ASSESSMENT OF CHALLENGES OF THE INTERNET OF THINGS IN SUPPLY CHAIN DURING PANDEMIC USING INTERVAL-VALUED NEUTROSOPHIC ANALYTICAL HIERARCHY PROCESS

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in

Industrial and Systems Engineering

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Industrial and Systems Engineering.

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"Aim for the moon. Even if you miss, you might land among the stars."

Friedrich Nietzsche

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Marzhan Doszhanova

Abstract

An extensive spreading of the Internet of Things (IoT) concept is still a hot topic for the research. Practical applications of IoT in daily life became an integral part of it: vehicle maintenance, surveillance systems, healthcare etc. The significant impact on the supply chain can be given by the example of radio frequency identification (RFID) tags letting retails save time and money on lost/damaged items. Undoubtedly, perpetual development of technology and global circumstances as COVID-19 pandemic urges firms to adopt new technologies and change the strategies. Thus, identifying challenges that prevent implementing IoT in the supply chain in order to determine their corresponding solutions, is of utmost importance. After performing a review of the most recent literature we identified five main criteria: cost, technology, security, business, and quality and their relevant subcriteria. By applying multi-criteria decision analysis (MCDA) tool analytical hierarchy process (AHP) in combination with interval-valued neutrosophic numbers we interviewed top experts in this field. Neutrosophic sets are known for their precision in comparison with crisp and fuzzy sets; interval-valued number sets let us to have even more precise results in evaluating weights of criteria since it provides not only truth-membership, indeterminacy-membership and falsity-membership function but also an upper and lower level for each. The critical part of this research is that we separately evaluated answers before the global pandemic and after, considering its effect on the whole supply chain performance. Evaluating judgements of decision-makers revealed that business-related concerns were and still are most important whereas unexpectedly security concerns were of least importance.

Keywords: Internet of Things (IoT), Analytical hierarchy process (AHP), Multi-criteria decision analysis (MCDA), interval-valued neutrosophic sets, supply chain management, COVID-19.

Aralıklı nötrosofik analitik hiyerarşi sürecini kullanarak pandemik sırasında tedarik zincirindeki nesnelerin interneti zorluklarının değerlendirilmesi

Marzhan Doszhanova

Öz

Nesnelerin Interneti (IoT) kavramının kapsamlı bir şekilde yaygınlaşması, günümüzde oldukça gündemde olan bir araştırma konusu olmasını sağlamıştır. Nesnelerin internetinin (IoT) günlük yaşamdaki; araç bakımı, gözetim sistemleri, sağlık hizmetleri gibi pratik uygulamaları hayatımızın ayrılmaz bir parçası haline gelmiştir. Tedarik zinciri üzerindeki önemli etkisine örnek olarak; perakendecilerin kayıp/hasarlı ürünlerde zamandan ve paradan tasarruf etmesini sağlayan radyo frekansı tanımlama (RFID) etiketleri verilebilir. Kuşkusuz, teknolojinin ve KOVID-19 pandemisi örneğinde olduğu gibi küresel koşulların sürekli gelişimi, firmaları yeni teknolojileri benimsemeye ve stratejilerini değiştirmeye sevk etmektedir. Dolayısıyla, bunlara tekabül eden çözümleri tespit etmek amacıyla tedarik zincirinde nesnelerin internetinin (IoT) uygulanmasını engelleyen zorlukları tanımlamak azami önem taşımaktadır. En son literatürü gözden geçirdikten sonra, beş ana kriter belirlemiş bulunmaktayız: Maliyet, teknoloji, güvenlik, iş, kalite ve bunlarla ilgili alt kriterler. Aralık-değerli nötrosofik sayılarla birlikte çoklu-kriterli karar verme (ÇKKV) analiz aracı analitik hiyerarşi prosesini (AHP) uygulayarak, bu alandaki önde gelen uzmanlarla görüşmüş bulunmaktayız. Net ve bulanık kümeler ile karşılaştırıldığında, nötrosofik kümeler kesinlikleri ile bilinir; ve, aralıklı-değerli sayı kümelerinin her biri için, yalnızca doğruluk-üyelik fonksiyonu, belirsizlik-üyelik fonksiyonu ve yanlışlık-üyelik fonksiyonu değil, aynı zamanda her biri için bir üst ve alt düzey sağlaması dolayısıyla kriterlerin ağırlıklarını değerlendirme konusunda daha da kesin sonuçlar elde etmemizi sağlarlar. Bu araştırmanın kritik noktası, tüm tedarik zinciri performansı üzerindeki etkisini göz önünde bulundurarak, küresel pandemiden önce ve sonra, cevapları ayrı ayrı değerlendirmiş olmamızdır. Karar vericilerin kararlarının değerlendirilmesi ile, beklenmedik bir şekilde, güvenlik kaygıları asgari önemde iken, işle ilgili endişelerin önceden beri ve hala en önemli endişe olduğu ortaya koyulmuştur.

Anahtar Sözcükler: Nesnelerin Interneti (IoT), Analitik hiyerarşi prosesi (AHP), çok-kriterli karar verme (ÇKKV) analizi, aralık-değerli notrosofik kumeler, tedarik zinciri yonetimi, KOVID-19.

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Huge appreciation goes to my friends and family that made this journey joyful and unforgettable; I am very grateful for their support and encouragement.

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Abbreviations

AHP	**A**nalytical **H**ierarchy **P**rocess
AMI	**A**bsolutely **M**ore **I**mportance
ANP	**A**nalytical **N**etwork **P**rocess
CI	**C**onsistency **I**ndex
CR	**C**onsistency **R**atio
EHI	**E**xtremely **H**igh **I**mportance
EI	**E**qual **I**mportance
EXI	**E**xtreme **I**mportance
INS	**I**nterval-valued **N**eutrosophic **S**et
IOT	**I**nternet **o**f **T**hings
MCDA	**M**ulti- **c**riteria **D**ecision **A**nalysis
MI	**M**oderate **I**mportance
MMI	**M**oderately **M**ore **I**mportance
RFID	**R**adio **F**requency **I**dentification
SCM	**S**upply **C**hain **M**anagement
SIMP	**S**trong **I**mportance
SMI	**S**trongly **M**ore **I**mportance
VSI	**V**ery **S**trong **I**mportance
VSMI	**V**ery **S**trongly **I**mportance
WMI	**W**eakly **M**ore **I**mportance

Chapter 1

Introduction

The Internet of Things (IoT) is ubiquitously entering many spheres of human life including healthcare, public safety, retail, manufacturing and many others. The term itself was minted by Kevin Ashton in 1999 and suggested a cluster of physical systems connected to the Internet through sensors. The simplest definition of IoT is creating a network of physical objects that can exchange and process information. It has already spread in daily life use letting consumers have a more comfortable and reliable utilisation of goods. For example, kitchen utilities as microwave and fridge can be monitored over the owner's cell phone, while controlling the meters can save a considerable amount of money in the long term and add its benefit to the environment. However, nowadays the interaction is occurred not the only machine to machine (M2M) but IoT also provides a channel for human to machine (H2M) and human to human (H2H) communications. All of these constantly developing technologies have an immense impact on the industry. There is a quite large amount of writings about IoT's influence on the industry which finally brought to the fact that the 4th Industrial Revolution (Industry 4.0) made IoT its main tool in automatization and digitalization of operations [1]. The vital part of any business is its supply chain management; it is defined as a cluster of three or more objects implicated in the up and downstream currents of services, products, finances and data exchange between the customer and supply source [2]. Supply chain depicts the whole chain of processes of producing and delivering the product or service from the source to the end consumer. To be able to deal with actively changing environment, strategic digitalization of processes and keeping the competitive edge in the market, integrating technologies in the supply chain is required. Applications of IoT in the supply chain are various: RFID based smart-inventory management lets businesses to get rid of "dark assets"; provide real-time visibility of goods; along with cameras might be used for detecting faulty pallets, etc. Real-life examples are provided by huge companies as DHL, Ericson and Bosch which not only attracting customers with smart solutions but also save on excessive expenditure [3], [4]. Despite its vast potential, IoT has yet unpredictable benefits and high expenditure, hence businesses need to carefully analyse challenges in order to allocate resources wisely. With the start of the pandemic of COVID-19, most businesses had to change the way they operate. It became clear that communication technologies are sufficient tools when human interaction can be mortally dangerous. Mobile networks became the backbones of most businesses these days enabling healthcare workers, security workers and other essential employees to stay in touch. While big companies as Ericsson inter [5] claim to undergo close to none fall off by the pandemic, SMEs are reported to experience loss of income and some even shut down their businesses. These cases show how a well-established supply chain is crucial for enterprises to survive uncertainties and keep the flow of products if not on full capacity but at least enough to maintain the company. It is predicted by experts that in the forthcoming months the demand for expendables will decrease whilst necessity for indispensables as medical goods and food will grow significantly. Which, if not tackled on time, might cause a huge gap between supply and demand. It is clear that on top of the existing challenges now we have new ones brought by the pandemic. The concept used for the enhancement of the systems - Industry 4.0, can still be beneficial in terms of automatization of operations which minimizes human interaction and speeds up the processes. However, challenges associated with the integration of IoT as a lack of specific knowledge or issues of heterogeneity are still obstacles on the way. The aim of this study is twofold. First, we define the most prominent challenges that firms confront on their way to adopt IoT technologies and find out their ranks; second, we want to assess how pandemic has changed those challenges by calculating weights before and after COVID-19. After the thorough scanning of the existing literature, the main criteria were identified and to find their rank multi-criteria decision analysis (MCDA) tool interval-valued neutrosophic analytical hierarchy process (AHP) is used. Neutrosophic logic helps to get more precise results comparing to other environments such as fuzzy and crisp, moreover using interval-valued numbers would provide us with better representation of uncertain and inconsistent information.

Chapter 2

Literature review

Since the impact of IoT is significant on supply chain performance, a lot of studies were published proposing solutions to different problems: security, management, financial issues etc. This chapter gives the summary of literature review done on the main concepts used in this study.

2.1 IoT in Supply Chain Management

As known from its definition SC encompasses many processes on the way from the manufacturer to the customer. Nowadays when "firmâs supply chain" is mentioned it usually means all integrated parts [2] of that chain. For example, as demonstrated in Figure 2.1 fields as research and development (RD) are also included in the supply chain [6].

The origins of IoT in supply chain and logistics are not recent and had already existed for some time e.g. technologies for monitoring objects. Hence, all the recent enhancements done in the field might be considered as taken base from existed developments. On the example of [7], the simplest scenario of implementing IoT in SC is as follows: RFID tags are tagged to goods and by scanning them with RFID reader emulated data transferred to the cloud; the information about goods is filled in database and management now have essential information as a type of product, expiration date etc. The given solution provides ease in data collection, ensures transparency of data sharing between managers and suppliers. Indeed, this is just one example of many which however shows the benefits

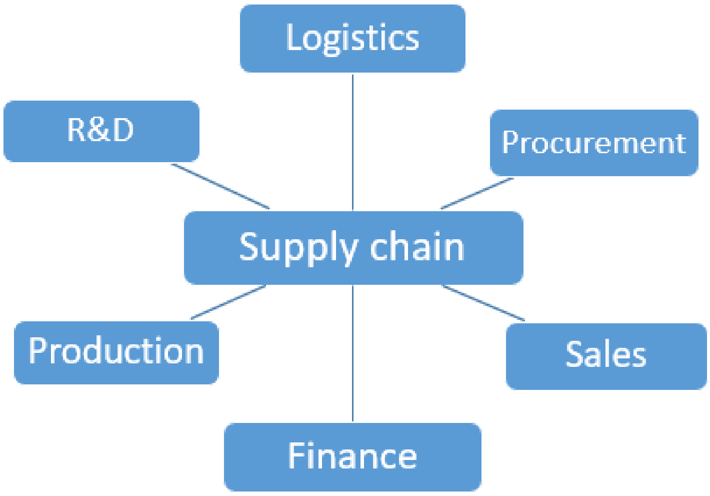

FIGURE 2.1: Dimensions of Supply chain

of applying IoT technology.
Several studies have been done on measuring the benefits and challenges of adopting IoT, for instance in [8] the empirical study demonstrates that technology benefits, external motivation and trustworthiness have a positive influence on IoT adoption, while uncertainties about IoT technology and cost have a negative effect. Authors in [9] concluded that to harvest the benefits of IoT companies should start investing in technology from the early stages. More about managerial implications of choosing IoT provider stated in [10] indicating on six considerations: IoT expertise, intelligent-switching potentials, provision of services, cost, security, and global reach. Authors in [11] used Unified Theory of Acceptance and Use of Technology to identify that "easiness of use" has a significant impact on IoT adoption while in [12] the importance of perceived value is shown by empirical research.

A recent survey done by Particle [13] shows that the hardest issue users face is a fixation of faulty devices while the easiest was purchasing and selecting hardware/software Figure 2.2. The reason is the complexity of development and the need for expertise to manage how the software will get the data from the edge devices.
As it can be seen many challenges are affecting the decision of adopting IoT technology. This study aims to identify the main challenges and verify their significance with experts.

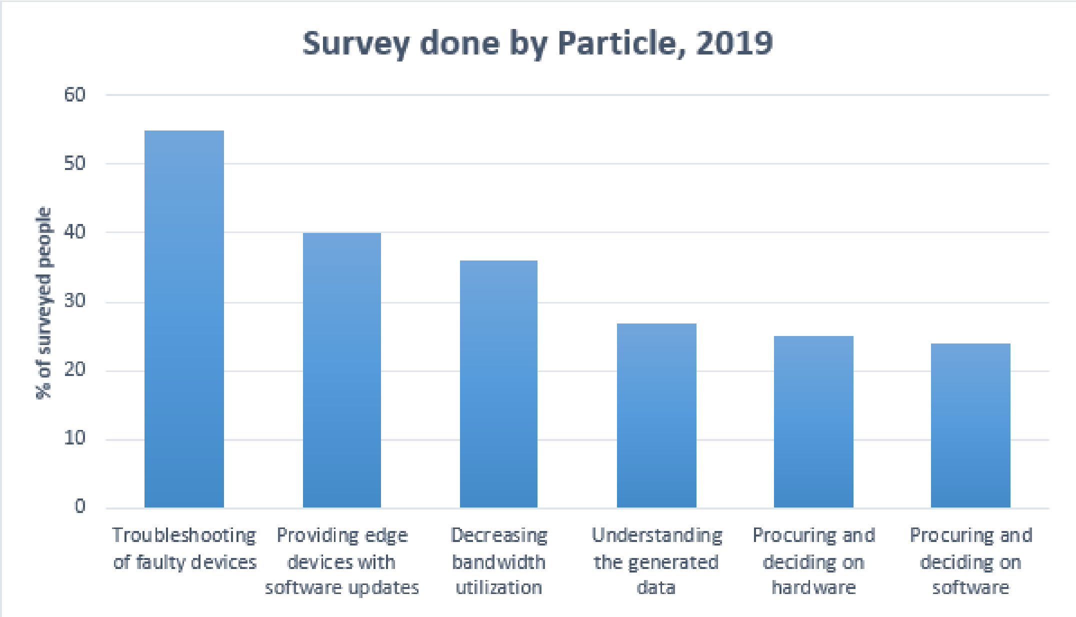

FIGURE 2.2: Survey on challenges of IoT

2.2 COVID-19 pandemic

First identified in Wuhan, China, Coronavirus disease 2019 (COVID-19) is a respiratory syndrome that has spread all over the world from approximately November 2019. It was announced to be a pandemic by the World Health Organization and caused lockdowns in many countries and shutdown of borders. Over 14 million people worldwide had or have been infected by this disease as for 21 of July; 36.5 million people as for 14 of May are reported to have lost their jobs due to the pandemic in U.S. only, as told by US Labour Department which shows the immense effect COVID-19 pandemic had on the global economy. Many fields as tourism, oil industry and retail are already suffering from the disruption; for example Figure 2.3 shows how predicted revenue from tourism worldwide changed drastically [14].

Macroeconomic effects of COVID-19 might be presented by several indicators [15]; for instance, shock in demand and supply that was first caused by the disruption in Chinese manufacturers and halt in international trade. Excess demand and incapability of providing excess supply cause holes in the economy resulting in shortages of essential goods. A shift in price levels is also an indicator of macroeconomic effect since the demand for non-essential goods fell drastically as opposed to essential, prices of first experienced deviation. It is predicted to affect overall prices in the influenced economy [15]. Restated

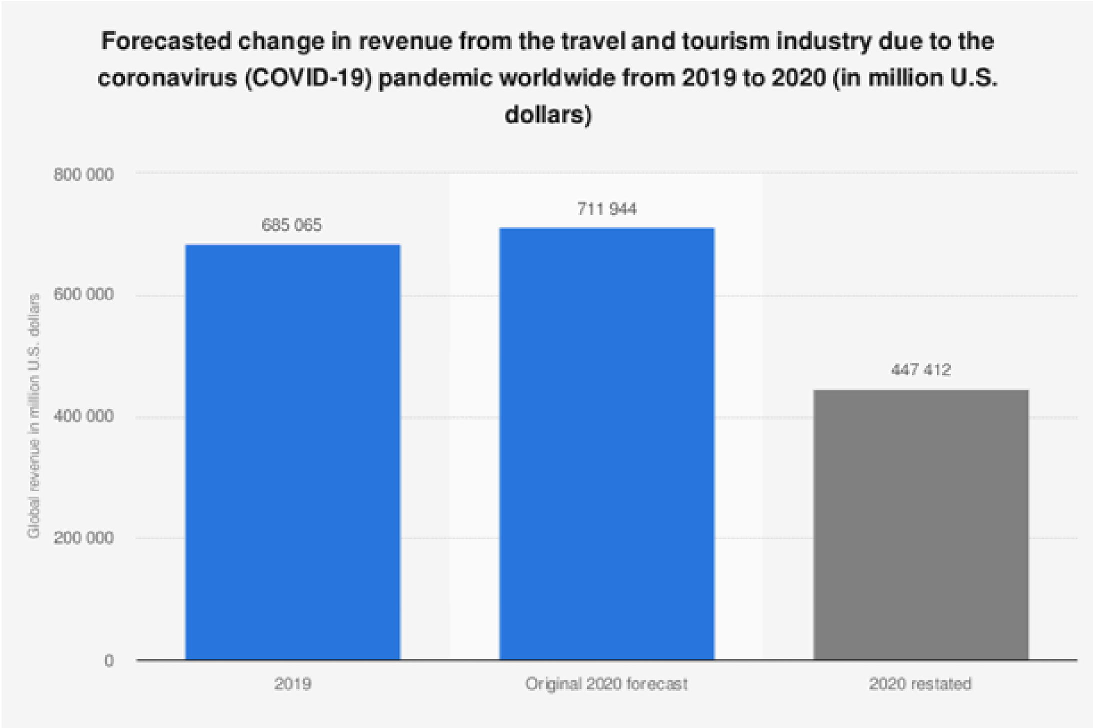

FIGURE 2.3: Forecasted change in revenue from tourism [14]

prediction of global GDP shows that for immediate future (the year of 2020) the indicator falls for 0.5%, however, for the next year 2021 the prediction shows to have higher numbers in Figure 2.4 [14]. Inevitably, it will cause perturbation in the supply chains of companies and a new supply chain models will have to be applied as well as strategies for the future when the initial shock will abate should be elaborated.

Some literature review based studies have been done on the topic of IoT during the pandemic. Most of them restate the importance of Industry 4.0 applications in times of crisis and provide examples of IoT usage. Thus, authors of [16] underline the merits of using IoT for fighting against disease as improved diagnosis, less probability of making mistake, lesser cost, better control and better treatment. Internet of Things can also be helpful for epidemiologists to detect the patient zero and people in contact with him as well as monitoring through drones the implementation of social distancing and wearing masks in public places [17]. Solution for the shortage of personal protection equipment supply suggested by Rowan et al. [18] as using smart communication channels in the supply chain, customizing the production of PPE and using sterilization to reprocess them. It is believed that IoT will have more applications despite the economical halt,

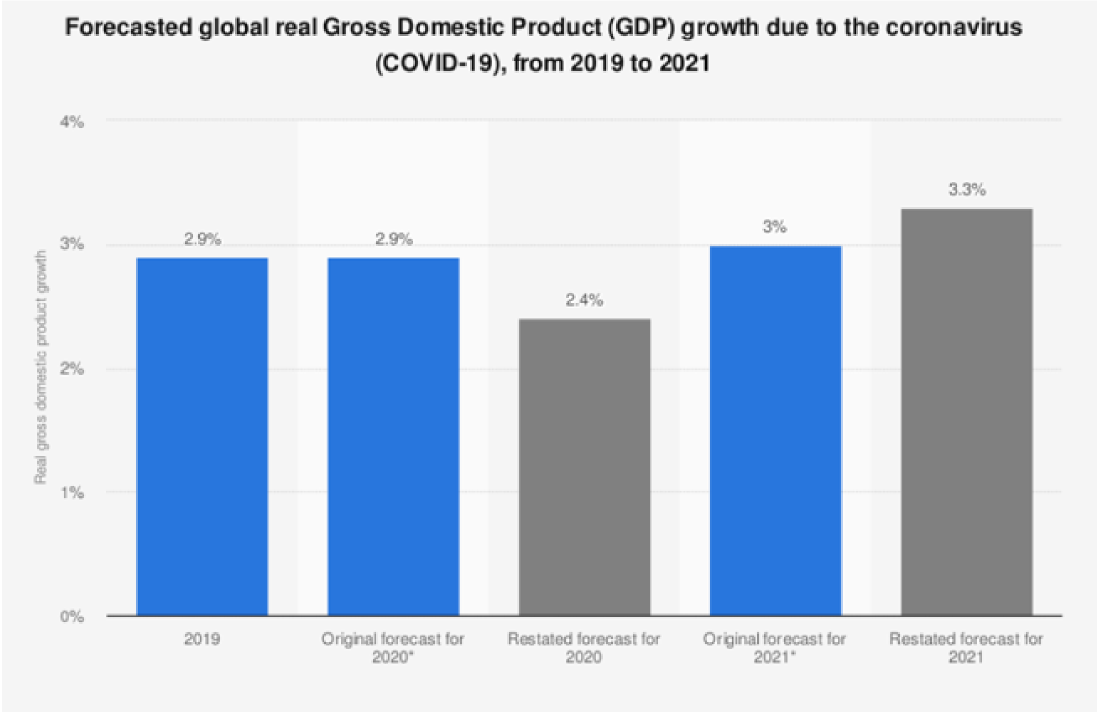

Figure 2.4: Forecasted GDP from 2019 to 2021 [14]

due to its usefulness in securing remote relations, quicker analysis and lowering risks of contagion. A study projected that growth in the IoT market will reach $243 billion in 2021 [19] primarily in the healthcare sector. Therefore, investigating the challenges occurring in the way of implementation of IoT is a methodology to overcome them quickly.

2.3 Multi-criteria decision analysis

Multi-criteria decision analysis is described as both a methodology and a group of strategies that offer a total order of choices, from the most favourable to the least favourable option [20]; Bonissone et al. [21] define an overlap of three elements: finding a solution over the space of alternative solutions, a chosen trade-off mechanism to direct down-selection and an informational presentation to explain the trade-off implications. Many tools can be used in MCDA starting from the most original one analytical hierarchy process (AHP), analytical network process (ANP) and their derivatives as DEMATEL, TOPSIS and VIKOR. MCDA is widely used in many industries for specific purposes and on the managerial level as well. ANP was used in studies of Kadoic et al. [22] to evaluate scientists and show the network of nodes with their sub-nodes, while Unver et al. [23] used this method to evaluate threat in air forces. The combination of the sets different than crisp numbers as fuzzy and neutrosophic sets with MCDA tools are of common practice. Using fuzzy and neutrosophic sets help to overcome the ambiguity of decision maker's judgements since unlike the crisp numbers they offer membership functions for more accurate evaluation. An intuitionistic fuzzy ANP with aggregation operator was used in [24] to choose the best CRM operator; a case study in Taiwan of TFT-LCD industry for designing efficient sustainable development strategies using DEMATEL-based ANP with the VIKOR method [25]. Evaluation of security system for IoT in the supply chain is done by Abdel-Basset [7] implementing AHP and DEMATEL together; an integrated IF-AHP-DEMATEL is proposed by Razieh et al. [26] presented in the example of selecting managers.

A generalization of intuitionistic fuzzy sets - neutrosophic sets were first introduced by Smarandache [27]; it is suggested to use the subsets of truth, falsity and indeterminacy instead of numbers because usually, it is not possible to precisely detect the percentage of truth and falsity (definitions will be given in the next chapter). Integration of neutrosophic sets with MCDA tools is of new practices and mostly it is done with AHP. The method was already used in many studies [28]-[32], implementing single-valued neutrosophic sets. However, a recent approach of using interval-valued neutrosophic sets [33] was not used much in real-life cases. For instance, neutrosophic sets with interval-valued parameters are used to assess solar energy systems [34], while Bolturk [35] presents the interval-valued neutrosophic AHP to evaluate the selection of alternative energy sources. Table 2.1 provides the most related works to our research using different methods.

Table 2.1: Literature review of MCDA methods

Author	AHP	ANP	Fuzzy ANP	Single-valued Neutrosophic AHP	Interval-valued neutrosophic AHP
Razieh and Ahmad [26]	x				
Abdel-Basset, Mohamed, and Smarandache [28]				x	
Abdel-Basset, Mohamed, and Sangaiah [30]				x	
Abdel-Basset, Manogaran, and Mohamed [36]	x				
Tey et al [31]				x	
Ossadnik, Schinke, and Kaspar [37]	x	x			
Nabeeh et al [29]	x			x	
Xia, Ma, and Lim [38]	x				
Cayir Ervural et al [39]		x			
Büyüközkan, Güleryüz, and Karpak [24]			x		
Zhu et al [40]		x			
Ossadnik et al [37]	x	x			
Boateng, Chen, and Ogunlana [41]		x			
Kahraman, Onar, and Oztaysi [42]			x		
Chen et al [43]		x			
Mohammadzadeh et al [44]			x		
Bolturk and Kahraman [35]					x
Radwan et al [32]				x	
Büyüközkan et al [24]			x		

2.4 Common architecture for IoT

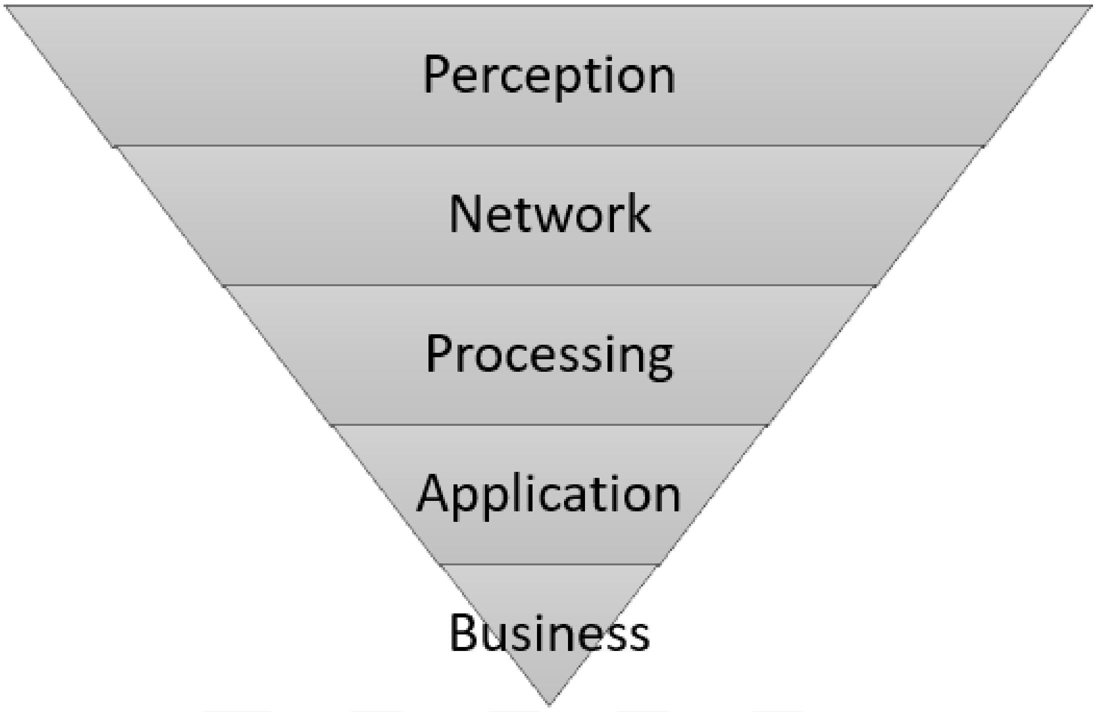

FIGURE 2.5: Typical IoT environment architecture

Although there is no common architecture of IoT setting, in terms of security it still can be characterized by layers as perception, network, processing, application and business Figure 2.5 Described in [45] as following:

- **Perception layer** is basically about sensors that identify objects and collect data about them. The sensors as RFID and 2-D barcodes are used to track the location and some sensors used to monitor the temperature etc. Those might be an object for attacks and illicit access.
- **Network layer** is a jointing layer between perception layer and application layer that transmits the data using communication channels like simple wires as well as wireless technology e.g. Bluetooth, Wi-Fi, Zigbee (short-ranged), mobile network (long-ranged). Linking channels are usually exposed to malware and DoS attacks.
- **Processing layer** is responsible for processing and filtering the data received from the network layer and might suffer when the amount of data is too large.

- **Application layer** is where IoT technology is used and devices which use IoT are established. Since the service type may differ they also rely on different information which means heterogeneity creates unprotected spots in security.

- **Business layer** administrates the integration of the IoT application and business and meeting goals of the firm. It is also responsible for creating profit models and operating with the client's personal information that could be a fatal point of the system.

Chapter 3

The model

Selection of criteria

The following chapter gives insight from the existing literature on challenges as presented in Figure 3.1. After reviewing most recent literature on challenges of IoT in supply chain by using services as Google Scholar and Science Direct we used following number of articles:

TABLE 3.1: Literature review of selected criteria

Financial Cost	Security and Privacy	Business	Quality	Technology
6	15	25	13	26

3.1 Security

Along with many benefits that IoT brings, several issues come along and one of them is security. In the interview published by McKinsey [46] for the question: "What's the biggest risk associated with the Internet of Things?" all eight experts answered as security and data privacy. A survey done by internetsociety.org [47] shows that:

- 75% of individuals doubt the way information is shared.
- 63% of individuals find connected gadgets "creepy".

- 50% of individuals know how to debilitate data gathering.
- 28% of individuals who do not possess a savvy gadget, will not purchase one due to security concerns.

In the flow of a big amount of data generated from IoT devices (as predicted by Gartner 5.8 billion endpoints in 2020), it is required for the transactions to be secure and safe [48]. Since the advent of IoT is still in nascent stage its security is still afflicting under multiple challenges [49]. The critical points to be highlighted in IoT we found as such:

- **Confidentiality** is one of the security requirements of IoT according to [49]; it is the ability of the system to resist unlicensed intervention of the third parties in confidential data exchange. The same authors state that it is crucial for almost all applications of IoT as healthcare (confidentiality of patient's data in hospitals), smart cities and manufacturing (protection from spyware attacks). In assessing security criteria Abdel-Basset et al. [36] used confidentiality in network criteria. Data confidentiality is an exceptionally challenging issue due to its heterogeneity and environment [44]. Which is why considering all the issues a special policy must be undertaken to regulate the access to data.
- **Network security** is defined as the safety of any action taken within the network [44]. For the physical components of IoT as RFID, cloud computing and wireless sensor network providing reliable security measures are of utmost importance. The vulnerability of those channels can cause the stealing of personal information and spreading erroneous data. Depending on the type of physical layer different approaches were suggested as a solution, for instance, cryptography and security protocols [50] which is however not standardized yet and requires further research.
- **Scalability** is the issue coming from a large number of objects and in certain areas as smart grids, healthcare and manufacturing create a wide range of security problems. Although the ways as asymmetric cryptography could address these problems, they still face shortcomings as high energy consumption [49].
- **Robustness and reliability** is another challenge for the security of the system e.g. in the cloud, servers where the data is stored may not be able to replicate it yielding gaps in the availability of the system. To guarantee a significant level of

availability and robustness, a reasonable trade-off between backup hardware and software is needed [51].

3.2 Business

A complex of operations is required for businesses to be undertaken to mitigate the issues emerging from penetrating new technologies. Businesses should move towards novel business models and processes in order to alleviate those challenges [44].

Business model

Introducing the IoT in business whether it be manufacturing or high tech production, will let businesses gain profit from the assets. Which means to embrace the new business model as a "service provider" not only through cloud computing but through evaluating an organization's products, channels of distribution etc. Economically it will open doors for opportunities as outsourcing to either save or earn money [3]. Sensors can transform the property insurance business by changing their risk calculations. This is possible due to the connected sensors that give more data for the calculations to be precise. The data also allows customization of risk calculations for the certain customer and set of risk prices objectively. These examples show that businesses have to be ready to rethink their corporative values since the propagation of IoT is constantly escalating and may require shifting of business models. However, in the study proposed by [52], the interrelations between business model elements are investigated and showed that changes made on individual component relatively affect others. Which is why it is important to point out that rigours evaluation is required before implementing IoT technologies in business [53].

Economic impact is an important value to consider, be it on the local or global level. On the local level, the impact can be assessed through the net profit of deploying IoT technologies. Despite the concern of leveraging IoT technologies taking over human force and creating unemployment, the collaborative study of World Economic Forum's Centre for Fourth Industrial Revolution concluded that IoT technology rather increases the productivity of workers and do not replace it.

On the global level, according to McKinsey's estimations, the economic impact of the Internet of Things will be approximate of $3.9 trillion to $11.1 trillion per year in 2025 and will comprise 11% of the world economy in that year.
Frontier economics [54] found that boost in GDP in Germany ($370 billion) and USA ($2.26 trillion) over a 15-year time span from 2018 to 2032, will be due to a 10% rise in IoT investment. However, there must be a policy applied to reach such result as fulfilling factors like business, transfer and innovation factors. The organization must possess tools and strategies to make the best of technology; which applies to produced data itself, management of data and systems to process it.
This is why decision-maker needs to understand possible benefits as well as economical risks of adopting IoT.

3.3 Financial cost

The financial cost is for sure one of the most important parts of the SC system since the objective function usually refers to the cost reduction. A study done by [8] reveals that cost as an organizational level concern is one of the main obstacles on the way to implementing IoT.
The report by Ericson done among Danish companies [4] on the adoption of IoT showed that the cost is the greatest barrier between the company and IoT adoption. Although the cost of sensors as an indicator for the whole system dropped drastically in 20 years from 1994 to 2014, the price is still an obstacle on the way.
In [55] financial cost referred as a total cost of purchasing software, hardware and maintenance of the system while [56] employ the cost as one of two main criteria for evaluating the optimal IoT resource. The cost includes energy consumption, communication etc. Therefore in our model, the cost of hardware and software will make sub-criterion called "**purchase cost**".
The lack of awareness and training causes the absence of value of IoT for companies [57]. This is why investing in the training of staff (providing workshops, sending to certified courses etc.) is an important part of adopting. This will make a sub-criterion called " **training cost**".
For businesses, it is essential to have the confidence of gaining profit from the investment. Gartner recommends the majority of IoT projects should target financial payback in less

than one year. Despite the "saving cost" being one of the main reasons for employing IoT, small and medium businesses usually confront with the standstill in economizing. A comprehensive study by CompTIA on Trends of IoT in the United States reports that 58% of companies stated defining return of investment is difficult which potentially could turn into the obstacle we used as "**rate of return**" in the current study.

3.4 Quality

Although purchasing high quality and probably high-cost devices do not necessarily ensure the high quality of service, it is still important to look into the factors lying behind the overall quality of service or experience.

Customer expectation has enormously improved due to the quick advancement of innovations and meeting those expectations is in the best interest of businesses. All the concerned parts must be ensured of benefits from implementing IoT and the ways of sustaining the trust should be considered preliminarily.

Information quality is the significance, dependability and idealness of information given by IoT servers that is critical for both business and its customers. It is also suggested that the customers' perception (in our case businesses implementing IoT devices) is determined by the way they receive the data from IoT and its quality [58].

Perception quality can be elaborated as a perception of a business owner and its customer. User's perception of the firm can be enhanced by "coolness" and "affordance" in [58] and by reducing any type of uncertainty and ambiguity linked to IoT the firm creates a better image [8]. Different scenarios of perception were studied in [59] and concluded that to have better perception within the supply chain, a crucial and challenging task - building trust between its channels is needed. Perception of the usefulness of IoT can be facilitated by the perception of convenience (ability to operate IoT device whenever and wherever) and intelligence (self- learning and self-recognizing work of IoT frameworks) [60] according to consumer's psychological perception [61].

3.5 Technology

Technology is the backbone of IoT and criteria we have selected as security, robustness and financial aspect as well. Technological infrastructure should provide solid ground for seamless integration of IoT technology for both hardware and software. The main concerns were found as follows:

- **Heterogeneity:** Billions of heterogeneous networks make up the IoT network. The technological infrastructure should indeed be able to validate the systems for transparent and scalable data transmission around through various administrative domains [55]. According to Gartner's report [62], the heterogeneous character of private and industry data makes IoT's architecture unfit for integration. Fast and reliably functioning IoT infrastructure will be in priority particularly when a real-time conveyance is needed to determine capacity and condition [63], [64]. In order to fulfil these requirements diverse applications, architecture and networking technologies need to be standardized.

- **Data management** is an issue hard to deal with for users after deciding on hardware/software according to [13]. Companies simply struggle with comprehending the data and have little knowledge about what to do with it. Although Biswas et al. [51] claim that with an enhancement of technology development it is no longer enough for companies just to know what to do with the data but know how to use it for future predictions, it is still an obstacle on the way. Not only the vast amount of data is an issue but also conveying it has to be secure technologically as well as legally [65].

- **Technological unawareness** is a holistic concept that describes the lack of technological trend awareness [66], lack of clear comprehension of IoT benefits, the resistance of employees to novelty [64]. These challenges need to be tackled to avoid sunk cost fallacy because of misconception or ignorance of both higher management and employees.

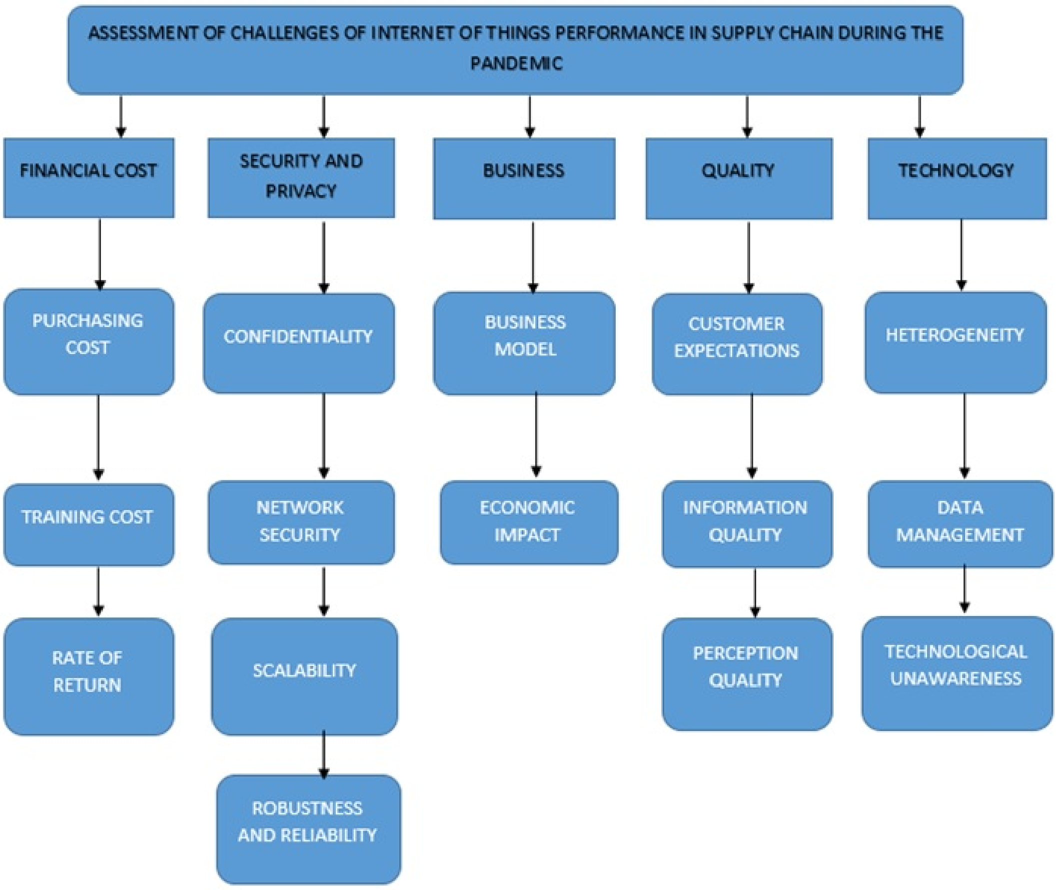

Figure 3.1: Hierarchy of challenges of IoT in SC

Chapter 4

Research methodology

The methodology used in this study is ultimately analytical hierarchy process (AHP) with using interval-valued neutrosophic numbers. First, the preliminaries that give insights to interval-valued neutrosophic numbers, then the methodology of proceeding AHP are given.

4.1 Preliminaries

Definition 1: Let X be a space of objects having a universal element referred as x. A truth membership function T_A characterizes a neutrosophic set A in X, similarly I_A is a function of an indeterminacy membership and F_A is a falsity membership. $T_A(x)$, $I_A(x)$ and $F_A(x)$ are real standard or nonstandard subsets of $]0^-, 1^+[$. That is:

$$T_A : X \rightarrow]0^-, 1^+[\qquad (4.1)$$

$$I_A : X \rightarrow]0^-, 1^+[\qquad (4.2)$$

$$F_A : X \rightarrow]0^-, 1^+[\qquad (4.3)$$

The sum of three is defined as follows:

$$0^- \leq \text{sum}\,(T_A(x), \text{l}_A(x), F_A(x)) \leq 3^+$$

Definition 2: Ā denotes the complement of a neutrosophical set A and is defined by:

$$T_{\bar{A}}(x) = \{1^+\} \ominus T_A(x) \qquad (4.4)$$
$$I_{\bar{A}}(x) = \{1^+\} \ominus I_A(x) \qquad (4.5)$$
$$F_{\bar{A}}(x) = \{1^+\} \ominus F_A(x) \qquad (4.6)$$

Definition 3: Another neutrosophical set B contains a neutrosophic set A, A $\subseteq B$, if and only if:

$$\inf T_A(x) \leq \inf T_B(x) \quad , \quad \sup T_A(x) \leq \sup T_B(x) \qquad (4.7)$$
$$\inf I_A(x) \geq \inf I_B(x) \quad , \quad \sup I_A(x) \geq \sup I_B(x) \qquad (4.8)$$
$$\inf F_A(x) \geq \inf F_B(x) \quad , \quad \sup F_A(x) \geq \sup F_B(x) \qquad (4.9)$$

For all x in X

Definition 4: Let X be a space of objects having a universal element referred as x. A neutrosophic interval set (INS) A in X is defined by I_A indeterminacy-membership, T_A truth-membership function, and F_A falsity-membership function. For each point x in X, $I_A(x)$, $T_A(x)$, $F_A(x) \subseteq [0,1]$.

Definition 5: A neutrosophic set of interval A is empty if and only if its inf $T_A(x) =$ sup $T_A(x) = 0$, inf $I_A(x) =$ sup $I_A(x) = 1$ and inf $F_A(x) =$ sup $T_A(x) = 0$, for all x in X.

Definition 6: An interval neutrosophic set B contains another interval neutrosophic A, A $\subseteq B$, if and only if

$$\inf T_A(x) \leq \inf T_B(x) \quad , \quad \sup T_A(x) \leq \sup T_B(x) \qquad (4.10)$$
$$\inf I_A(x) \geq \inf I_B(x) \quad , \quad \sup I_A(x) \geq \sup I_B(x) \qquad (4.11)$$
$$\inf F_A(x) \geq \inf F_B(x) \quad , \quad \sup F_A(x) \geq \sup F_B(x) \qquad (4.12)$$

For all x in X

Definition 7: Ā denotes a complement interval of a neutrosophical set A and is defined by:

$$T_{\tilde{A}}(x) = F_A(x) \qquad (4.13)$$
$$\inf I_{\tilde{A}}(x) = 1 - \sup I_A(x) \qquad (4.14)$$
$$\sup I_{\tilde{A}}(x) = 1 - \inf I_A(x) \qquad (4.15)$$
$$F_{\tilde{A}}(x) = T_A(x) \qquad (4.16)$$

4.2 Research methodology

Application of the interval-valued neutrosophic AHP will be done according to [29], [35].

Step 1 Defining criteria and sub-criteria through literature review and interviewing experts.

Step 2 Building a hierarchy appropriate for implementing AHP as in example Figure 4.1.

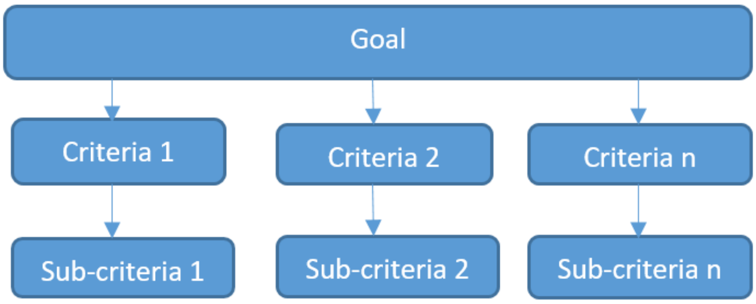

FIGURE 4.1: Example of hierarchy

Step 3 Model interval valued neutrosophic sets based pairwise comparison matrices from decision-makers. Decision-makers are given the linguistic terms of as of Saaty's crisp number in Table 5.1. The matrices with interval-valued neutrosophic values will look as following pairwise comparison matrix of criteria with respect to the goal:

$$\mathrm{Ac} = \begin{array}{c} C_1 \\ \vdots \\ C_n \end{array} \begin{bmatrix} \left[\mathrm{T}_{11}^{\mathrm{L}}, \mathrm{T}_{11}^{\mathrm{U}}\right], \left[\mathrm{I}_{11}^{\mathrm{L}_1}, \mathrm{I}_{11}^{\mathrm{U}}\right], \left[\mathrm{F}_{11}^{\mathrm{L}}, \mathrm{F}_{11}^{\mathrm{U}}\right]\right\rangle & \cdots & \left\langle\left[\mathrm{T}_{1n}^{\mathrm{L}}, \mathrm{T}_{1n}^{\mathrm{U}}\right], \left[\mathrm{I}_{1n}^{\mathrm{C}}, \mathrm{I}_{\mathrm{in}}^{\mathrm{U}}\right], \left[\mathrm{F}_{1n}^{\mathrm{L}}, \mathrm{F}_{1n}^{\mathrm{U}}\right]\right) \\ \vdots & \ddots & \\ \left[\left[\mathrm{T}_{\mathrm{n1}}^{\mathrm{L}}, \mathrm{T}_{\mathrm{n1}}^{\mathrm{U}}\right] \cdot \left[\mathrm{I}_{\mathrm{n1}}^{\mathrm{L}}, \mathrm{I}_{\mathrm{n1}}^{\mathrm{U}}\right], \left[\mathrm{F}_{\mathrm{n1}}^{\mathrm{L}}, \mathrm{F}_{\mathrm{n1}}^{\mathrm{U}}\right]\right\rangle & \cdots & \left\langle\left[\mathrm{T}_{nn}^{\mathrm{L}}, \mathrm{T}_{nn}^{\mathrm{U}}\right], \left[\mathrm{I}_{nn}^{\mathrm{L}}, \mathrm{I}_{nn}^{\mathrm{U}}\right], \left[\mathrm{F}_{nn}^{\mathrm{L}}, \mathrm{F}_{nn}^{\mathrm{U}}\right]\right\rangle \end{bmatrix} \tag{4.17}$$

Step 4 Check consistency ration to see the consistency of decision-makers' judgment.

1. Convert neutrosophic values to crisp values using Table 5.1
2. Calculate normalized values by dividing each. value by its corresponding column's summation.
3. Calculate criteria weight by averaging each row.
4. Multiply criteria weight (column) to each criteria row of non-normalized matrix.
5. The sum of resulting column gives us λmax.

6. Calculate consistency index (CI).

$$CI = \frac{\lambda_{\max} - n}{n - 1} \qquad (4.18)$$

where n is the number of criteria

7. Calculate consistency ratio:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \qquad (4.19)$$

where RI stands for random index and is chosen depending on the number of criteria according to Table 4.2.

TABLE 4.1: Table for random index (RI) for various criteria numbers defined by Saaty

0	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0.0	**0.0**	**0.58**	**0.90**	**1.12**	**1.24**	**1.32**	**1.4**	**1.45**	**1.49**

It is recommended to keep CR less than 0.1. If CR $\leq$ 0.1, proceed to the next step.

Step 5 Calculate normalized matrices by dividing each cell by the sum of corresponding columns as in Eq. (4.20).

$$= \left\langle \left[\frac{\mathrm{T}^{\mathrm{L}}_{\mathrm{kj}}}{\sum_{k=1}^{m} T^{U}_{kj}}, \frac{\mathrm{T}^{\mathrm{U}}_{kj}}{\sum_{k=1}^{m} T^{U}_{kj}} \right], \left[\frac{I^{\mathrm{L}}_{\mathrm{kj}}}{\sum_{k=1}^{m} I^{U}_{kj}}, \frac{\mathrm{I}^{\mathrm{U}}_{kj}}{\sum_{k=1}^{m} I^{U}_{kj}} \right], \times \left[\frac{\mathrm{F}^{\mathrm{L}}_{\mathrm{kj}}}{\sum_{k=1}^{m} F^{U}_{kj}}, \frac{\mathrm{F}^{\mathrm{U}}_{kj}}{\sum_{k=1}^{m} F^{U}_{kj}} \right] \qquad (4.20)$$

Step 6 Calculate the average of each component for each criteria as in Eq. (4.21).

$$\tilde{W}_A = \left(\frac{\left[\sum_{k=1}^{m} \frac{\mathrm{T}^{L}_{1j}}{\sum_{k=1}^{m} T^{U}_{kj}}, \sum_{k=1}^{m} \frac{\mathrm{T}^{U}_{1j}}{\sum_{k=1}^{m} T^{U}_{k}} \right]}{m}, \frac{\left[\sum_{k=1}^{m} \frac{\mathrm{L}^{\mathrm{L}}_{1j}}{\sum_{k=1}^{m} I^{U}_{kj}}, \sum_{k=1}^{m} \frac{\mathrm{I}^{\mathrm{U}}_{1j}}{\sum_{k=1}^{n} I^{U}_{kj}} \right]}{m}, \right.$$
$$\times \left(\frac{\left[\sum_{k=1}^{m} \frac{\mathrm{F}^{\mathrm{L}}_{1j}}{\sum_{k=1}^{m} F^{U}_{kj}}, \sum_{k=1}^{m} \frac{\mathrm{F}^{\mathrm{U}}_{1j}}{\sum_{k=1}^{m} F^{U}_{kj}} \right]}{m}, \mathrm{j} = 1, \ldots, \mathrm{m} \qquad (4.21)\right.$$

Step 7 Apply the formula for deneutrosophication as suggested in [35] Eq. (4.22). Obtain crisp values of criteria weights.

$$\mathrm{d} = \left(\frac{T_x^L + T_x^U}{2}\right) + \left(1 - \frac{\left(I_x^L + I_x^U\right)}{2}\right) * I_x^U - \left(\frac{F_x^L + F_x^U}{2}\right) * \left(1 - F_x^U\right) \quad (4.22)$$

Step 8 Normalize weights and create the ranking according to the goal of research.

Chapter 5

Data and results

The main goal of our study is to find what challenges affect the most the performance of IoT in supply chain management. For this reason we contacted experts in the field of supply chain and conducted a meeting to get their judgments in consensus.

Table 5.1: Linguistic terms and corresponding neutrosophic importance

Shortened term	Linguistic term	Neutrosophic sets
EI	Equal importance	<[0.5, 0.5], [0.5, 0.5], [0.5, 0.5]>
WMI	Weakly more importance	< [0.50, 0.60], [0.35, 0.45], [0.40, 0.50]>
MI	Moderate importance	< [0.55, 0.65], [0.30, 0.40], [0.35, 0.45]>
MMI	Moderately more importance	< [0.60, 0.70], [0.25, 0.35], [0.30, 0.40]>
SIMP	Strong importance	< [0.65, 0.75], [0.20, 0.30], [0.25, 0.35]>
SMI	Strongly more importance	< [0.70, 0.80], [0.15, 0.25], [0.20, 0.30]>
VSI	Very strong importance	< [0.75, 0.85], [0.10, 0.20], [0.15, 0.25]>
VSMI	Very strongly more importance	< [0.80, 0.90], [0.05, 0.10], [0.10, 0.20]>
EXI	Extreme importance	< [0.90, 0.95], [0, 0.05], [0.05, 0.15]>
EHI	Extremely high importance	< [0.95, 1.0], [0.0, 0.0], [0.0, 0.10]>
AMI	Absolutely more importance	< [1.0, 1.0], [0.0, 0.0], [0.0, 0.0]>

Step 1. After interviewing experts (Table 5.2) and having discussion, a set of feasible criteria and sub-criteria were selected.

Table 5.2: Decision makers (experts) and their positions

Interviewer	**Position**
Interviewer 1	Professor of Supply Chain Management
Interviewer 2	CEO of consulting company in SCM
Interviewer 3	Associate Professor of Industrial Engineering
Interviewer 4	CIO in the Ministry of Labour of Republic of Kazakhstan
Interviewer 5	CIO of IT department of national post company

Step 2. As stated in Chapter 2, we performed literature review of challenges of IoT and constructed a model as in Figure 3.1.

Step 3. Experts in supply chain management area were contacted and an online meeting via ZOOM application was conducted to decide on consensus-based judgments. In this research the linguistic variables that were initially used in Saaty's scale for crisp numbers (1-9) are converted into their corresponding neutrosophic values [32], [35]. We added shortened terms to avoid confusion while filling up the matrices as in Table 5.1.

Table 5.3: Decision makers (experts) and their positions

	C1	**C2**	**C3**	**C4**	**C5**
C1	EI	VSMI	1/VSI	SIMP	SMI
C2		EI	1/AMI	1/SIMP	1/MI
C3			EI	EXI	EHI
C4				EI	WMI
C5					EI

Overall, we worked out twelve matrices (six for the period before pandemic, six for the period after the pandemic). The pairwise comparison matrices of sub-criteria with respect to the main criteria are provided in the Appendix A.

TABLE 5.4: Example of converting linguistic values into neutrosophic values for first three criteria

	C1									C2					C3					C4					C5					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
C1	0.50	0.50	0.50	0.50	0.50	0.50	0.75	0.85	0.10	0.20	0.15	0.25	0.15	0.25	0.10	0.20	0.75	0.85	0.55	0.65	0.30	0.40	0.35	0.45	0.65	0.75	0.20	0.30	0.25	0.35
C2	0.15	0.25	0.10	0.20	0.75	0.85	0.50	0.50	0.50	0.50	0.50	0.50	0.00	0.00	0.00	0.00	1.00	1.00	0.25	0.35	0.20	0.30	0.65	0.75	0.35	0.45	0.30	0.40	0.55	0.65
C3	0.70	0.80	0.15	0.25	0.20	0.30	1.00	1.00	0.00	0.00	0.00	0.00	0.50	0.50	0.50	0.50	0.50	0.50	0.90	0.95	0.00	0.05	0.05	0.15	0.95	1.00	0.00	0.00	0.00	0.10
C4	0.25	0.35	0.20	0.30	0.65	0.75	0.55	0.65	0.30	0.40	0.35	0.45	0.05	0.15	0.00	0.05	0.90	0.95	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.60	0.35	0.45	0.40	0.50
C5	0.20	0.30	0.15	0.25	0.70	0.80	0.55	0.65	0.15	0.25	0.70	0.80	0.00	0.10	0.00	0.00	0.95	1.00	0.40	0.50	0.35	0.45	0.50	0.60	0.50	0.50	0.50	0.50	0.50	0.50

Step 4. After obtaining pairwise comparison matrices check for consistency ratio of each matrix. We use Eq. 4.22 to obtain deneutrosophicated numbers as in Table 5.5 and convert them into crisp numbers from 1 to 9 as in Table 5.6.

TABLE 5.5: Deneutrosophicated values of decision maker's judgements

	C1	**C2**	**C3**	**C4**	**C5**
C1	0.5	0.82	0.25	0.64	0.73
C2	0.25	0.5	0	0.35	0.45
C3	0.775	1	0.5	0.88875	0.93
C4	0.35	0.64	0.1025	0.5	0.595
C5	0.3	0.65	0.05	0.5	0.5

TABLE 5.6: Pairwise comparison with crisp values

	C1	**C2**	**C3**	**C4**	**C5**
C1	1.00	6.00	0.25	3.00	4.00
C2	0.17	1.00	0.11	0.25	0.33
C3	4.00	9.00	1.00	6.50	8.00
C4	0.33	4.00	0.15	1.00	2.00
C5	0.25	3.00	0.13	0.50	1.00

We calculate normalized matrix as in Table 5.7

TABLE 5.7: Normalized pairwise comparison matrix

	C1	**C2**	**C3**	**C4**	**C5**
C1	0.173913	0.260836	0.152443	0.266667	0.26087
C2	0.028986	0.043473	0.067752	0.022222	0.021739
C3	0.695652	0.391253	0.609772	0.577778	0.521739
C4	0.057971	0.17389	0.093811	0.088889	0.130435
C5	0.043478	0.130548	0.076221	0.044444	0.065217
SUM	1	1	1	1	1

Calculate the criteria weights by averaging rows of the normalized matrix (Table 5.7) as in Table 5.8

TABLE 5.8: Criteria weights

CRITERIA WEIGHTS
0.222946
0.036834
0.559239
0.108999
0.071982

To calculate the λmax multiply criteria weights (Table 5.8) by the rows of initial matrix (Table 5.6); the sum of this row will result in $\lambda max = 5.376331$. Using the Eq. 4.18 and Eq. 4.19 we calculate Consistency Ratio (CR) for the pairwise comparison matrix of criteria with respect to goal (n=5, RI=1.12) as:

$$\text{Cl} = \frac{5.3763 - 5}{5 - 1} = 0.094 \qquad \text{CR} = \frac{0.094}{1.12} = 0.0839$$

We consider the matrix consistent since CR $\leqslant 0.1$ and proceed to further step.

Step 5. Calculate normalized matrix of interval valued neutrosophic comparison matrix by dividing each cell by the sum of columns using Eq. 4.20

TABLE 5.9: Normalized matrix of initial interval valued neutrosophic comparison matrix

	C1						C2						C3						C4						C5					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
C1	0.28	0.23	0.45	0.33	0.18	0.16	0.22	0.23	0.10	0.15	0.09	0.13	0.21	0.25	0.17	0.27	0.18	0.20	0.21	0.22	0.22	0.24	0.17	0.18	0.22	0.23	0.15	0.18	0.15	0.17
C2	0.08	0.11	0.09	0.13	0.27	0.27	0.15	0.14	0.48	0.37	0.29	0.25	0.00	0.00	0.00	0.00	0.24	0.23	0.10	0.12	0.15	0.18	0.32	0.31	0.12	0.14	0.22	0.24	0.32	0.31
C3	0.39	0.36	0.14	0.17	0.07	0.09	0.30	0.27	0.00	0.00	0.00	0.00	0.71	0.50	0.83	0.67	0.12	0.12	0.35	0.32	0.00	0.03	0.02	0.06	0.32	0.30	0.00	0.00	0.00	0.05
C4	0.14	0.16	0.18	0.20	0.23	0.23	0.16	0.18	0.29	0.30	0.21	0.23	0.07	0.15	0.00	0.07	0.22	0.22	0.19	0.17	0.37	0.29	0.24	0.20	0.17	0.18	0.26	0.27	0.24	0.24
C5	0.11	0.14	0.14	0.17	0.25	0.25	0.16	0.18	0.14	0.19	0.41	0.40	0.00	0.10	0.00	0.00	0.23	0.23	0.15	0.17	0.26	0.26	0.24	0.24	0.17	0.15	0.37	0.30	0.29	0.24

Step 6. Calculate the average of each component for each criteria as in Table 5.10

TABLE 5.10: Calculating criteria weights

	Average of components						Criteria Weights	Normalized c.w.	Ranking
	Tl	**Tu**	**Il**	**Iu**	**Fl**	**Fu**			
C1	0.229564	0.231552	0.217364	0.233052	0.153505	0.165853	0.277929	0.27	2
C2	0.089477	0.101126	0.187494	0.18452	0.289296	0.272766	0.041124	0.04	5
C3	0.413974	0.352535	0.193939	0.172549	0.043554	0.063775	0.473943	0.46	1
C4	0.147259	0.167697	0.219432	0.225962	0.227347	0.224496	0.157915	0.15	3
C5	0.119726	0.147091	0.18177	0.183918	0.286298	0.27311	0.080383	0.08	4

Step 7. Using Eq. 4.22 calculate the criteria weights for each criteria.

$$\mathrm{d} = \left(\frac{T_x^L + T_X^U}{2}\right) + \left(1 - \frac{\left(I_x^L + I_x^U\right)}{2}\right) * I_x^U - \left(\frac{F_x^L + F_x^U}{2}\right) * \left(1 - F_x^U\right) \qquad (4.22)$$

Step 8. After normalizing criteria weights, find rankings of criteria and arrange them in order.

TABLE 5.11: Result of ordering the criteria

Ranking	**Criteria**
1	C3
2	C1
3	C4
4	C5
5	C2

Chapter 6

Conclusion and discussion

This research was intended to identify challenges of implementing IoT in the supply chain. The significant addition to the topic is that we observed the change in the significance of identified challenges to see how pandemic of COVID-19 affected the performance.

The results showed resemblance [44], as well as different results in comparison with similar studies [64], [36].

Noticeably, the ranking of the main criteria did not change for both periods, except for the small difference in weights. "Business" related challenges come first when the implementation of IoT is a question. It was explained by decision-makers that economic impact (profit) and effective business model are the core of any business, therefore firms first need to pay great attention to the productiveness of the business plan. The same result with "Business model" being the most important challenge showed the study done in Iran [44], however security related issues in that study assessed to be second of importance while in our study it showed the least value.

Table 6.1: Ranking of the challenges with their corresponding weights before the pandemic

BEFORE					
			WEIGHTS	**RANKING**	**CR**
CRITERIA	C1	FINANCIAL COST	0.27	2	0.08
	C2	SECURITY AND PRIVACY	0.04	5	
	C3	BUSINESS	0.46	1	
	C4	QUALITY	0.15	3	
	C5	TECHNOLOGY	0.08	4	
SUBCRITERIA	C1.1	PURCHASING COST	0.52	1	0.07
C1 FINANCIAL COST	C1.2	TRAINING COST	0.29	2	
	C1.3	RATE OF RETURN	0.18	3	
SUBCRITERIA	C2.1	CONFIDENTIALITY	0.15	3	0.09
C2 SECURITY	C2.2	NETWORK SECURITY	0.37	2	
	C2.3	SCALABILITY	0.04	4	
	C2.4	ROBUSTNESS AND RELIABILITY	0.44	1	
SUBCRITERIA	C3.1	BUSINESS MODEL	0.77	1	0.00
C3 BUSINESS	C3.2	ECONOMIC IMPACT	0.23	2	
SUBCRITERIA	C4.1	CUSTOMER EXPECTATIONS	0.55	1	0.03
C4 QUALITY	C4.2	INFORMATION QUALITY	0.15	3	
	C4.3	PERCEPTION QUALITY	0.29	2	
SUBCRITERIA	C5.1	HETEROGENEITY	0.48	1	0.04
C5 TECHNOLOGY	C5.2	DATA MANAGEMENT	0.35	3	
	C5.3	TECHNOLOGICAL UNAWARENESS	0.17	2	

As can be seen from Table 6.1 and Tale 6.2 the ranking remained the same with slightly different weights in both assessment periods: Business, Financial cost, Quality, Technology and Security.

As for sub-criteria ranking, we observed the change during the pandemic in two criteria: financial cost and security. For financial cost criteria "purchasing cost" gained more than half of weights (0.52 for before, 0.61 for after the pandemic); however if before pandemic managers paid attention to the "training" expenditure (0.29) Table 6.3, after the pandemic it became secondary to the "rate of return" Table 6.5. The change is based on the necessity of adjusting finances for the crisis caused by the pandemic, as well as changes in delivering services due to quarantine measures.

TABLE 6.2: Ranking of the challenges with their corresponding weights after the pandemic

AFTER					
			WEIGHTS	RANKING	CR
CRITERIA	C1	FINANCIAL COST	0.28	2	0.092
	C2	SECURITY AND PRIVACY	0.03	5	
	C3	BUSINESS	0.45	1	
	C4	QUALITY	0.16	3	
	C5	TECHNOLOGY	0.08	4	
SUBCRITERIA C1 FINANCIAL COST	C1.1	PURCHASING COST	0.61	1	0.077
	C1.2	TRAINING COST	0.14	3	
	C1.3	RATE OF RETURN	0.25	2	
SUBCRITERIA C2 SECURITY	C2.1	CONFIDENTIALITY	0.01	4	0.096
	C2.2	NETWORK SECURITY	0.22	3	
	C2.3	SCALABILITY	0.42	1	
	C2.4	ROBUSTNESS AND RELIABILITY	0.35	2	
SUBCRITERIA C3 BUSINESS	C3.1	BUSINESS MODEL	0.77	1	0
	C3.2	ECONOMIC IMPACT	0.23	2	
SUBCRITERIA C4 QUALITY	C4.1	CUSTOMER EXPECTATIONS	0.62	1	0.057
	C4.2	INFORMATION QUALITY	0.08	3	
	C4.3	PERCEPTION QUALITY	0.30	2	
SUBCRITERIA C5 TECHNOLOGY	C5.1	HETEROGENEITY	0.48	1	0.054
	C5.2	DATA MANAGEMENT	0.35	3	
	C5.3	TECHNOLOGICAL UNAWARENESS	0.17	2	

Security related challenges coming the last as a main criterion, experienced changes in sub-criteria ranking; robustness and reliability had substantial importance (0.44) before the pandemic whereas after its weight decreased to 0.35. "Scalability" was the least priority for the experts before the pandemic with weight 0.04 Table 6.4; however after for the period after the pandemic it became first priority (0.42) Table 6.6. Experts suggest that economic impact of the COVID-19 pandemic will require security network to be expandable since most of the operations are converted to online format.

TABLE 6.3: Ranking of sub-criteria under "Financial cost" before the pandemic

PURCHASING COST	0.52
TRAINING COST	0.29
RATE OF RETURN	0.18

Table 6.4: Ranking of sub-criteria under "Security" before the pandemic

ROBUSTNESS AND RELIABILITY	0.44
NETWORK SECURITY	0.37
CONFIDENTIALITY	0.15
SCALABILITY	0.04

The study conducted on challenges and benefits of IoT in supply chain in [64] determined that for individual organizations security is the first priority and business related risks ranked 4^{th} among overall fifteen criteria. Mohammadzadeh [44] detected that technological issues are of huge value in industries in Iran, whilst in our study it was ranked fourth just before the "security".

Table 6.5: Ranking of sub-criteria under "Financial cost" after the pandemic

PURCHASING COST	0.61
RATE OF RETURN	0.25
TRAINING COST	0.14

Table 6.6: Ranking of sub-criteria under "Security" after the pandemic

SCALABILITY	0.42
ROBUSTNESS AND RELIABILITY	0.35
NETWORK SECURITY	0.22
CONFIDENTIALITY	0.01

The interview with experts revealed some factors of our ranking being identical for both periods: the time span is not clear enough for determining substantial effect. It was recommended to repeat the study after another six month and observe increment in weights. Also it is recommended to involve more decision-makers of various management rankings to consider different perspectives. As for the tool for evaluation AHP with interval-valued neutrosophic numbers, since the tool is quite new and not widely used it is recommended to perform sensitivity analysis with using other MCDA tools like fuzzy AHP, Pythagorean AHP. The difference in rankings with other studies might be explained by the specific field the study was implemented to; thus it is recommended to apply the assessment to certain region and channels.

Bibliography

[1] A. Rojko, "Industry 4.0 concept: Background and overview," Int. J. Interact. Mob. Technol., vol. 11, no. 5, pp. 77-90, 2017.

[2] J. T. Mentzer, J. S. Keebler, N. W. Nix, C. D. Smith, and Z. G. Zacharia, "JOURNAL OF BUSINESS LOGISTICS, Vol.22, No. 2, 2001 1," J. Bus., vol. 22, no. 2, pp. 1-25, 2001.

[3] D. Express, "INTERNET OF THINGS IN LOGISTICS A COLLABORATIVE REPORT BY DHL AND CISCO ON IMPLICATIONS ANDUSE CASES FOR THE LOGISTICS INDUSTRY Powered by DHL Trend Research," 2017.

[4] "Every. Thing. Connected."

[5] "How we are responding to the coronavirus at Ericsson - Ericsson." [Online]. Available: https://www.ericsson.com/en/blog/2020/3/coronavirus-response-ericsson. [Accessed: 03-Jul-2020].

[6] D. Kozma, P. Varga, and C. Hegedus, "Supply Chain Management and Logistics 4.0-A Study on Arrowhead Framework Integration," Proc. 2019 8th Int. Conf. Ind. Technol. Manag. ICITM 2019, pp. 12-16, 2019.

[7] M. Abdel-basset, G. Manogaran, and M. Mohamed, "Internet of Things (IoT) and its impact on supply chain.: A framework for building smart , secure and efficient systems," Futur. Gener. Comput. Syst., vol. 86, pp. 614-628, 2018.

[8] M. Tu, "An exploratory study of internet of things (IoT) adoption intention in logistics and supply chain management a mixed research approach," Int. J. Logist. Manag., vol. 29, no. 1, pp. 131-151, 2018.

[9] E. Manavalan and K. Jayakrishna, "A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements," Comput. Ind. Eng., vol. 127, no. November 2018, pp. 925-953, 2019.

[10] K. Baroudy, S. Kishore, S. Nair, and M. Patel, "Unlocking value from IoT connectivity: Six considerations for choosing a provider | McKinsey Company," no. February, pp. 1-8, 2018.

[11] Y. Kim, B. Choi, and J. Choi, "A Study on the Successful Adoption of IoT Services.: Focused on iBeacon and Nearby," J. Korea Soc. IT Serv., vol. 14, no. 1, pp. 217-236, 2015.

[12] C. L. Hsu and J. C. C. Lin, "Exploring factors affecting the adoption of internet of things services," J. Comput. Inf. Syst., vol. 58, no. 1, pp. 49-57, 2018.

[13] Particle, "2019 State of IoT Report," pp. 1-34, 2019.

[14] Statista, "Coronavirus: impact on the global economy," no. 212, pp. 1-4, 2020.

[15] S. Barua, "Munich Personal RePEc Archive Understanding Coronanomics: The economic implications of the coronavirus (COVID-19) pandemic Understanding Coronanomics: The economic implications of the coronavirus (COVID-19) pandemic," no. 99693, 2020.

[16] R. P. Singh, M. Javaid, A. Haleem, and R. Suman, "Internet of things (IoT) applications to fight against COVID-19 pandemic," Diabetes Metab. Syndr., vol. 14, no. 4, pp. 521-524, 2020.

[17] M. Javaid, A. Haleem, R. Vaishya, S. Bahl, R. Suman, and A. Vaish, "Industry 4.0 technologies and their applications in fighting COVID-19 pandemic," Diabetes Metab. Syndr. Clin. Res. Rev., vol. 14, no. 4, pp. 419-422, 2020.

[18] N. J. Rowan and J. G. Laffey, "Challenges and solutions for addressing critical shortage of supply chain for personal and protective equipment (PPE) arising from Coronavirus disease (COVID19) pandemic - Case study from the Republic of Ireland," Sci. Total Environ., vol. 725, p. 138532, 2020.

[19] "Covid-19 Impact on Internet of Things (IoT) Market | Coronavirus Outbreak IoT Industry | MarketsandMarkets." [Online]. Available:

https://www.marketsandmarkets.com/Market-Reports/covid-19-impact-on-iot-market-212332561.html. [Accessed: 03-Jul-2020].

[20] DETR, Multicriteria Analysis - A manual. Crown, 2009.

[21] P. P. Bonissone, R. Subbu, and J. Lizzi, "Multicriteria decision making (MCDM): A framework for research and applications," IEEE Comput. Intell. Mag., vol. 4, no. 3, pp. 48-61, 2009.

[22] N. Kadoic, N. B. Redep, and B. Divjak, "Decision making with the analytic network process," Proc. 14th Int. Symp. Oper. Res. SOR 2017, vol. 2017-Septe, no. Section 2, pp. 180-186, 2017.

[23] S. Unver and T. Gurbuz, "Threat evaluation using analytic network process," IFAC-PapersOnLine, vol. 28, no. 3, pp. 8-13, 2015.

[24] G. Büyüközkan, S. Güleryüz, and B. Karpak, "A new combined IF-DEMATEL and IF-ANP approach for CRM partner evaluation," Int. J. Prod. Econ., vol. 191, no. October 2016, pp. 194-206, 2017.

[25] I. Y. Lu, T. Kuo, T. S. Lin, G. H. Tzeng, and S. L. Huang, "Multicriteria decision analysis to develop effective sustainable development strategies for enhancing competitive advantages: Case of the TFT-LCD industry in Taiwan," Sustain., vol. 8, no. 7, 2016.

[26] K. Razieh and M. Ahmad, "An IF-DEMATEL-AHP based on Triangular Intuitionistic Fuzzy Numbers (TIFNs)," Decis. Sci. Lett., vol. 4, no. 2, pp. 237-246, 2015.

[27] F. Smarandache, "Neutrosophic Logic - a Generalization of the Intuitionistic Fuzzy Logic," SSRN Electron. J., 2016.

[28] M. Abdel-Basset, M. Mohamed, and F. Smarandache, "An extension of neutrosophic AHP-SWOT analysis for strategic planning and decision-making," Symmetry (Basel)., vol. 10, no. 4, 2018.

[29] N. A. Nabeeh, M. Abdel-Basset, H. A. El-Ghareeb, and A. Aboelfetouh, "Neutrosophic Multi-Criteria Decision Making Approach for IoT-Based Enterprises," IEEE Access, vol. 7, pp. 59559-59574, 2019.

[30] M. Abdel-Basset, M. Mohamed, and A. K. Sangaiah, "Neutrosophic AHP-Delphi Group decision making model based on trapezoidal neutrosophic numbers," J. Ambient Intell. Humaniz. Comput., vol. 9, no. 5, pp. 1427-1443, 2018.

[31] D. J. Y. Tey et al., "A Novel Neutrosophic Data Analytic Hierarchy Process for Multi-Criteria Decision Making Method: A Case Study in Kuala Lumpur Stock Exchange," IEEE Access, vol. 7, pp. 53687-53697, 2019.

[32] N. M. Radwan, M. B. Senousy, and A. E. D. M. Riad, "Neutrosophic AHP Multi Criteria Decision Making Method Applied on the Selection of Learning Management System," Int. J. Adv. Comput. Technol., vol. 8, no. 5, pp. 95-105, 2016.

[33] H. Wang, F. Smarandache, Y.-Q. Zhang, and R. Sunderraman, "Interval Neutrosophic Sets and Logic: Theory and Applications in Computing," 2005.

[34] S. Aydın, C. Kahraman, and M. Kabak, "Decision making for energy investments by using neutrosophic present worth analysis with interval-valued parameters," Eng. Appl. Artif. Intell., vol. 92, no. April, p. 103639, 2020.

[35] E. Bolturk and C. Kahraman, "A novel interval-valued neutrosophic AHP with cosine similarity measure," Soft Comput., vol. 22, no. 15, pp. 4941-4958, 2018.

[36] M. Abdel-Basset, G. Manogaran, and M. Mohamed, "Internet of Things (IoT) and its impact on supply chain: A framework for building smart, secure and efficient systems," Futur. Gener. Comput. Syst., vol. 86, pp. 614-628, 2018.

[37] W. Ossadnik, S. Schinke, and R. H. Kaspar, "Group Aggregation Techniques for Analytic Hierarchy Process and Analytic Network Process: A Comparative Analysis," Gr. Decis. Negot., vol. 25, no. 2, pp. 421-457, 2016.

[38] L. X. X. Xia, B. Ma, and R. Lim, "Supplier performance measurement in a supply chain," IEEE Int. Conf. Ind. Informatics, pp. 877-881, 2008.

[39] B. Cayir Ervural, S. Zaim, O. F. Demirel, Z. Aydin, and D. Delen, "An ANP and fuzzy TOPSIS-based SWOT analysis for Turkey's energy planning," Renew. Sustain. Energy Rev., vol. 82, no. April 2016, pp. 1538-1550, 2018.

[40] B. Zhu, Z. Xu, R. Zhang, and M. Hong, "Generalized analytic network process," Eur. J. Oper. Res., vol. 244, no. 1, pp. 277-288, 2015.

[41] P. Boateng, Z. Chen, and S. O. Ogunlana, "An Analytical Network Process model for risks prioritisation in megaprojects," Int. J. Proj. Manag., vol. 33, no. 8, pp. 1795-1811, 2015.

[42] C. Kahraman, S. C. Onar, and B. Oztaysi, "Fuzzy Multicriteria Decision-Making: A Literature Review," Int. J. Comput. Intell. Syst., vol. 8, no. 4, pp. 637-666, 2015.

[43] Y. Chen et al., "Analytic network process: Academic insights and perspectives analysis," J. Clean. Prod., vol. 235, pp. 1276-1294, 2019.

[44] A. K. Mohammadzadeh, S. Ghafoori, A. Mohammadian, R. Mohammadkazemi, B. Mahbanooei, and R. Ghasemi, "A Fuzzy Analytic Network Process (FANP) approach for prioritizing internet of things challenges in Iran," Technol. Soc., vol. 53, pp. 124-134, 2018.

[45] M. Park, H. Oh, and K. Lee, "Security risk measurement for information leakage in IoT-based smart homes from a situational awareness perspective," Sensors (Switzerland), vol. 19, no. 9, 2019.

[46] J. Ito, D. Kaufman, M. Olson, and J. Bruner, "The Internet of Things: Five crucial questions," McKinsey Q., no. August, 2015.

[47] "The Trust Opportunity: Exploring Consumer Attitudes to the Internet of Things | Internet Society." [Online]. Available: https://www.internetsociety.org/resources/doc/2019/trust-opportunity-exploring-consumer-attitudes-to-iot/. [Accessed: 03-Jul-2020].

[48] B. D. Weinberg, G. R. Milne, Y. G. Andonova, and F. M. Hajjat, "Internet of Things: Convenience vs. privacy and secrecy," Bus. Horiz., vol. 58, no. 6, pp. 615-624, 2015.

[49] D. E. Kouicem, A. Bouabdallah, and H. Lakhlef, "Internet of things security: A top-down survey," Comput. Networks, vol. 141, pp. 199-221, 2018.

[50] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A vision, architectural elements, and future directions," Futur. Gener. Comput. Syst., vol. 29, no. 7, pp. 1645-1660, 2013.

[51] S. Biswas and J. Sen, "A Proposed Framework of Next Generation Supply Chain Management Using Big Data Analytics," Proc. Natl. Conf. Emerg. Trends Bus. Manag. Issues Challenges, Kolkata, India, March 17 -18, 2016., 2016.

[52] D. Kiel, C. Arnold, and K. I. Voigt, "The influence of the Industrial Internet of Things on business models of established manufacturing companies - A business level perspective," Technovation, vol. 68, no. September 2016, pp. 4-19, 2017.

[53] R. M. Dijkman, B. Sprenkels, T. Peeters, and A. Janssen, "Business models for the Internet of Things," Int. J. Inf. Manage., vol. 35, no. 6, pp. 672-678, 2015.

[54] Frontier Economics, "The Economic Impact of IoT PUTTING NUMBERS ON A REVOLUTIONARY TECHNOLOGY," no. March, 2018.

[55] S. Wibowo and S. Grandhi, "Fuzzy multicriteria analysis for performance evaluation of internet-of-things-based supply chains," Symmetry (Basel)., vol. 10, no. 11, 2018.

[56] R. Martinho and D. Domingos, "Quality of Information and Access Cost of IoT Resources in BPMN Processes," Procedia Technol., vol. 16, pp. 737-744, 2014.

[57] M. Chui, "Taking the pulse of enterprise IoT," McKinsey, no. July, 2017.

[58] D. H. Shin, "Conceptualizing and measuring quality of experience of the internet of things: Exploring how quality is perceived by users," Inf. Manag., vol. 54, no. 8, pp. 998-1011, 2017.

[59] P. Khanna and A. Sharma, "Integrating SCM with internet of things: Implication on HR management," ACM Int. Conf. Proceeding Ser., 2017.

[60] D. Kudou, A. Okamoto, and Y. Murata, INTERNET OF THINGS- ROBUSTNESS AND RELIABILITY, no. July. Elsevier Inc., 2018.

[61] X. Dong, Y. Chang, Y. Wang, and J. Yan, "Understanding usage of Internet of Things (IOT) systems in China: Cognitive experience and affect experience as moderator," Inf. Technol. People, vol. 30, no. 1, pp. 117-138, 2017.

[62] "Gartner's 2015 Hype Cycle for Emerging Technologies Identifies the Computing Innovations That Organizations Should Monitor." [Online]. Available: https://www.gartner.com/en/newsroom/press-releases/2015-08-18-gartners-2015-hype-cycle-for-emerging-technologies-identifies-the-computing-innovations-that-organizations-should-monitor. [Accessed: 03-Jul-2020].

[63] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi, "Internet of things for smart cities," IEEE Internet Things J., vol. 1, no. 1, pp. 22-32, 2014.

[64] A. Haddud, A. DeSouza, A. Khare, and H. Lee, "Examining potential benefits and challenges associated with the Internet of Things integration in supply chains," J. Manuf. Technol. Manag., vol. 28, no. 8, pp. 1055-1085, 2017.

[65] K. Rose, "The Internet of Things: An Overview," 2015.

[66] "Technology Trend Awareness: 15 Examples for Setting Performance Goals - EMPLOYEEPEDIA." [Online]. Available: https://www.employeepedia.com/manage/setting-goals/8259-technology-trend-awareness-15-examples-for-setting-performance-goals. [Accessed: 10-Jul-2020].

Appendix A

Performing AHP with interval-valued neutrosophic numbers

Table A.1: Judgments of decision-makers on sub-criteria under "Business"

BEFORE

	C1						C2					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
C1	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	0.95	1.00	0.00	0.00	0.00	0.10
C2	0.00	0.10	0.00	0.00	0.95	1.00	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**
Sum	0.50	0.60	0.50	0.50	1.45	1.50	1.45	1.50	0.50	0.50	0.50	0.60

Normalized	**C1**						**C2**					
C1	1.00	0.83	1.00	1.00	0.34	0.33	0.66	0.67	0.00	0.00	0.00	0.17
C2	0.00	0.17	0.00	0.00	0.66	0.67	0.34	0.33	1.00	1.00	1.00	0.83

Table A.2: Calculated criteria weights of sub-criteria under "Business"

Average of columns						**Criteria Weight**	**Normalized c.w.**
Tl	**Tu**	**Il**	**Iu**	**Fl**	**Fu**		
0.83	0.75	0.50	0.50	0.17	0.25	0.88	0.77
0.17	0.25	0.50	0.50	0.83	0.75	0.26	0.23

Table A.3: Judgments of decision-makers on sub-criteria under "Business"

AFTER

	C1						C2					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
C1	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	1.00	1.00	0.00	0.00	0.00	0.00
C2	0.00	0.00	0.00	0.00	1.00	1.00	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**
Sum	0.50	0.50	0.50	0.50	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.50

Normalized	C1						C2					
C1	1.00	1.00	1.00	1.00	0.33	0.33	0.67	0.67	0.00	0.00	0.00	0.00
C2	0.00	0.00	0.00	0.00	0.67	0.67	0.33	0.33	1.00	1.00	1.00	1.00

Table A.4: Calculated criteria weights of sub-criteria under "Business"

Average of columns						**Criteria Wei.**	**Normalized c.w.**
Tl	**Tu**	**Il**	**Iu**	**Fl**	**Fu**		
0.83	0.83	0.50	0.50	0.17	0.17	0.94	0.77
0.17	0.17	0.50	0.50	0.83	0.83	0.28	0.23

Table A.5: Judgments of decision-makers on sub-criteria under "Financial cost"

Before

	C1						C2						C3					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
C1	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	0.90	0.95	0.00	0.05	0.05	0.15	1.00	1.00	0.00	0.00	0.00	0.00
C2	0.05	0.15	0.00	0.05	0.90	0.95	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	0.65	0.75	0.20	0.30	0.25	0.35
C3	0.00	0.00	0.00	0.00	1.00	1.00	0.25	0.35	0.20	0.30	0.65	0.75	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**
Sum	0.55	0.65	0.50	0.55	2.40	2.45	1.65	1.80	0.70	0.85	1.20	1.40	2.15	2.25	0.70	0.80	0.75	0.85

Norm.	C1						C2						C3					
C1	0.91	0.77	1.00	0.91	0.21	0.20	0.55	0.53	0.00	0.06	0.04	0.11	0.47	0.44	0.00	0.00	0.00	0.00
C2	0.09	0.23	0.00	0.09	0.38	0.39	0.30	0.28	0.71	0.59	0.42	0.36	0.30	0.33	0.29	0.38	0.33	0.41
C3	0.00	0.00	0.00	0.00	0.42	0.41	0.15	0.19	0.29	0.35	0.54	0.54	0.23	0.22	0.71	0.63	0.67	0.59

Table A.6: Calculated criteria weights of sub-criteria under "Financial cost"

Average of columns						**Criteria Wei.**	**Normalized c.w.**
Tl	**Tu**	**Il**	**Iu**	**Fl**	**Fu**		
0.64	0.58	0.33	0.32	0.08	0.10	0.74	0.68
0.23	0.28	0.33	0.35	0.38	0.39	0.25	0.23
0.13	0.14	0.33	0.33	0.54	0.51	0.09	0.09

Table A.7: Judgments of decision-makers on sub-criteria under "Financial cost"

After

	C1						**C2**						**C3**					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
C1	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	1.00	1.00	0.00	0.00	0.00	0.00	0.75	0.85	0.10	0.20	0.15	0.25
C2	0.00	0.00	0.00	0.00	1.00	1.00	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	0.50	0.60	0.35	0.45	0.40	0.50
C3	0.15	0.25	0.10	0.20	0.75	0.85	0.40	0.50	0.35	0.45	0.50	0.60	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**
Sum	0.65	0.75	0.60	0.70	2.25	2.35	1.90	2.00	0.85	0.95	1.00	1.10	1.75	1.95	0.95	1.15	1.05	1.25

Norm.	**C1**						**C2**						**C3**					
C1	0.77	0.67	0.83	0.71	0.22	0.21	0.53	0.50	0.00	0.00	0.00	0.00	0.43	0.44	0.11	0.17	0.14	0.20
C2	0.00	0.00	0.00	0.00	0.44	0.43	0.26	0.25	0.59	0.53	0.50	0.45	0.29	0.31	0.37	0.39	0.38	0.40
C3	0.23	0.33	0.17	0.29	0.33	0.36	0.21	0.25	0.41	0.47	0.50	0.55	0.29	0.26	0.53	0.43	0.48	0.40

Table A.8: Calculated criteria weights of sub-criteria under "Financial cost"

Average of columns						**Criteria Wei.**	**Normalized**
Tl	**Tu**	**Il**	**Iu**	**Fl**	**Fu**		
0.57	0.53	0.31	0.30	0.12	0.14	0.65	0.61
0.18	0.19	0.32	0.31	0.44	0.43	0.15	0.14
0.24	0.28	0.37	0.40	0.44	0.44	0.26	0.25

Table A.9: Judgments of decision-makers on sub-criteria under "Security"

Before

	C1						**C2**						**C3**						**C4**					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
C1	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	0.2	0.3	0.15	0.25	0.7	0.8	0.55	0.65	0.3	0.4	0.35	0.45	0.1	0.2	0.05	0.1	0.8	0.9
C2	0.7	0.8	0.15	0.25	0.2	0.3	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	0.8	0.9	0.05	0.1	0.1	0.2	0.35	0.45	0.3	0.4	0.55	0.65
C3	0.35	0.45	0.3	0.4	0.55	0.65	0.1	0.2	0.05	0.1	0.8	0.9	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	0	0.1	0	0	1	1
C4	0.8	0.9	0.05	0.1	0.1	0.2	0.55	0.65	0.3	0.4	0.35	0.45	0.95	1	0	0	0	0.1	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
Sum	2.35	2.65	1	1.25	1.35	1.65	1.35	1.65	1	1.25	2.35	2.65	2.8	3.05	0.85	1	0.95	1.25	0.95	1.25	0.85	1	2.85	3.05

Norm	**C1**						**C2**						**C3**						**C4**					
C1	0.21	0.19	0.5	0.4	0.37	0.3	0.15	0.18	0.15	0.2	0.3	0.3	0.2	0.21	0.35	0.4	0.37	0.36	0.11	0.16	0.06	0.1	0.28	0.3
C2	0.3	0.3	0.15	0.2	0.15	0.18	0.37	0.3	0.5	0.4	0.21	0.19	0.29	0.3	0.06	0.1	0.11	0.16	0.37	0.36	0.35	0.4	0.19	0.21
C3	0.15	0.17	0.3	0.32	0.41	0.39	0.07	0.12	0.05	0.08	0.34	0.34	0.18	0.16	0.59	0.5	0.53	0.4	0	0.08	0	0	0.35	0.33
C3	0.34	0.34	0.05	0.08	0.07	0.12	0.41	0.39	0.3	0.32	0.15	0.17	0.34	0.33	0	0	0	0.08	0.53	0.4	0.59	0.5	0.18	0.16

Table A.10: Calculated criteria weights of sub-criteria under "Security"

Average of columns						**Criteria Wei.**	**Normalize**
Tl	**Tu**	**Il**	**Iu**	**Fl**	**Fu**		
0.17	0.19	0.27	0.28	0.33	0.31	0.16	0.15
0.33	0.31	0.27	0.28	0.16	0.19	0.38	0.37
0.10	0.13	0.23	0.23	0.41	0.37	0.05	0.04
0.40	0.37	0.23	0.23	0.10	0.13	0.46	0.44

TABLE A.11: Judgments of decision-makers on sub-criteria under "Security"

	After																							
	C1						**C2**						**C3**						**C4**					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
C1	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	0.25	0.35	0.2	0.3	0.65	0.75	0.05	0.15	0	0.05	0.9	0.95	0	0.1	0	0	1	1
C2	0.65	0.75	0.2	0.3	0.25	0.35	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	0.15	0.25	0.1	0.2	0.75	0.85	0.35	0.45	0.3	0.4	0.55	0.65
C3	0.9	0.95	0	0.05	0.05	0.15	0.75	0.85	0.1	0.2	0.15	0.25	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	0.55	0.65	0.3	0.4	0.35	0.45
C4	0.95	1	0	0	0	0.1	0.55	0.65	0.3	0.4	0.35	0.45	0.35	0.45	0.3	0.4	0.55	0.65	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
Sum	3	3.2	0.7	0.85	0.8	1.1	2.05	2.35	1.1	1.4	1.65	1.95	1.05	1.35	0.9	1.15	2.7	2.95	1.4	1.7	1.1	1.3	2.4	2.6

Norm	**C1**						**C2**						**C3**						**C4**					
C1	0.17	0.16	0.71	0.59	0.63	0.45	0.12	0.15	0.18	0.21	0.39	0.38	0.05	0.11	0	0.04	0.33	0.32	0	0.06	0	0	0.42	0.38
C2	0.22	0.23	0.29	0.35	0.31	0.32	0.24	0.21	0.45	0.36	0.3	0.26	0.14	0.19	0.11	0.17	0.28	0.29	0.25	0.26	0.27	0.31	0.23	0.25
C3	0.3	0.3	0	0.06	0.06	0.14	0.37	0.36	0.09	0.14	0.09	0.13	0.48	0.37	0.56	0.43	0.19	0.17	0.39	0.38	0.27	0.31	0.15	0.17
C4	0.32	0.31	0	0	0	0.09	0.27	0.28	0.27	0.29	0.21	0.23	0.33	0.33	0.33	0.35	0.2	0.22	0.36	0.29	0.45	0.38	0.21	0.19

TABLE A.12: Calculated criteria weights of sub-criteria under "Security"

Average of colums						**Criteria Wei.**	**Normalize**
Tl	**Tu**	**Il**	**Iu**	**Fl**	**Fu**		
0.08	0.12	0.22	0.21	0.44	0.39	0.01	0.01
0.21	0.22	0.28	0.30	0.28	0.28	0.23	0.22
0.38	0.35	0.23	0.24	0.12	0.15	0.43	0.42
0.32	0.30	0.27	0.25	0.16	0.18	0.36	0.35

TABLE A.13: Judgments of decision-makers on sub-criteria under "Quality"

	Before																	
	C1						**C2**						**C3**					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
C1	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	0.90	0.95	0.00	0.05	0.05	0.15	0.70	0.80	0.15	0.25	0.20	0.30
C2	0.05	0.15	0.00	0.05	0.90	0.95	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	0.35	0.45	0.30	0.40	0.55	0.65
C3	0.20	0.30	0.15	0.25	0.70	0.80	0.55	0.65	0.30	0.40	0.35	0.45	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**
Sum	0.75	0.95	0.65	0.80	2.10	2.25	1.95	2.10	0.80	0.95	0.90	1.10	1.55	1.75	0.95	1.15	1.25	1.45

Norm.	**C1**						**C2**						**C3**					
C1	0.67	0.53	0.77	0.63	0.24	0.22	0.46	0.45	0.00	0.05	0.06	0.14	0.45	0.46	0.16	0.22	0.16	0.21
C2	0.07	0.16	0.00	0.06	0.43	0.42	0.26	0.24	0.63	0.53	0.56	0.45	0.23	0.26	0.32	0.35	0.44	0.45
C3	0.27	0.32	0.23	0.31	0.33	0.36	0.28	0.31	0.38	0.42	0.39	0.41	0.32	0.29	0.53	0.43	0.40	0.34

TABLE A.14: Calculated criteria weights of sub-criteria under "Quality"

Average of columns						**Criteria Wei.**	**Normalized**
Tl	**Tu**	**Il**	**Iu**	**Fl**	**Fu**		
0.53	0.48	0.31	0.30	0.15	0.19	0.57	0.55
0.18	0.22	0.31	0.31	0.47	0.44	0.16	0.15
0.29	0.30	0.38	0.39	0.37	0.37	0.30	0.29

TABLE A.15: Judgments of decision-makers on sub-criteria under "Quality"

	After																	
	C1						C2						C3					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
C1	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	1.00	1.00	0.00	0.00	0.00	0.00	0.75	0.85	0.10	0.20	0.15	0.25
C2	0.00	0.00	0.00	0.00	1.00	1.00	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	0.25	0.35	0.20	0.30	0.65	0.75
C3	0.15	0.25	0.10	0.20	0.75	0.85	0.65	0.75	0.20	0.30	0.25	0.35	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**
Sum	0.65	0.75	0.60	0.70	2.25	2.35	2.15	2.25	0.70	0.80	0.75	0.85	1.50	1.70	0.80	1.00	1.30	1.50

Norm	C1						C2						C3					
C1	0.77	0.67	0.83	0.71	0.22	0.21	0.47	0.44	0.00	0.00	0.00	0.00	0.50	0.50	0.13	0.20	0.12	0.17
C2	0.00	0.00	0.00	0.00	0.44	0.43	0.23	0.22	0.71	0.63	0.67	0.59	0.17	0.21	0.25	0.30	0.50	0.50
C3	0.23	0.33	0.17	0.29	0.33	0.36	0.30	0.33	0.29	0.38	0.33	0.41	0.33	0.29	0.63	0.50	0.38	0.33

TABLE A.16: Calculated criteria weights of sub-criteria under "Quality"

Average of columns						**Criteria Wei.**	**Normalized**
Tl	**Tu**	**Il**	**Iu**	**Fl**	**Fu**		
0.58	0.54	0.32	0.30	0.11	0.13	0.66	0.62
0.13	0.14	0.32	0.31	0.54	0.50	0.09	0.08
0.29	0.32	0.36	0.39	0.35	0.37	0.32	0.30

TABLE A.17: Judgments of decision-makers on sub-criteria under "Technology"

	Before																	
	C1						C2						C3					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
C1	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	0.60	0.70	0.25	0.35	0.30	0.40	0.75	0.85	0.10	0.20	0.15	0.25
C2	0.30	0.40	0.25	0.35	0.60	0.70	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	0.65	0.75	0.20	0.30	0.25	0.35
C3	0.15	0.25	0.10	0.20	0.75	0.85	0.25	0.35	0.20	0.30	0.65	0.75	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**
Sum	0.95	1.15	0.85	1.05	1.85	2.05	1.35	1.55	0.95	1.15	1.45	1.65	1.90	2.10	0.80	1.00	0.90	1.10

Norm	C1						C2						C3					
C1	0.53	0.43	0.59	0.48	0.27	0.24	0.44	0.45	0.26	0.30	0.21	0.24	0.39	0.40	0.13	0.20	0.17	0.23
C2	0.32	0.35	0.29	0.33	0.32	0.34	0.37	0.32	0.53	0.43	0.34	0.30	0.34	0.36	0.25	0.30	0.28	0.32
C3	0.16	0.22	0.12	0.19	0.41	0.41	0.19	0.23	0.21	0.26	0.45	0.45	0.26	0.24	0.63	0.50	0.56	0.45

TABLE A.18: Calculated criteria weights of sub-criteria under "Technology"

Average of columns						**Criteria Wei.**	**Normalized**
Tl	**Tu**	**Il**	**Iu**	**Fl**	**Fu**		
0.46	0.43	0.33	0.33	0.21	0.24	0.49	0.48
0.34	0.34	0.36	0.36	0.32	0.32	0.36	0.35
0.20	0.23	0.32	0.32	0.47	0.44	0.18	0.17

Table A.19: Judgments of decision-makers on sub-criteria under "Technology"

	After																	
	C1						**C2**						**C3**					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
C1	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	0.60	0.70	0.25	0.35	0.30	0.40	0.75	0.85	0.10	0.20	0.15	0.25
C2	0.30	0.40	0.25	0.35	0.60	0.70	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	0.65	0.75	0.20	0.30	0.25	0.35
C3	0.15	0.25	0.10	0.20	0.75	0.85	0.25	0.35	0.20	0.30	0.65	0.75	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**
Sum	0.95	1.15	0.85	1.05	1.85	2.05	1.35	1.55	0.95	1.15	1.45	1.65	1.90	2.10	0.80	1.00	0.90	1.10

Norm.	**C1**						**C2**						**C3**					
C1	0.53	0.43	0.59	0.48	0.27	0.24	0.44	0.45	0.26	0.30	0.21	0.24	0.39	0.40	0.13	0.20	0.17	0.23
C2	0.32	0.35	0.29	0.33	0.32	0.34	0.37	0.32	0.53	0.43	0.34	0.30	0.34	0.36	0.25	0.30	0.28	0.32
C3	0.16	0.22	0.12	0.19	0.41	0.41	0.19	0.23	0.21	0.26	0.45	0.45	0.26	0.24	0.63	0.50	0.56	0.45

Table A.20: Calculated criteria weights of sub-criteria under "Technology"

Average of columns						**Criteria Wei.**	**Normalized**
Tl	**Tu**	**Il**	**Iu**	**Fl**	**Fu**		
0.46	0.43	0.33	0.33	0.21	0.24	0.49	0.48
0.34	0.34	0.36	0.36	0.32	0.32	0.36	0.35
0.20	0.23	0.32	0.32	0.47	0.44	0.18	0.17