability problem of a single buyer, system’s security problem in reaching critical pricing information, time spent in receiving quotes, and checking compliance with the quality standard, GDPR compliance of the system and reaching suppliers’ sensitive data.

A technology selection process requires the inspection of the entire supply chain, not just focusing on one process or its activities. As blockchain technology is suitable for systems that necessitate multiple participants, and they have many potentials especially for enterprise systems, we examined blockchain technology in this study. We made an interview-based discovery involving process participants from the case company, customer, and supplier sides, which offered a detailed picture of the processes. In this study, three stakeholders in the system represent the supplier, customer, procurement personal, and three software developers. Here, we followed the steps of the methodology in Figure 4.1.

Step 1. Determination of supply chain processes using SCOR and BPMN.

Given that a primary modelling tool does not satisfy all the criteria required for a good process definition (Aoulaid, 2016), we combined SCOR and BPMN in this study to model as-is processes of the supply chain following the top-down participation approach. The SCOR Level 1 highlights the main processes of all supply chain actors. For the case supply chain, we identified processes of the actors: Plan, Source, Make and Deliver, as can be seen in Figure 5.1. Level 2 identifies key process categories found in supply chains, such as Make-to-Stock, Make-to-Order, and Engineer-to-Order (APICS, 2015). Level 1 processes are then decomposed to sub-processes at Level 2: Make-to-Stock (sM1), Make-to-Order (sM2), Make Engineer-to-Order (sM3), Source Stocked Product (sS1), Source to order Product (sS2), Source Engineer to order Product (sS3), Deliver stocked product (sD1), Deliver Source to order Product (sD2), Plan Supply Chain (sP1), Plan Source (sP2), Plan Make (sP3), Plan Deliver (sP4) as can be seen in Figure 5.2. In this figure, lines represent information flow, and dotted lines represent the material flow. In this study, the manufacturing strategy of the case company is Engineer-to-Order.

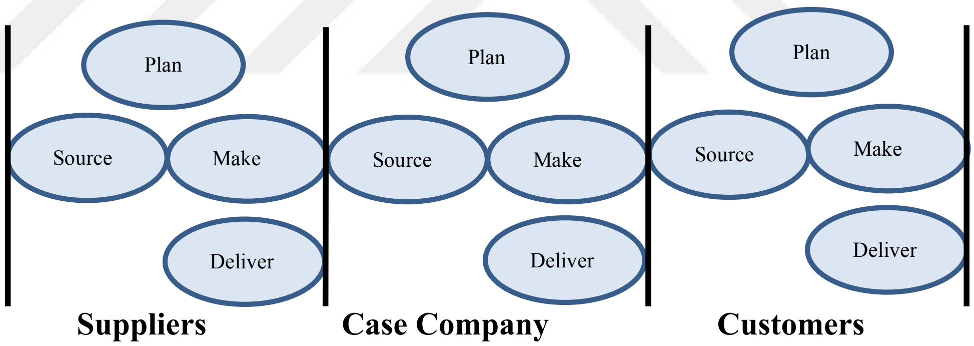

Figure 5.1: Key processes and supply chain actors

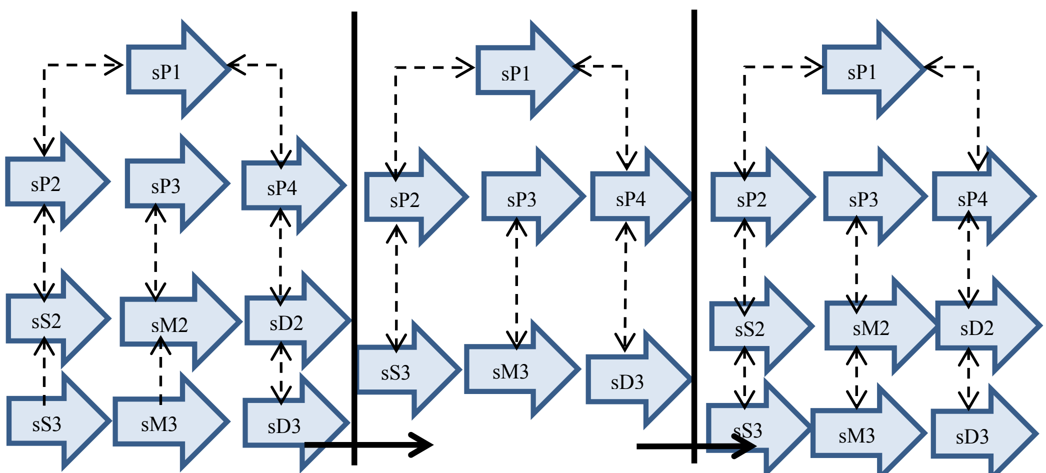

Figure 5.2: SCOR Level 2 processes

Level 3 allows companies to identify their processes in detail, performance metrics, and best practices (APICS, 2015). Level 3 does not represent only one activity. It involves and represents various activities, while Level 4 represents the unique activities of companies. For SCOR Level 3, process element level, we demonstrated Level 3 processes of the supply chain for engineer-to-order products using the Camunda BPMN Modeler 3.5.0, as shown in Figure 5.3. There are 4 Level 3 process elements in the case company's source engineer-to-order product, as shown in Figure 5.3.

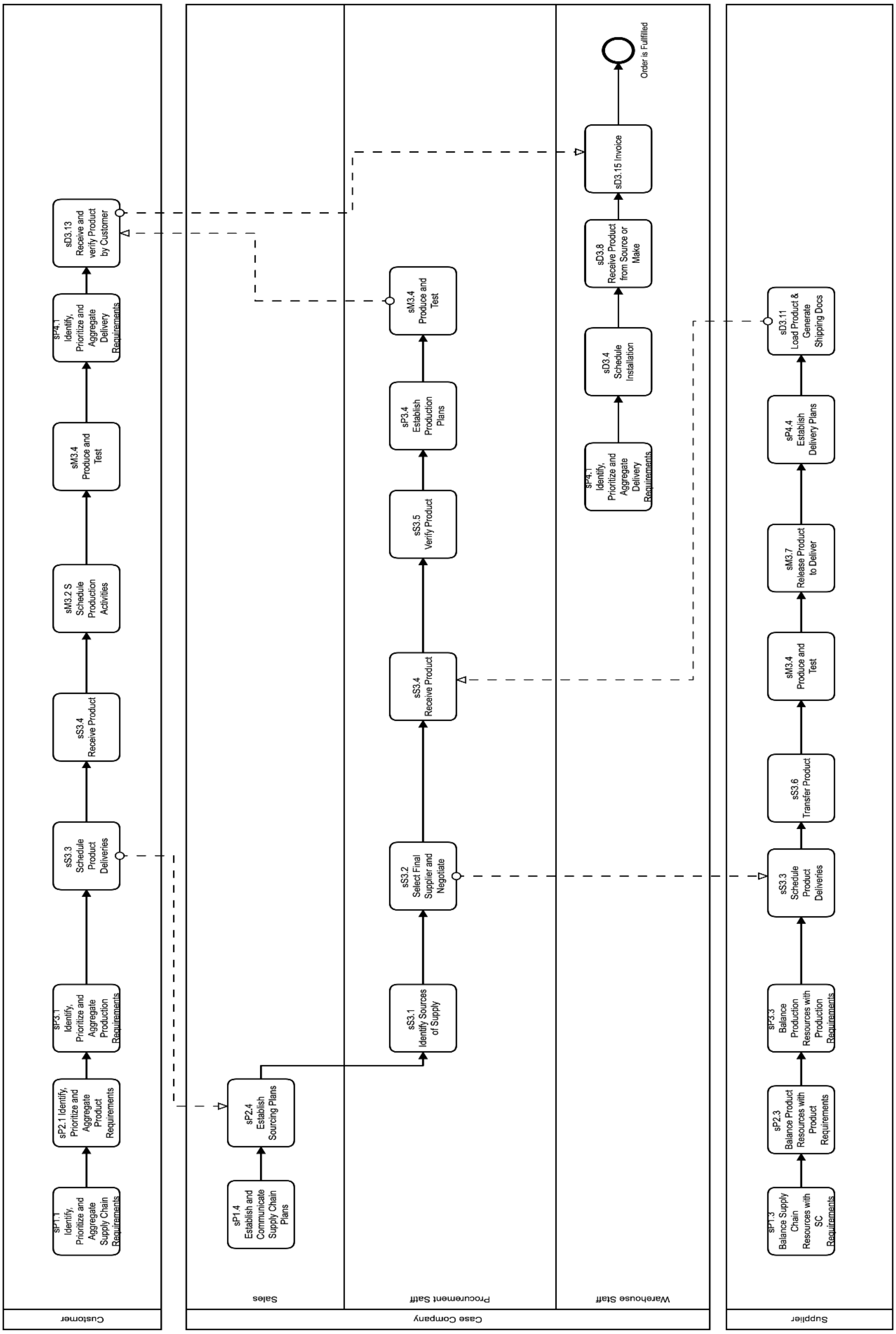

Figure 5.3: SCOR Level 3 for the case supply chain for engineer-to-order products (Camunda Modeler 3.5.0)

Step 2. Determine SCOR engineer-to-order performance metrics, inspect relations between them and focus on essential metrics using Fuzzy Cognitive Map.

The supply chain strategy of the company is based on cost, time, reliability, and agility. Hence, in this study, we used cost, time, reliability, and agility-related metrics. There are three sub-processes in the SCOR Source process: Source Stocked Product, Source Make-to-Order Product, and Source Engineer-to-Order Product. We focused on the engineer-to-order sub-process since the product strategy of the case company works in this way. Source Engineer-to-Order Product has seven sub-processes: Identify Sources of Supply, Select Final Supplier and Negotiate, Schedule Product Deliveries, Receive Product, Verify Product, Transfer Product and Authorize Supplier Payment. SCOR model offers specific metrics for each of these sub-processes. Therefore, any company using standardized metrics can focus on these metrics and eliminate required ones according to their processes and strategy.

As can be seen in Figure 5.3, the case company has 4 Level 3 sub-processes of Source Engineer-to-Order Product (sS3): Identify Sources of Supply (sS3.1), Select Final Supplier, and Negotiate (sS3.2), Receive Product (sS3.4) and Verify Product (sS3.5). There are 24 SCOR Level 3 performance metrics of sS3, sS3.1, sS3.2, sS3.4, and sS3.5 processes in the SCOR model seeing the company strategy (cost, responsiveness, reliability, and agility related). The top priority SCOR metrics of the case company will be determined after prioritizing and eliminating these metrics using Fuzzy Cognitive Maps. Depending on the company's processes and strategy (cost, time, agility, and reliability), 24 SCOR performance metrics in the Source-Engineer-to-Order product can be seen in Table 5.1.

Table 5.1: SCOR Level 3 performance metrics

	AG.3.9	Additional source volumes obtained in 30 days
	AG.3.40	Current Purchase Order Cycle Times
	AG.3.42	Current Source Volume
	AG.3.46	Demand sourcing-supplier constraints
sS3	CO.3.005	Sourcing Labour Cost
	CO.3.006	Sourcing Automation Cost
	CO.3.007	Sourcing Property, Plant and Equipment Cost

	CO.3.008	Sourcing GRC, Inventory, and Overhead Cost
	CO.3.009	Purchased Materials Cost
	CO.3.010	Material Transportation Cost
	CO.3.011	Material Customs, Duties, Taxes and Tariffs Cost
	CO.3.012	Material Risk and Compliance Cost
sS3.1	RS.3.35	Identify Sources of Supply Cycle Time
sS3.2	RL.3.17	% of suppliers with an EMS or ISO 14001 certification
	RS.3.125	Select Supplier and Negotiate Cycle Time
sS3.4	RL.3.18	% Orders/ Lines Processed Complete
	RL.3.20	% Orders/ Lines Received On-Time To Demand Requirement
	RL.3.22	% Orders/ lines received with correct packaging
	RL.3.23	% Orders/ Lines Received with Correct Shipping Documents
	RS.3.113	Receiving Product Cycle Time
sS3.5	RL.3.19	% Orders/ Lines Received Defect Free
	RL.3.21	% Orders/ lines received with the correct content
	RL.3.24	% Orders/lines received damage-free
	RS.3.140	Verify Product Cycle Time

According to the company stakeholders, these 24 metrics are measurable, understandable, and unambiguous. We reduced 24 metrics using the Fuzzy Cognitive Maps method, which enabled us to have a sufficient number of metrics without loss of information. We chose the average value as the threshold value to focus on more critical metrics according to their weights. However, scenario analysis in Fuzzy Cognitive Map allowed us to include different metrics in our calculations. We started with defining the relationships between SCOR Level 3 metrics using the arrows that show positive or negative relationships. As the initial concept values of the Fuzzy Cognitive Map method, we used average operator to aggregate evaluations of 3 experts. Here, the concepts are SCOR Level 3 metrics. Then, we defuzzified the fuzzy influence matrix and found aggregated crisp values of the decision makers' evaluation. In this study, a triangular fuzzy number $(\widetilde{A}) = (l, m, u)$ is defuzzified using the centroid method. Relationships between SCOR Level 3 metrics can be seen in Figure 5.4,

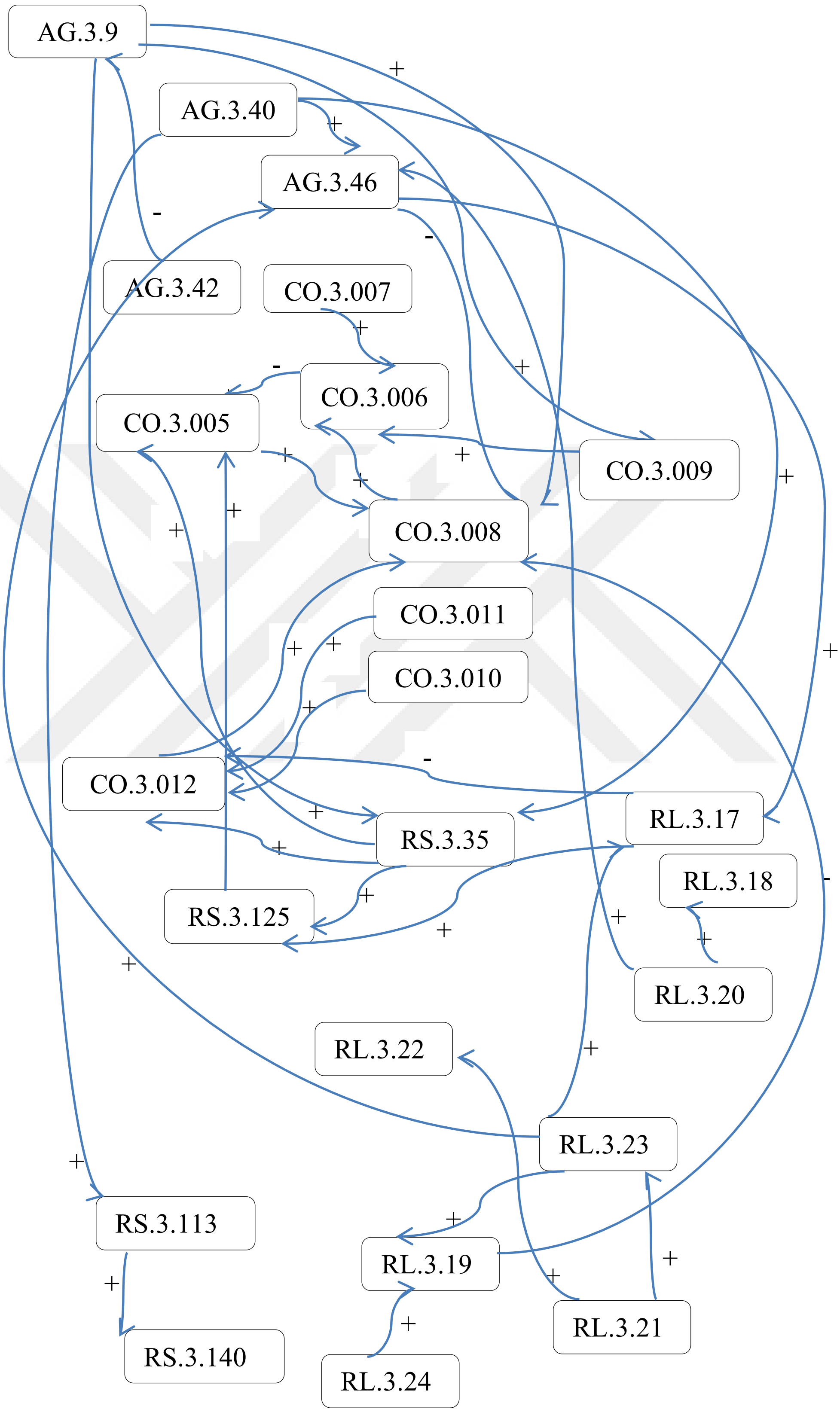

Figure 5.4: Relationships between SCOR Level 3 metrics

Relationships between the SCOR Level 3 metrics

In the case company, as the percentage of suppliers with a validated Environmental Management System or ISO 14000 certification increases, the selection of suppliers and negotiation cycle time increases. As the percent of suppliers who used a validated Environmental Management System or ISO 14000 certification increases, material risk and compliance cost (cost of theft, fraud, and cost of mitigation of potential risk of supply disruption) decreases. As the supply sources identification cycle time (the average time associated with identifying sources of supply) increases, sourcing labour cost (costs related to ordering, receiving, processing, and storing materials. It also includes the costs of covering supplier data, processing payment, requesting and reviewing quotations, creating, changing, and deleting purchase orders, requesting and providing status updates, and approving payment of invoices) increases.

In addition, as the percent of the orders received with correct shipping documents (number of orders received on time with correct shipping documents divided by the total orders processed in the measurement period) increases, demand sourcing-supplier constraints (percentage of orders with on-time and accurate documentation supporting the order, including packing slips, bills of lading, invoices) also increases in the company. As the percent of the orders received with correct shipping documents increases, the percent of the orders received defect-free (the number of orders received defect-free divided by the total orders processed in the measurement period) also increases.

As the percent of the orders received defect-free increases, sourcing GRC, inventory, and overhead cost (Governance, risk management, compliance, inventory and overhead costs allocated to acquisition process; the ordering, receiving and inspecting costs. This also includes costs of the legal department, quality management costs, risk mitigation costs, and compliance remediation costs) decreases. In addition, as the percent of the orders received with correct content (percent of orders received that have the correct material content as specified in the product design specs and supplier agreements) increases in the company, the percent of the orders received with proper packaging (percent of orders received that are packaged correctly with the right type and quantity of packaging material) increases. Additionally, as the percent of the orders received with correct content increases, the percent of the orders received with correct shipping documents also increases.

As the current source volume (amount of each item purchased) increases, other source volumes obtained in 30 days (additional source volume to be determined given ramped-up resources) decrease. In addition, as the additional source volumes obtained in 30 days (additional source volume to be determined given ramped up resources) increases, the supply sources identification cycle time increases as well. Besides, as the additional source volumes obtained in 30 days increase, purchased materials cost (the total cost of the materials, merchandise, and services purchased to produce the final product) increases well. In addition, as the additional source volumes gathered in 30 days increases, sourcing GRC, inventory, and overhead cost increases.

As the current purchase order cycle times (sum of time to place a purchase order and supplier lead time) increases, demand sourcing-supplier constraints increases as well. Moreover, as the current purchase order cycle times increase, the supply sources identification cycle time increases. As the current purchase order cycle times increases, receiving product cycle time (total elapsed time from time product is received to the time it is passed to the following process) increases. As the demand sourcing-supplier constraints increase, the percent of suppliers used have a validated Environmental Management System or ISO 14000 certification increases.

As the demand sourcing-supplier constraints increases, sourcing GRC, inventory and overhead cost decreases. As the sourcing automation cost (costs associated with the automation -software, hardware, maintenance - in support of the acquisition of materials) increases, sourcing labor cost decreases. As the sourcing labour cost increases, sourcing GRC, inventory and overhead cost increases.

In addition, as the sourcing GRC, inventory and overhead cost increases, the sourcing automation cost (the costs associated with the automation-software, hardware, maintenance - in support of the acquisition of materials) increases. As the cost of the purchased materials increases, the sourcing automation cost increases. In addition, material risk and compliance costs increase as material transportation costs and customs, duties, taxes, and tariffs increase.

In the company, as the material risk and compliance cost (cost of theft, fraud; and cost of mitigation of potential risk of supply disruption) increases, the sourcing GRC, inventory, and overhead cost (governance, risk management, compliance, inventory, and overhead costs allocated to acquisition process; the ordering, receiving and inspecting costs. This also includes costs of the legal department, quality management costs, risk mitigation costs, and compliance remediation costs) increases. As the supply sources identification cycle time (the average time associated with the identification of sources of supply) increases, the selection of supplier and negotiation cycle time increases.

As the supply sources identification cycle time increases, material risk and compliance cost increase. As the sourcing property, plant, and equipment cost increases, sourcing automation cost increases. As the percent of the orders received defect-free (the number of received defect-free orders divided by the total orders processed in the measurement period) increases, material risk, and compliance cost decrease.

As the initial concept values of the Fuzzy Cognitive Map method, we used aggregated evaluations of 3 experts. Here, the concepts are SCOR Level 3 metrics. Then, we defuzzified the fuzzy influence matrix of the metrics using the centroid formula in equation 4.2, and we found aggregated crisp values of the decision makers’ evaluation using the average operator. Aggregated crisp values of the decision makers’ evaluation can be seen in Table 5.2.

Then, Fuzzy Cognitive Map was simulated, and final weights were obtained. Different activation (threshold) functions can be used in FCMs. In this study, the sigmoid function was used since it gives values between 0 and 1. λ parameter is related to the function's slope to obtain the proper shape. To reach the long-term influences among the

SCOR metrics, aggregated crisp values of decision-makers were entered into FCMapper software, and steady-state values were reached in 10 iterations, as in Table 5.3. In Table 5.3, columns indicate metrics while rows indicate iterations.

After finding the steady-state concept values, we calculated the normalized weights of the metrics dividing each metric value by the summation of the steady-state values. The final normalized weights of the metrics can be seen in Table 5.4.

Table 5.2: Aggregated crisp values of the decision makers' evaluation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1								0,400	0,400				0,900											
2				0,900									0,900							0,400				
3	-0,500																							
4								-0,200						0,100							0,600			
5								0,300																
6					-0,400																			
7						0,600																		
8						0,700																		
9						0,800																		
10												0,600												
11												0,600												
12						0,300		0,300																
13					0,400							0,500			0,600									
14												-0,200			0,900									
15					0,300																			
16																								
17																0,400								
18																								
19				0,800										0,200							0,800			
20																								
21								-0,500				-0,500												0,400
22																		0,400	0,200					
23																					0,900			
24																								

Table 5.3: Steady-state concept values

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0,622	0,731	0,731	0,891	0,731	0,968	0,731	0,786	0,750	0,731	0,731	0,881	0,943	0,769	0,924	0,750	0,731	0,750	0,769	0,750	0,964	0,731	0,731	0,750
2	0,564	0,675	0,675	0,833	0,672	0,944	0,675	0,702	0,693	0,675	0,675	0,831	0,897	0,718	0,899	0,695	0,675	0,695	0,714	0,695	0,941	0,675	0,675	0,695
3	0,556	0,663	0,663	0,813	0,658	0,934	0,663	0,677	0,679	0,663	0,663	0,814	0,882	0,705	0,889	0,682	0,663	0,682	0,700	0,682	0,932	0,663	0,663	0,682
4	0,556	0,660	0,660	0,808	0,655	0,930	0,660	0,671	0,676	0,660	0,660	0,809	0,879	0,702	0,886	0,679	0,660	0,679	0,697	0,679	0,929	0,660	0,660	0,679
5	0,556	0,659	0,659	0,807	0,654	0,930	0,659	0,670	0,675	0,659	0,659	0,808	0,878	0,701	0,885	0,678	0,659	0,678	0,696	0,678	0,929	0,659	0,659	0,679
6	0,556	0,659	0,659	0,806	0,654	0,929	0,659	0,669	0,675	0,659	0,659	0,807	0,878	0,701	0,885	0,678	0,659	0,678	0,696	0,678	0,928	0,659	0,659	0,678
7	0,556	0,659	0,659	0,806	0,654	0,929	0,659	0,669	0,675	0,659	0,659	0,807	0,878	0,701	0,885	0,678	0,659	0,678	0,696	0,678	0,928	0,659	0,659	0,678
8	0,556	0,659	0,659	0,806	0,654	0,929	0,659	0,669	0,675	0,659	0,659	0,807	0,878	0,701	0,885	0,678	0,659	0,678	0,696	0,678	0,928	0,659	0,659	0,678
9	0,557	0,659	0,659	0,806	0,654	0,929	0,659	0,669	0,675	0,659	0,659	0,807	0,878	0,701	0,885	0,678	0,659	0,678	0,696	0,678	0,928	0,659	0,659	0,678
10	0,557	0,659	0,659	0,806	0,654	0,929	0,659	0,669	0,675	0,659	0,659	0,807	0,878	0,701	0,885	0,678	0,659	0,678	0,696	0,678	0,928	0,659	0,659	0,678

Table 5.4: Normalized weights

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0,0324	0,0384	0,0384	0,0469	0,0381	0,0541	0,0384	0,0390	0,0393	0,0384	0,0384	0,0470	0,0511	0,0408	0,0516	0,0395	0,0384	0,0395	0,0405	0,0395	0,0541	0,0384	0,0384	0,0395

Then, we chose the metrics equal to or above the average of the normalized 24 metrics; 0,0416 value (1/24); to be used for analysis. Determined metrics are AG.3.46-Demand sourcing-supplier constraints, CO.3.006-Sourcing Automation Cost, CO.3.012 Material Risk, and Compliance Cost, RS.3.35-Identify Sources of Supply Cycle Time, RS.3.125-Select Supplier and Negotiate Cycle Time, RL.3.19 Percent of the Orders/Lines Received Defect Free. Using same aggregated values in Table 5.2, the selected six metrics were activated by setting the other metrics' values to 0 in FCMapper software. Thus, relations between these six metrics were the same as in the previous applied Fuzzy Cognitive Map. To reach the long-term influences between the six SCOR Level 3 metrics, steady-state values are calculated, and we reached the steady-state values in 13 iterations as in Table 5.5. In Table 5.5, columns indicate metrics while rows indicate iterations.

Table 5.5: Steady-state concept weights

	1	2	3	4	5	6
1	0,599	0,786	0,731	0,731	0,832	0,832
2	0,525	0,732	0,664	0,675	0,781	0,767
3	0,514	0,717	0,650	0,663	0,766	0,747
4	0,514	0,713	0,647	0,660	0,762	0,742
5	0,514	0,713	0,647	0,659	0,761	0,741
6	0,514	0,712	0,647	0,659	0,761	0,741
7	0,514	0,712	0,647	0,659	0,761	0,741
8	0,515	0,712	0,647	0,659	0,761	0,741
9	0,515	0,712	0,647	0,659	0,761	0,741
10	0,515	0,712	0,647	0,659	0,761	0,741
11	0,515	0,712	0,647	0,659	0,761	0,741
12	0,515	0,712	0,647	0,659	0,761	0,741
13	0,515	0,712	0,647	0,659	0,761	0,741

We simulated the Fuzzy Cognitive Map and reached the final weights. After finding the steady-state values, we found the normalized weights of the metrics divided by the summation of the steady-state values. Final normalized weights of the six metrics can be seen in Table 5.6,

Table 5.6: Normalized weights of the concepts

1	2	3	4	5	6
0,128	0,177	0,160	0,163	0,189	0,184

Step 3. Determine ISO software quality characteristics, inspect relations between them and focus on essential characteristics using Fuzzy Cognitive Map.

Considering the software problems of the case supply chain related to software product quality, data product quality, and quality in use, we determined to evaluate existing software systems of the case supply chain in a broader perspective using all three quality models of the SQuaRE. We used ISO/IEC 25022 (ISO/IEC 25022:2016, 2016), ISO/IEC 25023 (ISO/IEC 25023:2016, 2016), and ISO/IEC 25024 (ISO/IEC 25024:2015, 2015) that define quality measures for quantitatively evaluating the software quality characteristics, and selecting their related sub-characteristics. Essential questions are which of these characteristics are essential and which have the most influence on the experts. ISO/IEC 25022 - Measurement of quality in use, ISO/IEC 25023- Measurement of system and software product quality, and ISO/IEC 25024 - Measurement of data quality propose several measures and ways to quantify them. In this study, we used these measures of sub-characteristics in QFD Stage 1 as design requirements, which enabled us to reflect correlations between SCOR metrics. We reduced 30 problematic software characteristics considering the characteristics' metrics and related performance gaps from their targets and primarily focusing on the relations between these problematic characteristics using Fuzzy Cognitive Maps. This method enabled us to have a sufficient number of software characteristics without loss of information. It is not practically possible to specify or measure all sub-characteristics for every part of a large computer system or software product. The complete set of quality characteristics across quality models will not be relevant to every stakeholder. For product quality, we focused on sub-characteristics of performance efficiency, reliability, compatibility, usability, maintainability, functional suitability, and security characteristics seeing their related metrics and performance gaps from the targets. For quality in-use, we focused on satisfaction and freedom from risk characteristics. Since we focused on the technological domain, we used only system-dependent data quality characteristics. Problematic software product quality, quality in use, and data product quality characteristics can be seen in Table 5.7, Table 5.8, and Table 5.9,

Table 5.7: Software product quality characteristics and sub-characteristics

Performance Efficiency	1. Time Behaviour 2. Resource Utilization 3. Capacity
Reliability	4. Maturity 5. Availability 6. Fault Tolerance 7. Recoverability
Security	8. Confidentiality 9. Integrity 10. Non-repudiation 11. Accountability 12. Authenticity
Compatibility	13. Interoperability 14. Co-existence
Usability	15. Operability
Maintainability	16. Modularity 17. Modifiability
Functional Suitability	18. Functional Completeness

Table 5.8: Quality in use characteristics and sub-characteristics

Satisfaction	1. Trust
Freedom from risk	2. Economic Risk Mitigation

Table 5.9: Data product quality characteristics

Quality of Data Product Characteristics	1. Accessibility 2. Compliance 3. Confidentiality 4. Efficiency 5. Precision 6. Traceability 7. Understandability 8. Availability 9. Portability 10. Recoverability

System and software product quality, quality in use, and data quality measures of related sub-characteristics used in this study can be seen in Table 5.10, Table 5.11, and Table 5.12,

Table 5.10: System and software product quality measures of used sub-characteristics

Characteristics	Sub-characteristics	Measure
Performance Efficiency	Time behaviour	Mean response time
		Response time adequacy
		Mean turnaround time
Performance Efficiency		Turnaround time adequacy
		Mean throughput
	Resource Utilization	Mean processor utilization
		Mean memory utilization
		Mean I/O devices utilization
		Bandwidth utilization
	Capacity	Transaction Processing Capacity
		User access capacity
		User access increases adequacy
	Maturity	Fault correction
		Mean time between failure (MTBF)
		Failure rate
Reliability		Test coverage
	Availability	System Availability
		Mean downtime
	Fault tolerance	Failure avoidance
		Redundancy of components
		Mean fault notification time
	Recoverability	Mean recovery time
		Backup data completeness
	Confidentiality	Access controllability
		Data encryption correctness
		Strength of cryptographic algorithms
Security	Integrity	Data Integrity
		Internal data corruption prevention
		Buffer overflow prevention
	Non-repudiation	Digital signature usage
	Accountability	User audit trail completeness
		System log retention
	Authenticity	Authentication mechanism sufficiency
		Authentication rules conformity

Table 5.11 Quality in use measures related to the used characteristics

Characteristics	Sub-characteristics	Measure
Satisfaction	Usefulness	Satisfaction with features
		Discretionary usage
		Feature utilization

		The proportion of customers complaining
	Trust	User Trust
Freedom from risk	Economic risk mitigation	Return on investment Time to achieve a return on investment Business performance Benefits of IT investment Service to customers Website visitors converted to customers Revenue from each customer Errors with economic consequences

Table 5.12: Data quality measures related to the used characteristics

Accessibility	User accessibility Device accessibility Accessibility of the data format
Compliance	Regulatory compliance of values and/or format of data Regulatory compliance due to technology
Confidentiality	Use of encryption No vulnerability
Efficiency	Efficient data item format Usable efficiency Efficiency in data format Efficiency in the data processing Risk of wasted space Space occupied by duplication of records Temporary data update delay
Precision	Accuracy of data values Accuracy of data format
Traceability	Traceability of data values (inherent) Traceability of data access Traceability of data values (system dependent)
Understandability	Understandability of symbols Semantic Understandability Understandability of master data Understandability of data values Understandability of the data model Understandability of data representation Understandability of linked master data
Availability	Data availability ratio Probability of available data Availability of architectural elements

Portability	Data portability ratio Portability of prospective data Portability of architectural elements
Recoverability	Data recoverability ratio Period backup Recoverability of the architecture

For time behavior sub-characteristic of the performance efficiency characteristic, all metrics are appropriate to use in their software systems. However, Mean turnaround time is more problematic, seeing the performance gap from the target. Mean response time is also suitable for their calculations. However, Mean response time is based on the first response time, while mean turnaround time is based on the full task completion, which is suitable for their system as they generally use task-based calculations.

All the metrics (Mean processor utilization, Mean memory utilization, Mean I/O devices utilization, and Bandwidth utilization) were similar in target accomplishment for resource utilization sub-characteristic of the performance efficiency. However, Bandwidth utilization was easy to calculate for them. On the other hand, Mean processor utilization, Mean memory utilization and Mean I/O devices utilization were hard to understand and measure for their system.

For capacity sub-characteristic of the performance efficiency, all the measures (Transaction processing capacity, User access capacity, and User access increases adequacy) were similar in target accomplishment. However, user access increase adequacy was especially important for their system as there can be problems when more stakeholders are involved.

For maturity sub-characteristic of reliability characteristic, Mean Time Between Failure (MTBF) and Failure rate were problematic for their systems considering the target accomplishments. However, they use ratio (not time) for failure calculation. Hence, the Failure rate is suitable for their system in maturity calculation. Fault correction and Test coverage measures were not problematic in their system. For availability sub-characteristic, both System availability (proportion of time that the system is available over the established time period) and Mean downtime (mean time that the system remains unavailable) were problematic, and these measures were suitable for calculating. However, they generally use ratios for this type of calculation. Hence, they focused on System availability measures. For fault-tolerance sub-characteristic, Failure avoidance (percentage of fault patterns under examination to prevent crucial and significant failures) is more critical for their system seeing the performance gap from the target. Redundancy of components and Mean fault notification time were ambiguous to understand for software stakeholders. For recoverability sub-characteristic, mean recovery time is problematic seeing the performance gap since it takes time to recover from failures in their SAP systems. Backup data completeness (rate of data items backed up periodically) was not a significant metric since their SAP systems regularly back-up data.

For confidentiality sub-characteristic, Access controllability (percentage of data items necessitating access control solely reached using appropriate authorization) was problematic since proper authorization was a massive problem for their software systems considering the faulty entries in their systems. The other metrics (Data encryption correctness and Strength of cryptographic algorithm) were ambiguous to measure for their SAP systems. For integrity sub-characteristic, Data integrity (percentage of data items to be protected that stay not disrupted) was problematic seeing the performance gap; since data from different departments remained corrupted. Internal data corruption prevention and Buffer overflow prevention were not significant. For non-repudiation sub-characteristic, Digital signature usage (calculated using the percentage of cases controlled with a digital signature, certificates, or other security algorithms) was significant especially considering the faulty works operated in their SAP systems. For accountability sub-characteristic, User access trail completeness (this measure is based on user access recording) was essential to trace users, especially when more stakeholders are in their systems. Finally, for authenticity, Authentication mechanism sufficiency (percentage of authentication mechanism necessitated in the system) was significant since there were not enough authentication mechanisms considering the unauthenticated users in their systems.

For co-existence sub-characteristic of compatibility, co-existence of different systems was problematic considering the whole supply chain. Since there are many industrial systems, more than one data format exist and this creates complexity when the interoperability sub-characteristic of compatibility is considered. For functional suitability characteristics, functional completeness was problematic as there were problems in their systems related to the rate between the number of functions identified in requirement specification and the number of missing or incorrect functions.

The consistent behavior measured by operational consistency was a must for their system since a reliable and deterministic execution pattern was required (for the operability sub-characteristic of usability). Moreover, a high proportion of modifications cause a quality degradation in their systems (for the Modification correctness measure of modifiability sub-characteristic). The ratio of completely independent components in their systems to the number of components that must be independent was problematic, so coupling of components was mainly focused on (for Coupling components measure of modularity sub-characteristic).

For freedom from risk characteristics, economic risk mitigation sub-characteristic was crucial. For software stakeholders, measuring errors with economic consequences was highly important considering the proportion of usage situations where system errors have economic consequences. Finally, satisfaction measures evaluate the degree to which user requirements are met when a product or system is utilized in a particular context of use. User trust measure was problematic since the degree of the information offered by their software systems is not honest, and it does not fulfill the commitments it assumes for the satisfaction characteristic.

Regarding data quality characteristics, confidentiality (encryption) was problematic, seeing the target's performance gap. Data values accomplish the needs using encryption according to the encryption usage which is set as a degree. This was not broadly used in the existing software systems. The data to be encrypted is not limited to personal data; any other data can be encrypted based on the system's needs or compliance with a regulation. Its base measure is calculated for each data file as the ratio of records whose fields include data suitably encrypted considering the determined needs. For compliance characteristics, regulatory compliance due to technology was problematic especially considering the KVKK law. Regulatory compliance due to technology is the degree to which data comply with particular standards, conventions, or regulations related to technical aspects of the computer system having the data. These rules can be set either internally by the company or by external law. Its base measure was calculated for each data file in the repository. Obtaining the ratio of records of that file whose value for their fields comply with the regulations.

For traceability, user access traceability was problematic, seeing the performance gap from the target. User access traceability is the degree to which users' access to the data value was followed using either data contained in the data repository or other system abilities. The software stakeholders determined user access traceability needs, indicating which files require traceability regarding access to data values. Its base measure was calculated for each data file in the repository, taking the ratio of records which have a traceable data concerning of users who have accessed its value (to read or change it) over the total number of records for which user access traceability is expected. For understandability, the understandability of data values was problematic. Some data are represented by values that any user cannot understand in the existing software system. For precision, the accuracy of data values was problematic. Data were not accurate where they should be; especially lack of precision in decimals created huge problems. For accessibility, user accessibility was problematic since highly critical data in the case company was accessed by some users who were not allowed to access it. Moreover, data availability, portability, and recoverability ratios were also problematic, considering their calculated ratios in the existing system.

As the performance efficiency (Mean Turnaround time or Bandwidth utilization metrics' improvements) increases, security (Access controllability, Data integrity, User audit trail completeness, or Digital signature usage metrics' improvements) decreases in their software systems. Moreover, as the performance efficiency increases, maintainability (Modularity; Coupling of components and Modifiability; Modification capability) decreases. Moreover, as the fault tolerance increases, maintainability

(Modularity and Modifiability metrics' improvements) increases. As the fault tolerance increases, availability (system availability) and functional completeness increase; maturity (failure rate) decrease in their systems as the resource utilization or capacity improvements increase time behaviour increases.

As the confidentiality (Access controllability) increases, fault tolerance (Failure avoidance), integrity (Data integrity), non-repudiation (Digital signature usage), data confidentiality, freedom from risk (economic risk mitigation), and user trust increases; resource utilization and time behaviour decrease in their systems. As the non-repudiation (Digital signature usage) increases, integrity (Data integrity), compliance (regulatory compliance due to technology), and user trust increase. As the authenticity (Authentication mechanism sufficiency) increases, fault tolerance (Failure avoidance) and confidentiality (Access controllability) increase as well. As the maintainability metrics improve (modularity or modifiability), performance efficiency metrics' improvements decrease. Finally, as the compatibility (coexistence or interoperability) improves, security (integrity, non-repudiation, and authenticity) decreases.

As the maintainability (Modularity or Modifiability) increases, compatibility (Coexistence and Interoperability) improves in their systems. As the usability (operability) and maintainability (modularity or modifiability) increase, functional completeness increases in their systems. As non-repudiation (digital signature usage) increases, compliance (regulatory compliance due to technology) also increases. However, as the functional completeness (functional coverage) improves; resource utilization, capacity, time behavior, and confidentiality decrease; operability, modularity, maturity fault tolerance, and modifiability increase. As the traceability of data values increases, efficiency in data processing increases as well. As the data traceability or fault tolerance increases, freedom from risk (economic risk mitigation) also increases.

To focus on the essential problematic sub-characteristics, a Fuzzy Cognitive Map was simulated, and final weights were obtained. Then, steady-state values were calculated in 12 iterations using FCMapper software to reach the long-term influences among the

ISO software characteristics, as in Table 5.14. In Table 5.14, columns indicate software characteristics, while rows indicate iterations.

After finding the steady-state concept values, we calculated the normalized weights of the metrics dividing each characteristic value by the summation of the steady-state values. Then, we chose the sub-characteristics from the normalized weights equal to or above the average value for subsequent evaluations. Because of the limited space, we did not show the positive and negative relations between 30 ISO software characteristics using the directed arrows. Positive and Negative Relations between ISO software characteristics can be seen in Table 5.13. After finding the steady-state concept values, we calculated the normalized weights of the metrics dividing each metric value by the summation of the steady-state values. Steady-state concept weights of the ISO software characteristics and final normalized weights of the ISO software characteristics can be seen in Table 5.14 and Table 5.15, respectively,

Table 5.13 Positive and negative relations between ISO software characteristics

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1			+					-																		-	-			
2	+		+																							+				
3	+							-					-													-	-			
4																														
5																														
6																+														
7				-	+																					+	+	+		+
8	-		-				+			+	+										+								+	+
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24								-		-	-	-									-	+								
25				+	+		+		+																			+		
26	-	-	-																				+	+				+		
27	-	-	-																				+	+				+		
28	-	-	-	+			+	-																	+	+	+			
29																														
30																														

Table 5.14: Steady-state concept weights of the ISO software characteristics

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0,917	0,622	0,891	0,769	0,786	0,731	0,948	0,881	0,750	0,731	0,731	0,786	0,858	0,769	0,769	0,769	0,786	0,731	0,786	0,731	0,769	0,750	0,769	0,786	0,769	0,931	0,931	0,846	0,786	0,786
2	0,872	0,543	0,838	0,711	0,741	0,675	0,923	0,835	0,696	0,676	0,677	0,734	0,806	0,715	0,714	0,714	0,735	0,675	0,733	0,675	0,724	0,696	0,722	0,741	0,719	0,914	0,914	0,808	0,738	0,740
3	0,854	0,527	0,818	0,697	0,731	0,663	0,914	0,822	0,683	0,664	0,665	0,721	0,791	0,701	0,700	0,700	0,722	0,663	0,719	0,663	0,713	0,684	0,712	0,730	0,707	0,909	0,909	0,797	0,726	0,729
4	0,848	0,524	0,811	0,693	0,728	0,660	0,911	0,818	0,680	0,661	0,663	0,718	0,787	0,698	0,697	0,697	0,719	0,660	0,716	0,660	0,711	0,681	0,710	0,728	0,704	0,907	0,907	0,795	0,722	0,726
5	0,846	0,523	0,809	0,692	0,727	0,659	0,911	0,817	0,679	0,660	0,662	0,717	0,786	0,697	0,696	0,696	0,718	0,659	0,715	0,659	0,710	0,680	0,709	0,727	0,703	0,907	0,907	0,794	0,722	0,725
6	0,846	0,523	0,808	0,692	0,727	0,659	0,910	0,817	0,679	0,660	0,662	0,717	0,786	0,697	0,696	0,696	0,718	0,659	0,715	0,659	0,710	0,680	0,709	0,727	0,703	0,907	0,907	0,794	0,721	0,725
7	0,846	0,523	0,808	0,692	0,727	0,659	0,910	0,817	0,679	0,660	0,662	0,717	0,786	0,697	0,696	0,696	0,717	0,659	0,714	0,659	0,709	0,680	0,709	0,727	0,703	0,907	0,907	0,794	0,721	0,725
8	0,846	0,523	0,808	0,692	0,727	0,659	0,910	0,817	0,679	0,660	0,662	0,717	0,786	0,697	0,696	0,696	0,717	0,659	0,714	0,659	0,709	0,680	0,709	0,727	0,703	0,907	0,907	0,794	0,721	0,725
9	0,846	0,523	0,808	0,692	0,727	0,659	0,910	0,817	0,679	0,660	0,662	0,717	0,786	0,697	0,696	0,696	0,717	0,659	0,714	0,659	0,709	0,680	0,709	0,727	0,703	0,907	0,907	0,794	0,721	0,725
10	0,846	0,523	0,808	0,692	0,727	0,659	0,910	0,817	0,679	0,660	0,662	0,717	0,786	0,697	0,696	0,696	0,717	0,659	0,714	0,659	0,709	0,680	0,709	0,727	0,703	0,907	0,907	0,794	0,721	0,725
11	0,846	0,523	0,808	0,692	0,727	0,659	0,910	0,817	0,679	0,660	0,662	0,717	0,786	0,697	0,696	0,696	0,717	0,659	0,714	0,659	0,709	0,680	0,709	0,727	0,703	0,907	0,907	0,794	0,721	0,725
12	0,846	0,523	0,808	0,692	0,727	0,659	0,910	0,817	0,679	0,660	0,662	0,717	0,786	0,697	0,696	0,696	0,717	0,659	0,714	0,659	0,709	0,680	0,709	0,727	0,703	0,907	0,907	0,794	0,721	0,725

Table 5.15: Final normalized weights of the ISO software characteristics

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
0,0386	0,0239	0,0369	0,0316	0,0332	0,0301	0,0416	0,0373	0,0310	0,0301	0,0302	0,0327	0,0359	0,0318	0,0318	0,0318	0,0328	0,0301	0,0326	0,0301	0,0324	0,0310	0,032	0,0324	0,0321	0,0414	0,0414	0,0362	0,0329	0,0331

Then, we chose the software characteristics that are equal or above the average of the normalized 30 metrics; 0,0333 value (1/30); to be used for analysis. After the elimination, 8 software sub-characteristics were determined: resource utilization, time behaviour, resource utilization, fault tolerance, confidentiality, compliance, modularity, modifiability and functional completeness.

Using the same aggregated values of ISO software characteristics, we activated the selected eight characteristics by setting the other characteristics' values to 0 in FCMapper software. Relations between these eight characteristics were the same as in the previous applied Fuzzy Cognitive Map. Steady-state weights of the ISO software characteristics and final normalized weights of the ISO software characteristics can be seen in Table 5.16 and Table 5.17, respectively.

Table 5.16: Steady-state concept weights of the important ISO software characteristics

	1	2	3	4	5	6	7	8
1	0,818	0,802	0,832	0,668	0,646	0,931	0,931	0,786
2	0,770	0,753	0,780	0,602	0,580	0,902	0,902	0,742
3	0,756	0,739	0,766	0,589	0,569	0,893	0,893	0,731
4	0,752	0,735	0,762	0,587	0,568	0,890	0,890	0,728
5	0,751	0,734	0,761	0,586	0,568	0,889	0,889	0,728
6	0,751	0,733	0,760	0,586	0,568	0,889	0,889	0,727
7	0,751	0,733	0,760	0,586	0,568	0,889	0,889	0,727
8	0,750	0,733	0,760	0,586	0,568	0,889	0,889	0,727
9	0,750	0,733	0,760	0,586	0,568	0,889	0,889	0,727
10	0,750	0,733	0,760	0,586	0,568	0,889	0,889	0,727
11	0,750	0,733	0,760	0,586	0,568	0,889	0,889	0,727
12	0,750	0,733	0,760	0,586	0,568	0,889	0,889	0,727
13	0,750	0,733	0,760	0,586	0,568	0,889	0,889	0,727
14	0,750	0,733	0,760	0,586	0,568	0,889	0,889	0,727

Table 5.17: Final normalized weights of the ISO software characteristics

1	2	3	4	5	6	7	8
0,127	0,124	0,129	0,099	0,096	0,151	0,151	0,123

Step 4. Calculate QFD Stage 1 correlations, integrate Fuzzy Cognitive Map results into QFD by multiplying the results.

In QFD Stage 1, ISO/IEC 25010 and ISO/IEC 25012 quality sub-characteristics were used as design requirements of the QFD. After determining the six SCOR Level 3 metrics as AG.3.46, CO.3.012, CO.3.006, RL.3.19, RS.3.35, and RS.3.125, we used them in the customer requirements part of the QFD Stage 1. In this study, we used fuzzy triangular numbers throughout the study.

In step 4, QFD Stage 1 correlations were determined between the SCOR performance metrics and software characteristics. Percentage of on-time orders with accurate documentation supporting the order, including packing slips, bills of lading, invoices, etc. (AG.3.46), can be handled chiefly focusing on resource utilization, time behaviour, confidentiality, and functional completeness. When considering the intense workloads in the procurement department, the amount of resources used by their software systems (bandwidth utilization) is high. Moreover, the processing times of their systems are higher than expected. With the help of efficiency in bandwidth utilization and mean turnaround time, the percentage of on-time orders with accurate documentation can be increased. As an agility metric, AG.3.46 is highly affected by external influences such as cyber-attacks. Hence, this metric can also be improved, increasing the confidentiality of the software systems (access controllability). Improving the missing or incorrect functions in their systems can also improve AG.3.46.

Sourcing automation cost (CO.3.006); the cost associated with the automation in acquiring services is high in their systems. According to the software stakeholders, the selection of suppliers according to specific quality standards and consideration of KVKK law necessitate excessive complex functions and costs. Sourcing Automation cost metric can be handled chiefly focusing on functional completeness, resource utilization, compliance, and modularity. CO.3.006 can be handled by improving regulatory compliance due to technology. It is the degree to which data comply with particular standards or regulations (quality standards and KVKK law) relating to technical aspects of their software systems retaining data. Excessive sourcing automation costs associated with the acquisition of materials can be handled by improving the performance efficiency regarding resource utilization of their software systems. Fixing the number of incorrect functions can create decreased automation costs.

Material risk and compliance costs can be handled chiefly by focusing on functional completeness and confidentiality. For example, the cost of fraud in their software systems associated with unauthorized access can be decreased by improving access controllability (confidentiality). Likewise, complex functions due to the compliance requirements can be handled chiefly focusing on functional completeness in their systems.

Identifying sources of supply cycle time metric (time for identification and qualification of potential suppliers capable of designing and delivering a product that will meet all of the required product specifications) can be handled chiefly focusing on performance efficiency (resource utilization and time behaviour), compliance to quality standards of potential suppliers, modularity (by preventing unexpected modifications in their systems) and functional completeness (by providing correct and complex functions).

Selection of a supplier and negotiation cycle time can be decreased by focusing on their software systems' performance efficiency, modularity, modifiability, and functional completeness. Most of the time, unauthorized users cause failures in their systems. Therefore, the percent of orders received defect-free can be increased by focusing on access controllability (confidentiality).

Aggregated evaluations of decision-makers in QFD Stage 1 can be seen in Table 5.18. After the aggregation, we multiplied the SCOR metrics' weights in Table 5.6 with the aggregated correlation values in Table 5.18. The normalized multiplication result can be seen in Table 5.19. To reflect the relationships of 8 sub-characteristics to the calculated value, we multiplied the result found in Table 5.19 with the Fuzzy Cognitive Map weights found in Table 5.17. The multiplication result is the normalized QFD Stage 1

Final HOW weights using the Fuzzy Cognitive Map relations between ISO characteristics, as shown in Table 5.20.

Table 5.18: Aggregated evaluations of decision-makers

	1	2	3	4	5	6	7	8
1	0,600	0,600	0,300	0,900	0,300	0,300	0,300	0,900
2	0,800	0,500	0,400	0,500	0,600	0,600	0,500	0,800
3	0,400	0,400	0,300	0,900	0,400	0,300	0,300	0,900
4	0,600	0,600	0,500	0,500	0,600	0,600	0,500	0,600
5	0,800	0,800	0,500	0,500	0,500	0,600	0,600	0,600
6	0,500	0,500	0,400	0,600	0,500	0,500	0,500	0,500

Table 5.19 Normalized QFD Stage 1 HOW weights without relations between ISO characteristics

1	2	3	4	5	6	7	8
0,142	0,130	0,093	0,144	0,082	0,082	0,077	0,117

Table 5.20 Normalized QFD Stage 1 final HOW weights with relations between ISO characteristics

1	2	3	4	5	6	7	8
0,146	0,130	0,096	0,116	0,087	0,137	0,128	0,159

Considering the values in Table 20, it can be concluded that this multiplication increased the QFD Stage 1 weights of resource utilization, fault tolerance, regularity compliance due to technology, modularity, modifiability, and functional completeness. However, the multiplication decreased the weights of confidentiality.

Step 5. Determine blockchain technology characteristics, inspect relations between them and focus on essential characteristics using Fuzzy Cognitive Map.

After inspecting all blockchain characteristics from the literature, we summarized 31 characteristics to support the selection of blockchain alternatives, especially for enterprise systems and their blockchain application development decisions. Then, we found the most critical characteristics using a Fuzzy Cognitive Map. Summarized blockchain characteristics can be seen in Table 5.21,

Table 5.21: Blockchain characteristics

1. Blockchain Data Structure
2. Non-Blockchain Data
3. Permissioned Network
4. Permissionless Network
5. Smart Contract Functionality
6. Privacy
7. Off-chain transactions
8. On-chain transactions
9. Security
10. TPS
11. Cost
12. Community Support
13. Scripting Language
14. Governance
15. Scalability
16. Cryptocurrency Support
17. Tokenization
18. Licensing
19. Popularity
20. Enterprise System Integration
21. Ease of use
22. Modularity
23. API support
24. Adversary Fault Tolerance
25. Verification Speed
26. Block Time
27. Double Spending
28. Transparency
29. Network Size
30. Transaction Capacity
31. Participation

A trade-off is a property that impacts more than one attribute. Since there are important positive and negative relationships between blockchain design characteristics, we applied Fuzzy Cognitive Map to reflect these relationships to the evaluation result. Here, the concepts are blockchain design requirements. We inspected positive and negative relations between the 31 blockchain characteristics. Blockchain is a secure technology with its chained and immutable structure. Unfortunately, blockchain blocks have limited capacity. Security is a fundamental feature of on-chain transactions (blockchain itself). Hence, there are positive relations between on-chain transactions and security. However, the more central solutions such as off-chain are used, the more basic features of blockchain such as security are compromised. Here, negative relations can be discovered between off-chain transactions and security. As the security increases in blockchain systems, double spending decreases. In addition, more secure blockchain systems create less transparency. Similarly, more private blockchain systems create less transparency.

Blockchain technologies developed after bitcoin are generally aimed at improving this limited structure of bitcoin. In this sense, it can be said that having a blockchain data structure represents a limited capacity. Here, whether or not to have a blockchain data structure represents the distinction between distributed ledgers, which are not a blockchain but are widely used and have a data structure different from the blockchain. There is even widespread use of distributed ledgers that are represented as enterprise blockchains. On-chain represents the blockchain itself. Hence, there are positive relations between blockchain data structure and on-chain transactions. Since blockchain data structure is secure, there are positive relations between blockchain data structure and adversary fault tolerance. Blockchain is a decentralized structure, but when we start using decentralized off-chain solutions, we compromise the unique features of the blockchain. When evaluating these positive and negative relations between blockchain design requirements, both legal and architectural characteristics of the blockchain technology were considered. For example, not deleting data in line with KVKK and GDPR laws poses a significant obstacle to using blockchain technology. Hence, on-chain transactions may limit privacy, especially when legal issues are significant. Size of the data can have scalability limits in blockchain, and off-chain storage reduces the blockchain scalability problem. Therefore, it can be said that there are trade-offs between on-chain transactions and scalability. Likewise, there are positive relations between scalability and off-chain transactions.

Additionally, it can be said that there are positive relations between scripting language and smart contract functionality. For example, bitcoin's scripting language is not Turing-complete, so it cannot accomplish complex functions. As TPS increases, verification speed, and block time increases.

As the diversity in scripting language increases, smart contract functionality increases as well. As the scalability increases in a blockchain system, transaction capacity also increases. As the cryptocurrency support increases, popularity increases (considering the coin market capitalization of blockchains like Bitcoin and Ethereum). As the integration of enterprise systems increases, modularity and API support increase as well. Licensing cost is one of the operational costs, and as the diversity in licensing increases (buying various types of licenses), cost increases as well. Cryptographic tokens indicate programmable assets or access rights that are operated by a smart contract. Smart contract functionality is positively correlated with tokenization in the relations between smart contract functionality and tokenization. For tokenization, cryptocurrency support gives power to blockchains. Hence, there are positive relations between tokenization and cryptocurrency support. A permissioned blockchain requires authorized participants, and these participants enter into network operations with their own identity. When compared to permissionless blockchains, permissioned blockchains' identity-shown characteristics and efficient network management nature make them ideal for supply chains. Therefore, a permissioned network structure makes a blockchain more private and secure. Permissionless networks are more transparent, and they have larger network sizes, transaction capacity, and participation than permissioned networks. Finally, it can be said that the stronger the governance a blockchain has, the stronger its community support.

After determining the positive and negative relations between blockchain characteristics as in Table 5.22, we aggregated and defuzzified the fuzzy influence matrix of the design requirements. Relations between the 31 blockchain characteristics can not be shown using directed arrows because of the limited space on the page. The steady-state values are reached to see the long-term influences between the blockchain design requirements, and then final normalized weights of the blockchain design requirements are found. Steady-state values were reached in 12 iterations using the FCMapper software to reach the long-term influences between blockchain design requirements, as in Table 5.23. In Table 5.23, columns indicate blockchain characteristics, while rows indicate iterations. Final normalized weights of the design requirements can be seen in Table 5.24,

Table 5.22 Positive and negative relations between blockchain characteristics

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1								+							-	+								+		+					
2															+																
3						+			+					+														-	-	-	-
4						-			-					-														+	+	-	+
5											+		+				+														
6																												-			
7		+				+			-						+																
8	+					-			+						-																
9														+				+									-	-			
10																									+	+					
11																															
12																															
13					+																										
14			+	+		+	+		+			+																-			
15										+																				+	
16											+						+		+												
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24									+																		-				
25										+																+					
26																															
27																															
28						-																									
29																															+
30																															
31																															

Table 5.23: Steady-state concept values

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	0,750	0,750	0,832	0,750	0,846	0,858	0,750	0,750	0,968	0,917	0,900	0,750	0,750	0,711	0,832	0,750	0,917	0,832	0,750	0,731	0,750	0,769	0,750	0,750	0,750	0,750	0,450	0,500	0,769	0,550	0,622
2	0,695	0,695	0,779	0,695	0,797	0,840	0,695	0,695	0,943	0,882	0,863	0,695	0,697	0,666	0,783	0,695	0,882	0,804	0,695	0,675	0,696	0,714	0,695	0,695	0,699	0,695	0,359	0,400	0,703	0,481	0,548
3	0,682	0,682	0,765	0,682	0,783	0,836	0,682	0,682	0,935	0,870	0,850	0,682	0,685	0,658	0,768	0,682	0,871	0,797	0,682	0,663	0,683	0,700	0,682	0,682	0,687	0,682	0,349	0,383	0,686	0,473	0,536
4	0,679	0,679	0,761	0,679	0,780	0,835	0,679	0,679	0,932	0,867	0,846	0,679	0,682	0,657	0,764	0,679	0,867	0,795	0,679	0,660	0,680	0,697	0,679	0,679	0,684	0,679	0,349	0,381	0,682	0,473	0,534
5	0,679	0,679	0,760	0,678	0,779	0,835	0,678	0,679	0,932	0,866	0,845	0,678	0,681	0,656	0,763	0,679	0,866	0,795	0,679	0,659	0,679	0,696	0,678	0,679	0,684	0,679	0,350	0,381	0,681	0,473	0,534
6	0,678	0,678	0,760	0,678	0,778	0,834	0,678	0,678	0,932	0,866	0,845	0,678	0,681	0,656	0,763	0,678	0,866	0,795	0,678	0,659	0,679	0,696	0,678	0,678	0,684	0,679	0,351	0,381	0,681	0,474	0,534
7	0,678	0,678	0,760	0,678	0,778	0,834	0,678	0,678	0,932	0,866	0,845	0,678	0,681	0,656	0,763	0,678	0,866	0,795	0,678	0,659	0,679	0,696	0,678	0,678	0,684	0,679	0,351	0,381	0,681	0,474	0,534
8	0,678	0,678	0,760	0,678	0,778	0,834	0,678	0,678	0,932	0,866	0,845	0,678	0,681	0,656	0,763	0,678	0,866	0,795	0,678	0,659	0,679	0,696	0,678	0,678	0,684	0,678	0,351	0,381	0,681	0,474	0,534
9	0,678	0,678	0,760	0,678	0,778	0,834	0,678	0,678	0,932	0,866	0,845	0,678	0,681	0,656	0,763	0,678	0,866	0,795	0,678	0,659	0,679	0,696	0,678	0,678	0,684	0,678	0,351	0,381	0,681	0,474	0,534
10	0,678	0,678	0,760	0,678	0,778	0,834	0,678	0,678	0,932	0,866	0,845	0,678	0,681	0,656	0,763	0,678	0,866	0,795	0,678	0,659	0,679	0,696	0,678	0,678	0,684	0,678	0,351	0,381	0,681	0,474	0,534
11	0,678	0,678	0,760	0,678	0,778	0,834	0,678	0,678	0,932	0,866	0,845	0,678	0,681	0,656	0,763	0,678	0,866	0,795	0,678	0,659	0,679	0,696	0,678	0,678	0,684	0,678	0,351	0,381	0,681	0,474	0,534
12	0,678	0,678	0,760	0,678	0,778	0,834	0,678	0,678	0,932	0,866	0,845	0,678	0,681	0,656	0,763	0,678	0,866	0,795	0,678	0,659	0,679	0,696	0,678	0,678	0,684	0,678	0,351	0,381	0,681	0,474	0,534

Table 5.24: Normalized weights of the blockchain characteristics

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0,0317	0,0317	0,0356	0,0317	0,0364	0,0390	0,0317	0,0317	0,0436	0,0405	0,0395	0,0317	0,0319	0,0307	0,0357	0,0317	0,0405	0,0372	0,0317	0,0308	0,0318	0,0326	0,0317	0,0317	0,0320	0,0317	0,0164	0,0178	0,0319	0,0222	0,0250

After finding the steady-state concept values, we calculated the normalized weights of the blockchain characteristics dividing each characteristics value by the summation of the steady-state values. Then, we chose the metrics equal to or above the average of the normalized 31 blockchain characteristics; 0,0322 value (1/31); to be used for analysis.

Blockchain characteristics are permissioned network, smart contract functionality, privacy, security, TPS, cost, scalability, tokenization, licensing, and modularity. Using the same aggregated blockchain characteristics, we activated the selected ten blockchain characteristics by setting the other characteristics' values to 0 in FCMapper. Relations between these ten characteristics were the same as in the previous applied Fuzzy Cognitive Map. Steady-state concept values can be seen in Table 5.25, and normalized weights of the blockchain characteristics can be seen in Table 5.26.

Table 5.25: Steady-state concept values

	1	2	3	4	5	6	7	8	9	10
1	0,731	0,731	0,917	0,858	0,818	0,668	0,731	0,870	0,832	0,731
2	0,675	0,675	0,874	0,809	0,766	0,603	0,675	0,822	0,794	0,675
3	0,663	0,663	0,860	0,794	0,751	0,590	0,663	0,807	0,782	0,663
4	0,660	0,660	0,857	0,790	0,747	0,588	0,660	0,803	0,779	0,660
5	0,659	0,659	0,856	0,789	0,746	0,588	0,659	0,802	0,778	0,659
6	0,659	0,659	0,856	0,789	0,746	0,588	0,659	0,801	0,777	0,659
7	0,659	0,659	0,855	0,788	0,746	0,588	0,659	0,801	0,777	0,659
8	0,659	0,659	0,855	0,788	0,746	0,588	0,659	0,801	0,777	0,659
9	0,659	0,659	0,855	0,788	0,746	0,588	0,659	0,801	0,777	0,659
10	0,659	0,659	0,855	0,788	0,746	0,588	0,659	0,801	0,777	0,659
11	0,659	0,659	0,855	0,788	0,746	0,588	0,659	0,801	0,777	0,659
12	0,659	0,659	0,855	0,788	0,746	0,588	0,659	0,801	0,777	0,659

Table 5.26: Normalized weights of the blockchain characteristics

1	2	3	4	5	6	7	8	9	10
0,092	0,092	0,119	0,110	0,104	0,082	0,092	0,111	0,108	0,092

Step 6. Calculate QFD Stage 2 correlations and integrate Fuzzy Cognitive Map results into QFD by multiplying the results and reaching final blockchain characteristics' weights.

ISO/IEC 25010 and ISO/IEC 25012 standard quality characteristics were benefited to determine which standardized quality characteristics can be met with which blockchain features in QFD stage 2.

Resource utilization in their software systems can be handled by primarily focusing on cost (cryptocurrency usage etc.), TPS, smart contract functionality (with the help of automatic and complex transactions), licensing (with the help of different cost alternatives in licensing), and scalability (scalability options in blockchains are mostly connected to performance efficiency). Time behaviour can be handled by focusing on TPS, scalability, permissioned network, smart contract functionality, and cost. Fault tolerance is primarily among the fundamental features of blockchain technology, which is also a reliability sub-characteristics of the ISO product quality model. Fault tolerance is mainly connected to the security-related characteristics of blockchain technology. It can be handled by primarily focusing on security, privacy, smart contract functionality, and tokenization characteristics. Confidentiality can be handled by mainly focusing on security, privacy, smart contract functionality, and tokenization characteristics. Regulatory compliance due to technology can be handled mostly focusing on privacy, security, and smart contract functionality characteristics of blockchain. Modularity can be handled by focusing on blockchain's modularity, scalability, and smart contract functionality characteristics. Modifiability can mainly focus on blockchain's modularity, scalability, and smart contract functionality characteristics. Functional completeness can be handled by focusing on smart contract functionality and tokenization (firmly connected to smart contracts) characteristics of blockchain.

In this stage, Fuzzy Cognitive Maps also enabled us to evaluate trade-offs between blockchain characteristics. In QFD stage 2, after calculating blockchain design requirements' weights without considering the relations between these requirements, we reflected the Fuzzy Cognitive Map calculations to these weights in the long run. After reaching the final weights of the design requirements by multiplying fuzzy cognitive map results and QFD Stage 2 HOW weights, we selected an enterprise blockchain alternative using these final weights. After taking the fuzzy correlation values of three decision-makers in QFD Stage 2, we defuzzified them. QFD Stage 2 defuzzified correlation values can be seen in Table 5.27,

After calculating the final QFD Stage 1 HOWs' weights, we used them in QFD stage 2 as new WHATs (customer requirements). After calculating the QFD Stage 2 defuzzified correlation values, we multiplied them using the values obtained through QFD Stage 1 final weights. Here, the result of this multiplication does not include relationships between blockchain design characteristics. Normalized QFD Stage 2 HOW weights without Fuzzy Cognitive map effect, and with Fuzzy Cognitive Map effect can be seen in Table 5.28 and Table 5.29, respectively,

Table 5.27: QFD Stage 2 defuzzified correlation values

	1	2	3	4	5	6	7	8	9	10
1	0,400	0,600	0,400	0,400	0,700	0,900	0,600	0,400	0,600	0,200
2	0,800	0,700	0,200	0,200	0,900	0,600	0,700	0,400	0,200	0,200
3	0,300	0,900	0,800	0,800	0,500	0,500	0,500	0,600	0,100	0,100
4	0,500	0,800	0,900	0,900	0,500	0,500	0,500	0,800	0,100	0,100
5	0,600	0,800	0,800	0,800	0,500	0,500	0,500	0,400	0,200	0,200
6	0,600	0,600	0,500	0,500	0,600	0,600	0,600	0,400	0,200	0,900
7	0,900	0,700	0,400	0,300	0,700	0,700	0,900	0,400	0,200	0,600
8	0,500	0,900	0,400	0,400	0,200	0,200	0,300	0,800	0,100	0,300

Table 5.28: Normalized QFD Stage 2 HOW weights without cognitive map effect

1	2	3	4	5	6	7	8	9	10
0,112	0,144	0,101	0,098	0,111	0,109	0,111	0,103	0,043	0,066

Table 5.29: Final QFD Stage 2 HOW weights with cognitive map effect

1	2	3	4	5	6	7	8	9	10
0,104	0,133	0,121	0,109	0,116	0,090	0,103	0,115	0,047	0,061

Considering the values in Table 5.29, this multiplication increased the QFD Stage 2 weights of privacy, security, TPS, tokenization, and licensing. However, the multiplication decreased the weights permissioned network, smart contract functionality, cost, scalability, and modularity.

Step 7. Selection of an Enterprise Blockchain Alternative using the blockchain characteristics' weights and Fuzzy TOPSIS.

After finding the blockchain design requirements' weights, we used them in choosing the appropriate blockchain alternative, adding the decision makers' weights for each alternative. With the help of the blockchain characteristics' weights that we found after the QFD Stage 2, we evaluated enterprise blockchain alternatives together with the assessments of the decision-makers. Here, we applied Fuzzy TOPSIS in order to choose an appropriate alternative. We converted the linguistic evaluations of decision-makers into fuzzy triangular numbers to construct the fuzzy decision matrix. A fuzzy decision matrix using the converted linguistic evaluations of the decision-makers can be seen in Table 5.30,

Table 5.30: Aggregated ratings of four alternatives by decision-makers

	Ethereum			**Hyperledger**			**Corda**			**Ripple**		
Permissioned Network	0,400	0,500	0,600	0,600	0,700	0,800	0,600	0,700	0,800	0,600	0,700	0,800
Smart Contract Functionality	0,800	0,900	1,000	0,500	0,400	0,300	0,400	0,300	0,200	0,300	0,400	0,500
Privacy	0,700	0,800	0,900	0,500	0,600	0,700	0,600	0,700	0,800	0,600	0,700	0,800
Security	0,700	0,800	0,900	0,500	0,600	0,700	0,600	0,700	0,800	0,600	0,700	0,800
TPS	0,500	0,600	0,700	0,700	0,800	0,900	0,500	0,600	0,700	0,600	0,700	0,800
Cost	0,500	0,600	0,700	0,800	0,900	1,000	0,600	0,700	0,800	0,500	0,600	0,700
Scalability	0,600	0,700	0,800	0,700	0,800	0,900	0,600	0,700	0,800	0,600	0,700	0,800
Tokenization	0,800	0,900	1,000	0,500	0,600	0,700	0,100	0,200	0,300	0,600	0,700	0,800
Licensing	0,400	0,500	0,600	0,400	0,500	0,600	0,500	0,600	0,700	0,400	0,500	0,600
Modularity	0,400	0,500	0,600	0,800	0,900	1,000	0,200	0,300	0,400	0,500	0,600	0,700

After establishing the fuzzy decision matrix, fuzzy decision matrix was normalized using the normalization procedure mentioned in equations 4.10, 4.11, 4.12, 4.13, and 4.14. As mentioned before, the normalization procedure used here protects the property that the ranges of normalized triangular fuzzy numbers belong to [0; 1].

The fuzzy normalized decision matrix of the ten blockchain design characteristics and the enterprise blockchain alternatives Ethereum, Hyperledger, Ripple, Corda can be seen in Table 5.31,

Table 5.31: The fuzzy normalized decision matrix

	Ethereum			Hyperledger			Corda			Ripple		
Permissioned Network	0,500	0,625	0,750	0,750	0,875	1,000	0,750	0,875	1,000	0,750	0,875	1,000
Smart Contract Functionality	0,800	0,900	1,000	0,500	0,400	0,300	0,400	0,300	0,200	0,300	0,400	0,500
Privacy	0,778	0,889	1,000	0,556	0,667	0,778	0,667	0,778	0,889	0,667	0,778	0,889
Security	0,778	0,889	1,000	0,556	0,667	0,778	0,667	0,778	0,889	0,667	0,778	0,889
TPS	0,556	0,667	0,778	0,778	0,889	1,000	0,556	0,667	0,778	0,667	0,778	0,889
Cost	0,500	0,600	0,700	0,800	0,900	1,000	0,600	0,700	0,800	0,500	0,600	0,700
Scalability	0,667	0,778	0,889	0,778	0,889	1,000	0,667	0,778	0,889	0,667	0,778	0,889
Tokenization	0,800	0,900	1,000	0,500	0,600	0,700	0,100	0,200	0,300	0,600	0,700	0,800
Licensing	0,571	0,714	0,857	0,571	0,714	0,857	0,714	0,857	1,000	0,571	0,714	0,857
Modularity	0,400	0,500	0,600	0,800	0,900	1,000	0,200	0,300	0,400	0,500	0,600	0,700

Considering the various significance of the blockchain characteristics, we constructed the weighted normalized fuzzy decision matrix using the final weights. By multiplying the final normalized weights of the design requirements in Table 5.31 and QFD Stage 2 Final HOW weights in Table 5.32, fuzzy weighted normalized decision matrix was constructed as can be seen in Table 5.32,

Table 5.32: The fuzzy weighted normalized decision matrix

	Ethereum			Hyperledger			Corda			Ripple		
Permissioned Network	0,052	0,065	0,078	0,078	0,091	0,104	0,078	0,091	0,104	0,078	0,091	0,104
Smart Contract Functionality	0,107	0,120	0,133	0,067	0,053	0,040	0,053	0,040	0,027	0,040	0,053	0,067
Privacy	0,094	0,107	0,121	0,067	0,081	0,094	0,081	0,094	0,107	0,081	0,094	0,107
Security	0,085	0,097	0,109	0,060	0,072	0,085	0,072	0,085	0,097	0,072	0,085	0,097
TPS	0,065	0,078	0,090	0,090	0,103	0,116	0,065	0,078	0,090	0,078	0,090	0,103
Cost	0,045	0,054	0,063	0,072	0,081	0,090	0,054	0,063	0,072	0,045	0,054	0,063
Scalability	0,069	0,080	0,092	0,080	0,092	0,103	0,069	0,080	0,092	0,069	0,080	0,092
Tokenization	0,092	0,104	0,116	0,058	0,069	0,081	0,012	0,023	0,035	0,069	0,081	0,092
Licensing	0,027	0,033	0,040	0,027	0,033	0,040	0,033	0,040	0,047	0,027	0,033	0,040
Modularity	0,025	0,031	0,037	0,049	0,055	0,061	0,012	0,018	0,025	0,031	0,037	0,043

After calculating both FPIS and FNIS values, we found the distance of each alternative from FPIS and FNIS (using equations 4.15, 4.16, 4.17, and 4.18), respectively, as can be seen in Table 5.33. Then, we reached the closeness coefficient of each alternative.

Table 5.33: The distance measurement

	A^*	A^-
Ethereum	9,232	0,774
Hyperledger	9,269	0,737
Corda	9,389	0,620
Ripple	9,302	0,705

CC values of Ethereum, Hyperledger, Corda and Ripple are 0,0774, 0,0737 0,0619 and 0,0704 respectively. CC values show that the best choice is Ethereum. Seeing the results, differences between different blockchain alternatives considering the requirements of a supply chain become evident. For example, smart contract functionality in Ethereum is important since Ethereum has widespread usage in smart contract applications. In addition, Ethereum has a popular cryptocurrency called 'Ether' (ETH) which highly supports tokenization characteristics. In a blockchain, cryptocurrency support can make transactions easier. However, a cryptocurrency's value can be affected by fluctuations, which may not be preferred in supply chains. For example, Hyperledger Fabric does not have a cryptocurrency and coin market capitalization. Higher TPS can be reached in Hyperledger. Modularity is also a prominent feature of Hyperledger.

Step 8. Scenario Analysis.

It was not easy for the supply chain experts and software stakeholders to determine the effect of complex relationships between the performance metrics or software characteristics on selecting alternative blockchain technology. Using the scenario analysis through Fuzzy Cognitive Map, several hypothetical scenarios can be created considering the different status of concepts. Comparing new and old concept values can explain whether the system advances or reduces their significance through the relations. In order to observe which scenarios evolve, we changed the values of the concepts using the FCMapper, just changing the values for concepts to manage. Concept values should be in the interval between [0; 1]. The value of each concept values can be 1 or 0 according to whether one concept is enhanced or not. For scenarios, we focused on two particular aspects; the impact of SCOR performance metrics' relations and ISO software characteristics' relations to the result. In order to see the effect of differences of one concept could have over the other variables, and to see the changes in the result of the case study, 15 scenarios were created, some of which depend on the specific circumstances of the case company and supply chain. Firstly, the baseline scenario (Scenario 1), which means the no change, is chosen as the initial vector to compare. Scenario 1 represents the result of this study found in step 7, which is called ‘no change.’ Values in the crated scenarios were compared with Scenario 1 in order to make a comparison. The importance levels of supply chain performance metrics, closely related to the company’s strategy, do not change much according to different projects. Scenario 2 represents supply chain performance metrics’ changes that occur with specific projects. However, it does not occur very often. From Scenarios 3 to 10, ISO software characteristics were set to 0 to see their impacts on the result and compare. From scenarios 13 to 15, specific circumstances that occur in their software systems were evaluated. Changed steady-state vectors of each concept value in the 14 scenarios are given in Table 5.35, which are ISO software characteristics’ varying concept values (steady-state concept values of scenario 2 were calculated using SCOR metrics),

Table 5.34: ISO characteristics’ concept values based on different scenarios

	C1	C2	C3	C4	C5	C6	C7	C8
Scenario 2								
Scenario 3	0							
Scenario 4		0						
Scenario 5			0					
Scenario 6				0				
Scenario 7					0			
Scenario 8						0		
Scenario 9							0	
Scenario 10								0
Scenario 11	0	0						
Scenario 12						0	0	
Scenario 13	1	1	0	0				0
Scenario 14				0	0	1	1	0
Scenario 15		1	0		0	1	1	0

Table 5.35: Steady-state concept values of the ISO characteristics in 15 scenarios

	1	3	4	5	6	7	8	9	10	11	12	13	14	15
C1	0,750	0,000	0,561	0,758	0,767	0,751	0,780	0,776	0,776	0,000	0,802	1,000	0,780	0,810
C2	0,733	0,532	0,000	0,743	0,751	0,734	0,780	0,760	0,762	0,000	0,802	1,000	0,762	1,000
C3	0,760	0,762	0,762	0,000	0,718	0,759	0,759	0,759	0,711	0,764	0,757	0,000	0,659	0,000
C4	0,586	0,617	0,618	0,587	0,000	0,568	0,585	0,586	0,630	0,635	0,585	0,000	0,000	0,604
C5	0,568	0,594	0,659	0,567	0,566	0,000	0,562	0,565	0,565	0,659	0,559	0,533	0,000	0,000

C6	0,889	0,899	0,899	0,779	0,884	0,889	0,000	0,886	0,780	0,904	0,000	0,598	1,000	1,000
C7	0,889	0,899	0,899	0,779	0,884	0,889	0,886	0,000	0,780	0,904	0,000	0,598	1,000	1,000
C8	0,727	0,728	0,728	0,702	0,726	0,727	0,705	0,705	0,000	0,728	0,681	0,000	0,000	0,000

Table 5.36: QFD Stage 1 weights of ISO characteristics

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
Scenario 1	0,146	0,130	0,096	0,116	0,087	0,137	0,128	0,160
Scenario 2	0,188	0,207	0,051	0,024	0,075	0,185	0,228	0,042
Scenario 3	0,000	0,114	0,116	0,147	0,110	0,167	0,155	0,192
Scenario 4	0,127	0,000	0,113	0,143	0,118	0,162	0,151	0,186
Scenario 5	0,169	0,152	0,000	0,134	0,100	0,139	0,129	0,177
Scenario 6	0,169	0,151	0,103	0,000	0,098	0,155	0,144	0,180
Scenario 7	0,160	0,143	0,106	0,123	0,000	0,151	0,141	0,175
Scenario 8	0,174	0,159	0,111	0,133	0,099	0,000	0,146	0,178
Scenario 9	0,172	0,154	0,110	0,132	0,099	0,156	0,000	0,176
Scenario 10	0,184	0,165	0,110	0,152	0,106	0,147	0,137	0,000
Scenario 11	0,000	0,000	0,129	0,167	0,134	0,185	0,173	0,212
Scenario 12	0,209	0,191	0,129	0,155	0,115	0,000	0,000	0,200
Scenario 13	0,307	0,281	0,000	0,000	0,130	0,146	0,136	0,000
Scenario 14	0,227	0,202	0,125	0,000	0,000	0,231	0,215	0,000
Scenario 15	0,209	0,236	0,000	0,159	0,000	0,205	0,191	0,000

Table 5.37: QFD Stage 2 weights of blockchain characteristics

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Scenario 1	0,104	0,133	0,121	0,109	0,116	0,090	0,103	0,116	0,047	0,061
Scenario 2	0,115	0,122	0,101	0,088	0,134	0,102	0,117	0,094	0,055	0,074
Scenario 3	0,107	0,138	0,129	0,116	0,108	0,080	0,101	0,121	0,033	0,066
Scenario 4	0,098	0,134	0,133	0,120	0,103	0,086	0,098	0,119	0,043	0,065
Scenario 5	0,109	0,131	0,115	0,103	0,118	0,091	0,104	0,115	0,050	0,064
Scenario 6	0,108	0,134	0,110	0,099	0,121	0,093	0,107	0,109	0,051	0,068
Scenario 7	0,104	0,133	0,115	0,103	0,118	0,092	0,105	0,119	0,048	0,064
Scenario 8	0,104	0,138	0,122	0,109	0,118	0,091	0,104	0,120	0,049	0,046
Scenario 9	0,097	0,136	0,126	0,116	0,115	0,089	0,096	0,121	0,049	0,055
Scenario 10	0,102	0,124	0,122	0,110	0,126	0,098	0,108	0,102	0,051	0,057
Scenario 11	0,102	0,138	0,139	0,125	0,098	0,077	0,096	0,124	0,031	0,069
Scenario 12	0,096	0,142	0,128	0,118	0,116	0,089	0,096	0,127	0,051	0,035
Scenario 13	0,113	0,119	0,095	0,084	0,144	0,110	0,117	0,087	0,068	0,064
Scenario 14	0,109	0,119	0,099	0,086	0,138	0,106	0,118	0,091	0,058	0,076
Scenario 15	0,112	0,117	0,102	0,090	0,137	0,103	0,116	0,098	0,055	0,070

Table 5.38: CC values of the alternatives

	ETH	**HYP**	**COR**	**RIPP**
Scenario 1	0,077	0,074	0,062	0,070
Scenario 2	0,076	0,076	0,063	0,706
Scenario 3	0,078	0,073	0,061	0,070

Scenario 4	0,078	0,073	0,062	0,070
Scenario 5	0,077	0,074	0,062	0,070
Scenario 6	0,077	0,074	0,062	0,070
Scenario 7	0,077	0,074	0,062	0,070
Scenario 8	0,078	0,073	0,062	0,070
Scenario 9	0,078	0,073	0,062	0,070
Scenario 10	0,077	0,074	0,063	0,071
Scenario 11	0,078	0,073	0,061	0,070
Scenario 12	0,079	0,072	0,062	0,070
Scenario 13	0,075	0,076	0,064	0,071
Scenario 14	0,075	0,076	0,063	0,071
Scenario 15	0,076	0,076	0,063	0,071

Scenario 2.

In the case company, although not very often, some projects necessitate specific certification of suppliers. This situation necessitates time for the supplier selection process. Procurement staff spends much more time for a qualified supplier selection and negotiation and identifying related sources. Using the exact relationships between SCOR Level 3 performance metrics and aggregated crisp values of the decision makers' evaluation in Table 5.2, Scenario 2 was created. This time, problematic metrics were CO.3.006 Sourcing automation cost, RS.3.35 Identify sources of supply cycle time, RL.3.17 Percent of suppliers with an EMS or ISO 14001 certification, RS.3.125 Select supplier and negotiate cycle time, RS.3.113 receiving product cycle time and RS.3.140 Verify product cycle time. Thus, it was ensured that the metrics whose threshold value is not above 0.5 are also included in the process with the help of a Fuzzy Cognitive Map. In the FCMapper scenario creation screen, all the other metrics other than these six metrics were set to 0. After the scenario creation using FCMapper, changes were reflected on the customer requirements part of the SCOR metrics in QFD Stage 1 to see the differences in the result. Seeing the scenario 2 results in QFD Stage 1, especially the weight of time behaviour was highly increased, as shown in Table 5.36. Regarding QFD Stage 2 results, the weights of permissioned network, TPS, cost, scalability, licensing, and modularity were increased. At the same time, the other concepts were decreased, as can be seen in Table 5.37. CC values show that the best choice is Hyperledger, as can be seen in Table 5.38.

Scenario 3.

The impact of increasing or decreasing a software characteristic can be investigated by setting concept values from 1 to 0. Firstly, the effect of decreasing the resource utilization improvements (sub-characteristic of performance efficiency) on all other ISO software characteristics can be tested by only setting its value to 0 in the FCMapper scenario screen. As can be seen in Table 5.35, steady-state concept values were impacted by this change. Decreased resource utilization decreases time behavior (performance efficiency sub-characteristic). However, decreased resource utilization causes improvements in fault tolerance, confidentiality, compliance, modularity, modifiability, and functional completeness characteristics. Seeing the scenario 3 results in QFD Stage 1, especially the weight of time behaviour was highly increased, as shown in Table 5.36.

Regarding QFD Stage 2 results, the weights of permissioned network, smart contract functionality, privacy, security, tokenization, and modularity were increased. At the same time, the other concepts were decreased, as can be seen in Table 5.37. CC values show that the best choice is Ethereum, as can be seen in Table 5.38.

Scenario 4.

The impact of decreasing the time behavior improvements (sub-characteristic of performance efficiency) on all other ISO software characteristics can be tested by only setting its value to 0 in the FCMapper scenario evaluation screen. Steady-state concept values were changed, as can be seen in Table 5.35. Decreased time behavior decreases resource utilization as well. However, decreased time behavior causes improvements in fault tolerance, confidentiality, compliance, modularity, modifiability, and functional completeness characteristics. Regarding QFD Stage 2 results, the weights of smart contract functionality, privacy, security, tokenization, and modularity were increased, while the other concepts were decreased, as shown in Table 5.37. In this scenario, CC values show that the best choice is Ethereum, as shown in Table 5.38.

Scenario 5.

The impact of decreasing the fault tolerance improvements (sub-characteristic of reliability) on all other ISO software characteristics was tested by only setting its value to 0. The steady-state values can be seen in Table 5.35. For fault tolerance, failure avoidance was problematic (percentage of fault patterns under examination to prevent critical failures). Decreased fault tolerance also decreases compliance, modularity, modifiability, and functional completeness. Regarding QFD Stage 2 results, the weights of permissioned network, TPS, cost, scalability, licensing, and modularity were increased, while the other concepts were decreased, as shown in Table 5.37. CC values show that the best choice is Ethereum, as can be seen in Table 5.38.

Scenario 6.

The impact of decreasing the confidentiality improvements (sub-characteristic of security) on all other ISO software characteristics was tested by only setting its value to 0 in the FCMapper scenario screen. For confidentiality, access controllability was especially important for their software system. Decreased confidentiality decreases fault tolerance, compliance, and functional completeness as well. However, decreased confidentiality increases resource utilization, time behavior, modularity, and modifiability. Regarding QFD Stage 2 results, the weights of permissioned network, smart contract functionality, TPS, cost, scalability, licensing, and modularity were increased. At the same time, the other concepts were decreased, as can be seen in Table 5.37. CC values show that the best choice is Ethereum, as can be seen in Table 5.38.

Scenario 7.

The impact of decreasing the compliance improvements on all other ISO software characteristics can be tested by only setting its value to 0 in the FCMapper scenario screen. For compliance, regulatory compliance due to technology was especially significant. Decreased compliance also decreases confidentiality and fault tolerance, while it increases performance efficiency. Regarding QFD Stage 2 results, the weights of permissioned network, TPS, cost, scalability, tokenization, licensing, and modularity were increased. At the same time, the other concepts were decreased, as can be seen in Table 5.37. CC values show that the best choice is Ethereum, as can be seen in Table 5.38.

Scenario 8.

The effect of decreasing the modularity improvements on all other ISO software characteristics was tested by only setting its value to 0 in the FCMapper scenario screen. For modularity, the ratio of completely independent components was problematic in their software systems. As the modularity decreases, fault tolerance, confidentiality compliance, modifiability, and functional completeness improvements decrease. However, decreased modularity increases resource utilization and time behavior. Regarding QFD Stage 2 results, the weights of permissioned network, smart contract functionality, privacy, security, TPS, cost, scalability, tokenization, licensing were increased. At the same time, the other concept was decreased, as can be seen in Table 5.37. For this scenario, CC values show that the best choice is Ethereum, as shown in Table 5.38.

Scenario 9.

The impact of decreasing the modifiability improvements on all other ISO software characteristics was tested by only setting its value to 0 in the FCMapper scenario screen. There were a high proportion of modifications that caused quality degradation in their systems. As the modifiability decreases, fault tolerance, compliance, modularity, and functional completeness decrease as well. However, decreased modifiability increases resource utilization and time behavior. Regarding QFD Stage 2 results, the weights of smart contract functionality, privacy, security, tokenization, and licensing were increased, while the other concepts were decreased, as shown in Table 5.37. CC values show that the best choice is Ethereum, as can be seen in Table 5.38.

Scenario 10.

The effect of decreasing the functional completeness improvements on all other ISO software characteristics was tested by only setting its value to 0 in the FCMapper scenario screen. For functional completeness, there was a high number of missing or incorrect functions. Decreased functional completeness increases resource utilization, time behavior, and confidentiality. However, as the functional completeness decreases, fault tolerance, compliance, modularity, and modifiability decrease. Regarding QFD Stage 2 results, the weights of privacy, security, TPS, cost, scalability, and licensing were increased, while the other concepts were decreased, as shown in Table 5.37. CC values show that the best choice is Ethereum, as can be seen in Table 5.38.

Scenario 11.

Scenario 11 deactivates the software sub-characteristics related to performance efficiency. Decreased performance efficiency increases fault tolerance, confidentiality, compliance, modularity, modifiability, and functional completeness. Regarding QFD Stage 2 results, the weights of smart contract functionality, privacy, security, tokenization, and modularity were increased, while the other concepts were decreased, as shown in Table 5.37. Even though both concepts of performance efficiency were decreased, CC values show that the best choice is Ethereum, as shown in Table 5.38.

Scenario 12.

Scenario 12 deactivates the software sub-characteristics related to maintainability (modularity and modifiability). Decreased maintainability decreases fault tolerance, confidentiality, compliance, and functional completeness; however, resource utilization and time behavior increase as the maintainability improvements decrease.

Regarding QFD Stage 2 results, the weights of smart contract functionality, privacy, security, TPS, tokenization, and licensing were increased, while the other concepts were decreased, as shown in Table 5.37. However, although both maintainability concepts were decreased, CC values show that the best choice is Ethereum, as shown in Table 5.38.

Scenario 13.

For some construction projects that require high workloads, their software systems' performance efficiency becomes more critical. In these projects, the case supply chain faces significant uncertainties in confidentiality, fault tolerance, and functional completeness-related metrics since there is no data about these metrics. Hence, scenario 13 deactivates the fault tolerance, confidentiality, and functional completeness, Performance efficiency concepts' values were enhanced and set to 1 in the FCMapper scenario screen. Regarding QFD Stage 2 results, the weights of permissioned network, TPS, cost, scalability, licensing, and modularity were increased, while the other concepts were decreased, as shown in Table 5.37. These changes decreased compliance, modularity, and modifiability characteristics' values and CC values show that the best choice is Hyperledger, as shown in Table 5.38.

Scenario 14.

In some situations, modularity in their software systems becomes more critical when more updates and modifications are in their systems. In these situations, there can be no information about confidentiality and functional coverage topics. Hence, scenario 14 deactivates confidentiality, compliance, and functional completeness. In addition, modularity and modifiability values were enhanced and set to 1 in the FCMapper scenario screen. These changes decreased fault tolerance and increased resource utilization and time behavior.

Regarding QFD Stage 2 results, the weights of permissioned network, TPS, cost, scalability, licensing, and modularity were increased, while the other's concepts were decreased, as shown in Table 5.37. Then, a new result was reached for the blockchain alternative selection. For this scenario, CC values show that the best choice is Hyperledger, as shown in Table 5.38.

Scenario 15.

Some construction projects necessitate so much time to spend on their software systems. Moreover, in these projects, modifiability becomes more critical since more updates and modifications are needed. Hence, scenario 15 deactivates the fault tolerance, compliance, and functional completeness. However, time behavior, modularity, and modifiability were enhanced and set to 1 in the FCMapper scenario screen. These changes increased resource utilization and confidentiality.

Regarding QFD Stage 2 results, the weights of permissioned network, TPS, cost, scalability, licensing, and modularity were increased, while the other concept was decreased, as shown in Table 5.37. Then, a new result was reached for the blockchain alternative selection. CC values show that the best choice is Hyperledger, as can be seen in Table 5.38. The scenario analysis enabled us to show different results if different supply chain metrics and software characteristics were at the forefront. Specifically, selected blockchain alternatives were Ethereum or Hyperledger because of the characteristics such as time, cost, functionality, modularity. On the other hand, although Corda and Ripple are among the Enterprise alternatives, they were not selected.

TCO Analysis of Blockchain

After the scenario analysis, we focused on blockchain features that are more technical to determine the total cost of ownership of the blockchain solutions. Primarily Ethereum was at the forefront in the ranking in 15 possible scenarios. In the case supply chain, cost emerged as an essential criterion in both SCOR performance metrics and software characteristics. We mainly focused on public blockchain total cost of ownership estimations as Etherum is a public blockchain.

Costs of both public and private solutions are influenced mainly by transaction volume, transaction size, node hosting method, and the consensus protocol (Broady et al., 2019). Node hosting methods are on-premises (new systems), on-premises (existing technology), and cloud-based methods (Broady et al., 2019). Moreover, each consensus protocol offers various levels of decentralization, security, and hardware requirements, which depend on specific situations and the aims of a company (Broady et al., 2019).

In this study, blockchain cost drivers cost assumptions and calculations were taken from a blockchain TCO study by Broady et al. (2019). The authors separated costs into four main categories: onboarding costs, cloud costs, ongoing maintenance costs, and monitoring costs. They assumed that a company necessitates a full-time employee to support blockchain for ongoing maintenance costs. Their monitoring cost assumptions are based on quality reviews and annual network evaluations. They also assumed that these costs are decreasing over time per the experience curve.

Moreover, they also made assumptions considering the estimated effects of transaction size and consensus protocol. The authors obtained deployment costs by multiplying hardware costs per new node and the number of full nodes. For initial education cost, they summed two multiplications: multiplication of full nodes and training hours per full node user and multiplication of end-users and training hours per end user. Then, they multiplied the result by the hourly instructor cost; initial education cost was obtained. For documentation cost, they summed full nodes and end-users; and they multiplied the result by the documentation costs per user. The authors calculated cloud Virtual Machine (VM) cost by multiplying the number of full nodes, cloud VM per full node, and annual cloud VM cost. They obtained cloud storage costs by multiplying storage capacity costs per 100 GB and transaction storage per 100.000 transactions. They calculated hardware administration by multiplying full nodes, hardware costs per new node, and annual hardware administration percent of the initial cost. They obtained transaction review costs by using the costs per 100.000 transactions. Blockchain TCO underlying assumptions can be seen in Table 5.39,

Table 5.39: Blockchain TCO underlying assumptions (Broady et al., 2019)

Assumptions - Base Cases			
Cost Drivers	On-Premise: Existing Technology	On-Premise: New Systems	Cloud-Based
Onboarding costs:			
Full nodes	10	10	10
End users	250	250	250
Hardware costs per new node	$0	$1.000	$0
Training hours per full node user	16	16	16
Training hours per end user	4	4	4
Hourly instructor cost	$82	$82	$82
Documentation costs per user	$10	$10	$10
Cloud costs:			
Cloud VM per full node	N/A	N/A	1,00
Annual cloud VM cost	N/A	N/A	$2.000
Storage capacity costs per 100GB	N/A	N/A	$2,40
Transaction storage per 100,000 transactions	N/A	N/A	$0,004
On-going maintenance costs:			
Blockchain technical support FTE	$98.000	$98.000	$98.000
Annual hardware admin % of initial cost	N/A	20%	N/A
Average lifespan of hardware (years)	N/A	3	N/A
On-going education costs per user	$164	$164	$164
Annual user turnover (education)	19%	19%	19%
Monitoring costs:			
Costs per 100,000 transactions	$15	$15	$15
Network assessment	$1.495	$1.495	$1.495
Direct variable transaction costs:			
Current ZKP variable costs	$5,0000	$5,0000	$5,0000
Future (next gen.) ZKP variable costs	$0,4167	$0,4167	$0,4167

In this study, our first cost assumptions were made using the calculations created by (Broady et al., 2019). For our first assumptions, daily transaction volume was determined as 1000, transaction size was considered large-500 bytes, node hosting method was assumed as cloud-based, and consensus protocol was considered proof-of-authority. The authors also estimated the effects of transaction size and consensus mechanism on cost drivers, which enabled us to compare. Estimated effects of transaction size and consensus protocol can be seen in Table 5.40,

Table 5.40: Effects of transaction size and the consensus protocol (Broady et al., 2019)

	Transaction Size - Estimated Impact			Consensus Protocol- Estimated Impact			
Cost Drivers	Small - 150 bytes	Large - 500 bytes	Medium - 250 bytes	Proof of Work	Proof of Stake	Byzantine Fault Tolerance	Proof of Authority
Onboarding costs:							
Full nodes	+- 0%	+- 0%	**+- 0%**	+ 100%	+ 20%	**+- 0%**	**+- 0%**
End users	+- 0%	+- 0%	**+- 0%**	+- 0%	+- 0%	**+- 0%**	**+- 0%**
Hardware costs per new node	- 15%	+ 30%	**+- 0%**	+ 50%	+ 10%	**+- 0%**	**+- 0%**
Training hours per full node user	- 5%	+ 5%	**+- 0%**	+ 10%	+ 5%	**+- 0%**	**+- 0%**
Training hours per end user	+- 0%	+- 0%	**+- 0%**	+- 0%	+- 0%	**+- 0%**	**+- 0%**
Hourly instructor cost	+- 0%	+- 0%	**+- 0%**	+- 0%	+- 0%	**+- 0%**	**+- 0%**
Documentation costs per user	+- 0%	+- 0%	**+- 0%**	+ 10%	+ 5%	**+- 0%**	**+- 0%**
Cloud costs:							
Cloud VM per full node	+- 0%	+- 0%	**+- 0%**	+- 0%	+- 0%	**+- 0%**	**+- 0%**
Annual cloud VM cost	- 5%	+ 10%	**+- 0%**	+ 15%	+ 10%	**+- 0%**	**+- 0%**
Storage capacity costs per 100GB	+- 0%	+- 0%	**+- 0%**	+- 0%	+- 0%	**+- 0%**	**+- 0%**
Transaction storage per 100,000 transactions	- 15%	+ 20%	**+- 0%**	+ 10%	+ 5%	**+- 0%**	**+- 0%**
On-going maintenance costs:							
Blockchain technical support employee	+- 0%	+- 0%	**+- 0%**	+- 0%	+- 0%	**+- 0%**	**+- 0%**
Annual hardware admin. % of initial cost	+- 0%	+- 0%	**+- 0%**	+ 15%	+ 10%	**+- 0%**	**+- 0%**
Average lifespan of hardware (years)	+- 0%	+- 0%	**+- 0%**	+- 0%	+- 0%	**+- 0%**	**+- 0%**
On-going education costs per user	+- 0%	+- 0%	**+- 0%**	+- 0%	+- 0%	**+- 0%**	**+- 0%**

Annual user turnover (education)	+- 0%	+- 0%	**+- 0BPS**	+- 0BPS	+- 0BPS	**+- 0BPS**	**+- 0BPS**
Monitoring costs:							
Costs per 100,000 transactions	- 10%	+ 20%	**+- 0%**	+ 10%	+ 5%	**+- 0%**	**+- 0%**
Network assessment	- 5%	+ 10%	**+- 0%**	+ 15%	+ 5%	**+- 0%**	**+- 0%**
Direct variable transaction costs:							
Current ZKP variable costs	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Future (next-gen.) ZKP variable costs	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Considering the assumptions and effects of the technology experience curve, year of year cost estimation of the blockchain (ZKP) can be seen in Table 5.41,

Table 5.41: Blockchain (ZKP) TCO model (Broady et al., 2019)

	Year 1	Year 2	Year 3	Year 4	Year 5
Onboarding Costs					
Initial Platform Build	$50.000				
Deployment	$0	$0	$0	$0	$0
Initial Education	$3.280	$150	$142	$135	$128
Documentation	$100	$5	$5	$5	$5
Cloud Costs					
Cloud VM	$8.799	$8.359	$7.941	$7.544	$7.167
Cloud Storage	$0	$0	$0	$0	$0
On-Going Maintenance Costs					
Technical Support/System Administration	$0	$0	$0	$0	$0
Hardware Administration	$0	$0	$0	$0	$0
On-going Education	$1.640	$1.636	$1.632	$1.628	$1.624
Monitoring Costs					
Transaction Review	$66	$62			
Network Assessment	$1.645	$1.645	$1.645	$1.645	$1.645

For variable costs, Broady et al. (2019) assumed the average ZKP transaction gas limit as 2.500.000, and they assumed long-run price of ether as $100. Then, they determined the variable cost per transaction as $5. They calculated variable costs by multiplying $5 with the daily transaction volume. The authors also made similar total cost calculations for the future state-third generation ZKPs. Public Blockchain (ZKP) cost forecasting-current state can be seen in Table 5.42,

Table 5.42: Public Blokchcain (ZKP) Cost Forecasting (Broady et al., 2019)

	Year 1	Year 2	Year 3	Year 4	Year 5
Initial Platform Build	$50.000				
Onboarding Costs	$3.380	$155	$147	$140	$133
Cloud Costs	$8.799	$8.359	$7.941	$7.544	$7.167
On-Going Maintenance Costs	$1.640	$1.636	$1.632	$1.628	$1.624
Monitoring Costs	$1.710	$1.707	$1.645	$1.645	$1.645
Variable Costs	$1.825.000	$1.825.000	$1.825.000	$1.825.000	$1.825.000
Total Costs	$1.890.529	$1.836.857	$1.836.364	$1.835.956	$1.835.568

In the supply chain, very different problems are encountered in their software systems, especially at higher transaction sizes. Hence, we examined costs that may arise when the daily average transaction volume reaches 5000 transactions without changing node hosting methods, transaction size, or consensus mechanism.

Public blockchain (ZKP) cost forecasting-current state for daily 5000 transactions can be seen in Table 5.43,

Table 5.43: Public Blokchcain (ZKP) Cost Forecasting (5000 transactions daily)

	Year 1	Year 2	Year 3	Year 4	Year 5
Initial Platform Build	$50.000				
Onboarding Costs	$3.380	$155	$147	$140	$133
Cloud Costs	$8.799	$8.359	$7.941	$7.544	$7.167
On-Going Maintenance Costs	$1.640	$1.636	$1.632	$1.628	$1.624
Monitoring Costs	$1.973	$1.957	$1.645	$1.645	$1.645
Variable Costs	$9.125.000	$9.125.000	$9.125.000	$9.125.000	$9.125.000
Total Costs	$9.190.792	$9.137.106	$9.136.364	$9.135.956	$9.135.568

As can be seen from Table 5.42 and Table 5.43, monitoring costs and variable costs highly increased when the daily average transaction volume reached 5000 transactions. The daily transaction volume significantly influenced the total costs of the public blockchain (ZKP-current), as public blockchains are highly sensitive to variable costs (Broady et al., 2019). When the cost estimations made by the authors considered, it was seen that private blockchains were highly affected by transaction size, node hosting, or consensus changes. It was discovered that the total private blockchain costs are highly increased when a proof-of-work consensus mechanism was used.

Considering the estimated public blockchain costs, the initial platform build and variable costs seem pretty high. However, if the software systems of the case supply chain maintain their current state, it can create more losses in the long run. Blockchain costs are one-time costs, and they will be more advantageous in the long run. According to the supply chain stakeholders, inspecting blockchain costs in 5 years gave concrete ideas to compare performance improvements. Due to the company's privacy policy, more detailed information on costs could not be reached.

6. CONCLUSION

Supply chains have to innovate their business processes in order to survive in the highly competitive world. Blockchain, which has come to the forefront only as a currency, attracts the attention of supply chains outside the field of finance. Blockchain has been a subject of curiosity by many people with its particular features as a brand new technology. However, there are not many studies on the description of its complex structure by simplifying it. There is not even a common consensus or framework on the essential architectural characteristics of Blockchain. In literature, blockchain technology studies in supply chains are either too supply chain-specific or too technical in software topics. Supply chain and software topics should be systematically linked to each other for the selection of a suitable blockchain technology. This study enabled us to involve both supply chain operations and the software design characteristics in the blockchain technology selection process using QFD. Evaluation of a software system from a broader perspective is an important issue. However, to the best of our knowledge, no study evaluates the software characteristics and their relationships from ISO/IEC 25010 and ISO/IEC 25012 standards using Fuzzy Cognitive Map. Moreover, there is no study on enterprise blockchain selection, especially inspecting the trade-offs between blockchain characteristics. This study aims to support the blockchain technology selection decision of a supply chain, primarily focusing on the purchasing process and considering the needs of the stakeholders. To the best of our knowledge, there is no QFD-Cognitive Map-TOPSIS integrated study on enterprise blockchain selection, specifically inspecting the trade-offs between blockchain characteristics. A case study application was carried out in order to validate how effective the proposed blockchain technology selection approach. In the case supply chain, cost is a significant criterion in both SCOR performance metrics and software characteristics. We also inspected the total costs of blockchain, which gave concrete ideas to compare performance improvements. We especially focused on public blockchain total cost of ownership estimations.

The results of this study have value to both the academic and industrial practice as they provide a systematic approach for blockchain technology selection decision. Businesses and supply chains that are weak in terms of performance measurement and management fail to achieve their goals in their business processes, which is among the topic of our case supply chain. Because of huge complications in customer-specific engineer-to-order projects, it is difficult to find project-based performance metrics and focus on the most problematic ones. Procurement stakeholders tend to evaluate performance metrics individually, and they cannot simultaneously analyse all the problematic metrics. In this study, SCOR modelling and BPMN language enabled us to analyse the case supply chain in a standardized way, using standardized process and metric descriptions both for as-is and to-be processes of the supply chain. In addition, we used Fuzzy Cognitive Maps to focus on important SCOR metrics since there are trade-offs between SCOR performance metrics. It is highly significant to determine the complex relationships between performance criteria, considering their contribution to the result. However, stakeholders in the case supply chain cannot easily predict the changes which are caused by complex relationships between performance metrics.

ISO standard quality characteristics were chosen to understand problematic quality characteristics that the supply chain should focus on. These common characteristics also made the blockchain more understandable. As a pioneering method in realizing quality, QFD was used to reflect the requirements of different functionalities in the blockchain design process, thanks to its cross-functional focus. From performance improvements to technology architectural design, all two stages of QFD enabled us to reflect customer requirements into the blockchain technology selection. In QFD stage 1, we used SCOR metrics as customer requirements to understand correlations between the SCOR metrics and the ISO software characteristics. QFD Stage 2 enabled us to find the final weights of blockchain characteristics with the help of the software characteristics' weights found in QFD Stage 1. ISO standard quality characteristics were also benefited to understand which standardized quality characteristics can be met with which blockchain features in QFD stage 2.

In this study, positive and negative relationships between the metrics, conflicting criteria, and lack of crisp data led us to apply Fuzzy Cognitive Map. Determination and evaluation of supply chain performance metrics using the SCOR model and scenario-based Fuzzy Cognitive Map enabled company stakeholders to have shared performance metrics and direction for change. FCM is an advantageous technique, especially for complex and dynamic systems. Cognitive Maps were considered best for evaluations since different stakeholders had different opinions about criteria because of stakeholders' cognitive limitations. FCM enabled stakeholders to obtain system behaviour using only matrix operations easily. FCMapper software solution was utilized to perform FCM calculations. Different scenarios create a series of promising futures, not just one predicted future. Different stakeholders (software and procurement stakeholders) benefited various scenarios to see their responsibilities and to take suitable actions. Scenario analysis has become a necessary step to verify the feasibility and reliability of a model or a method. In this study, the ranking between Corda and Ripple does not change in most of the scenarios. Hence, scenario analysis shows that the ranking between Corda and Ripple is robust to changes in importance levels. On the other hand, it can be said that the rankings between Ethereum and Hyperledger are sensitive to important changes in the weights of certain criteria.

When evaluating the architectural characteristics of a technology design, the trade-offs that may arise should be carefully examined. Blockchain is a brand new technology, and it has highly complex characteristics because of its architectural, legal (immutability; GDPR, KVKK, etc.), and financial (cryptocurrencies) structure. The summarized blockchain characteristics for selecting enterprise blockchain alternatives are pretty comprehensive, and additional criteria can be included or excluded from the selection process. Without clearly evaluating the positive and negative relationships between blockchain characteristics, the selection of enterprise blockchain alternatives cannot be efficient. In this study, using the Fuzzy Cognitive Maps, trade-offs between blockchain design requirements were evaluated. We also proposed a framework to select an appropriate blockchain alternative using Fuzzy TOPSIS and the reviewed main architectural characteristics of blockchain technology, reflecting all evaluation results into the selection process. This selection may help to re-organize or re-design the business processes of the supply chain to make them perform better**.** Supply chain experts and software stakeholders should carefully evaluate complex relationships between performance metrics and characteristics as the alternative blockchain technology selection process could be highly impacted. The impact of an increase or a decrease in particular characteristics or metrics is determined using scenario analyses.

Scenario analyses enabled us to discover new concept values that vary when a concept's significance degree is changed. We also revealed specific blockchain characteristics that satisfy specific standard ISO characteristics. For example, functional completeness sub-characteristic of ISO standard overlaps with smart contract functionality as it represents functionality. Moreover, the modifiability sub-characteristic of ISO has the potential to represent blockchain scalability. Modularity is already mentioned frequently in both blockchain and ISO characteristics.

We also evaluated our approach using eight quality attributes: Reusability, Scalability, Understandability, Usability, Completeness, Cost, Accuracy, Accountability (Wohlin et al., (2003), Moaven & Habibi (2020)). Our approach is highly reusable for metric and software characteristics determination and selection since we used a scenario-based Fuzzy Cognitive Map. In a scenario-based approach, the scenario planner can manage the evaluation process to be reusable. QFD can be used to evaluate the existing software architectures and also to design new architectures. Metric determination in supply chains can be done using the steps we followed at the beginning of the application with the help of SCOR. Since ISO software characteristics enable evaluating any software architecture using a standardized language and a wide range of characteristics, software problems can be easily discovered using ISO characteristics. After the determination of software problems, QFD can provide identification of any suitable software design characteristics for the problematic software characteristics. Thus, our study might be useful to build causal model of supply chain performance metrics or software characteristics.

Our approach for the blockchain alternative selection is understandable and usable since it is step-by-step from metric selection to blockchain alternative selection. Moreover, it includes widespread methods like QFD and Cognitive Map that are easy-to-calculate. It also uses a bottom-to-top approach in strategy-related metric determination and selection, which is quite understandable. Our approach satisfies completeness since it can evaluate and select different blockchain alternatives other than enterprise blockchains. In addition, definitive judgments can be offered using Fuzzy Cognitive Map-based scenario analysis, not depending entirely on a sole evaluator. Besides, ISO characteristics, SCOR, and the reviewed blockchain characteristics can offer various topics. Our approach is not that costly considering the scenario analysis and its related calculations as there is no need to calculate all the problems from the beginning. Besides, the methods used in this study are not extremely difficult to learn and apply. For accuracy evaluation, our approach progresses step-by-step so that any mistakes can be identified and solved easily. However, since we used fuzzy numbers in this study, accuracy was not achieved ultimately. Moreover, uncertainties in the metrics based on risk also decreased accuracy in the final results.

Limitations and Future Work

Ayyildiz and Gumus (2021) added new metrics to SCOR to adapt to the Industry 4.0 environment. Therefore, although we used a conventional version of the SCOR model in this study, the adapted version of the SCOR model (for Industry 4.0) will benefit in the future to satisfy attributes like digital technology and information systems. Moreover, BSC can be preferred to SCOR model in cases where financial metrics are taken into account or customer performance measurement systems should be used (Maestrini et al., 2017).

In this study, we inspected KPIs considering the overall projects of the case company, although it is recommended to update and change KPIs as the business atmosphere changes dynamically. We evaluated performance metrics, basically focusing on the metrics' understandability, measurability, and unambiguity. However, performance metrics can be evaluated in detail and a broader perspective using the criteria such as specificity, measurability, relevancy, verifiability, unambiguity, and comparability. Moreover, an MCDM method can be used to weigh these criteria to select appropriate performance metrics. Blockchain is a brand new technology, and it has highly complex characteristics because of its architectural, legal (immutability; GDPR, KVKK, etc.), and financial (cryptocurrencies) structure. In the future, the result of the blockchain alternative selection can be outdated as the blockchain technology advances. However, as changes occur in the structure of blockchain or different areas such as GDPR and KVKK regulations, there will be different trade-offs that need to be examined.

Quality models enable quality characteristics concerned to different stakeholders, such as system integrators, acquirers, software developers, owners, maintainers, contractors, quality assurance and control professionals, and users. For example, in our case study, software stakeholders from the case supply chain were software developers who know software product quality, data product quality, and quality in use. However, every type of stakeholder, from software developers to users, should be represented in reviewing and considering the suitability of the quality characteristics in each model before finishing the quality characteristics that will be utilized in the system.

Specific company and supply chain situations were considered when creating the scenarios, although they often do not occur. However, all possible combinations can be tried by making each metric passive (equalizing the concept value to zero) or increasing its effects (equalizing the concept value to one). Thus, the changes that may occur in the result can be observed in detail. Although we chose the average value as a threshold value to evaluate essential metrics and characteristics in the Fuzzy Cognitive Map, different threshold values such as 0,25 and 0,75 can also be evaluated to make comparisons. But, the number of scenarios may increase in this case. A scenario-based Fuzzy Cognitive Map can already include different metrics and characteristics in evaluations outside a specific threshold value. In this study, we used many metrics and characteristics both to demonstrate that a wide variety of criteria can be included in the methods we used, and to demonstrate the relationships between them. We used threshold values to draw attention to the important ones. However, if working with fewer metrics and characteristics, a threshold may not be needed. Moreover, to evaluate and select from the determined scenarios in Fuzzy Cognitive Map, specific evaluation criteria such as occurrence probability, usability, influence, etc. can be considered. Fuzzy ANP and DEMATEL methodologies can also be used instead of Fuzzy Cognitive Map in order to determine interrelations when there are only positive relationships between metrics or characteristics.

In this study, the focus of the evaluation process was primarily on procurement. For further research, we plan to include different processes other than procurement into our evaluations. Moreover, supply chain metrics of different companies in the case supply chain will be included in our evaluations. In addition, we plan to use a suitable enterprise architecture framework to evaluate blockchain technology architectures more systematically. In our study, there is uncertainty because of the subjectivity in human judgments. The increase or decrease in the calculated SCOR performance metrics was determined by subjective judgments. In our future study, the degree of increase or decrease of the metrics from their target values will be examined in detail. Our future work will use data-driven modelling of the performance metrics focusing on more accurate tools to find problematic metrics. In order to make sure about the validation of the proposed approach, a survey with industrial experts is in progress using different methods.

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BIOGRAPHICAL SKETCH

Ayça Maden received a B.S. degree in Industrial Engineering from Kocaeli University as a second-ranking graduate. In 2015, she obtained an M.S. degree in Industrial Engineering from Galatasaray University. She has been working as a research assistant in the Management Engineering Department at Beykent University since 2016. Her areas of interest include quality function deployment and multi-criteria decision-making. Her selected publications are as follows:

Maden, A., & Alptekin, E. (2020). Evaluation of factors affecting the decision to adopt blockchain technology: A logistics company case study using Fuzzy DEMATEL, *Journal of Intelligent & Fuzzy Systems*, 1-14.

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