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Research Article

Evaluation of Augmented Reality Tools Performance in Digital Supply Chain Management: A Group Decision Making Method

Abdullah Yıldızbası [1]*, Babak Daneshvar Rouyednegh (B. Erdebilli)[2], Barış Ozen[3], Yavuz Selim Özdemir[4]

[1*] Department of Industrial Engineering, Ankara Yıldırım Beyazıt University (AYBU), 06010, Ankara, TURKEY, (ORCID: 0000-0001-8104-3392), ayildizbasi@ybu.edu.tr

[2] Department of Industrial Engineering, Ankara Yıldırım Beyazıt University (AYBU), 06010, Ankara, TURKEY, (ORCID: 0000-0001-8860-3903), babek.erdebilli2015@gmail.com

[3] Department of Industrial Engineering, Ankara Yıldırım Beyazıt University (AYBU), 06010, Ankara, TURKEY, (ORCID: 0000-0003-4319-4688), ozennbaris@gmail.com

[4] Department of Industrial Engineering, Ankara Bilim University (ABU), 06200, Ankara, TURKEY, (ORCID: 0000-0001-8992-2148), ysozdemir@gmail.com

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Abstract

The supply chain plays a key role for companies that want to gain an advantage in the competitive market. Most of the companies are want to make their supply chain processes more reliable and sustainable with technological developments. With Industry 4.0, augmented reality is one of the most important technological developments in daily lives and companies' supply chain processes. In this study, the effects of augmented reality tools, which companies will increasingly recognize, are discussed on digital supply chain processes. The purpose of this study is to integrate the increasingly augmented reality tools in the supply chain in the most appropriate way and determine the most suitable one for the supply chain processes among the hardware augmented reality tools. Three augmented reality tools were evaluated with 4 main criteria and 12 sub-criteria. The Fuzzy Analytic Hierarchy Process (AHP) and Fuzzy Technique for Ordering Preference by Similarity to Ideal Solution (TOPSIS) methods are among the most important multi-criteria decision-making methods, are used in the decision-making process. As a result, the obtained results were evaluated and managerial implications were presented.
Keywords: Augmented Reality, Performance Evaluation, Digital Supply Chain Management, Fuzzy Group Decision Making

Dijital Tedarik Zinciri Yönetiminde Artırılmış Gerçeklik Araçlarının Performans Değerlendirmesi: Bir Grup Karar Verme Yöntemi

Öz

Tedarik zinciri, rekabetçi pazarda avantaj elde etmek isteyen şirketler için kilit bir rol oynamaktadır. Şirketlerin çoğu, teknolojik gelişmelerle tedarik zinciri süreçlerini daha güvenilir ve sürdürülebilir hale getirmek istemektedir. Endüstri 4.0 ile artırılmış gerçeklik, günlük yaşamda ve şirketlerin tedarik zinciri süreçlerinde en önemli teknolojik gelişmelerden biri haline gelmiştir. Bu çalışmada, şirketlerin giderek daha fazla kullanacağı artırılmış gerçeklik araçlarının dijital tedarik zinciri süreçlerine etkileri tartışılmaktadır. Bu çalışmanın amacı, tedarik zincirinde giderek artan artırılmış gerçeklik araçlarını en uygun şekilde entegre etmek için Artırılmış Gerçeklik (AR) araçları arasından tedarik zinciri süreçlerine en uygun olanı belirlemektir. Üç artırılmış gerçeklik aracı 4 ana kriter ve 12 alt kriter altında değerlendirilmiştir. Karar verme sürecinde en önemli çok kriterli karar verme yöntemleri arasında yer alan Bulanık Analitik Hiyerarşi Süreci (AHP) ve İdeal Çözüme Benzerliğe Göre Tercih Sıralaması İçin Bulanık Teknik (TOPSIS) yöntemleri kullanılmaktadır. Sonuç olarak, elde edilen sonuçlar değerlendirilerek yönetimsel çıkarımlar sunulmaktadır.
Anahtar Kelimeler: Artırılmış Gerçeklik, Performans Analizi, Dijitl Tedarik Zinciri Yönetimi, Bulanık Grup Karar Verme

* **Corresponding author:** Ankara Yıldırım Beyazıt Üniversitesi, Mühendislik ve Doğa Bilimleri Fakültesi, Endüstri Mühendisliği Bölümü, Ankara, Türkiye, ORCID: 0000-0001-8104-3392, ayildizbasi@ybu.edu.tr

1. Introduction

Technological developments and the spread of industry 4.0, many industrial companies are trying to digitize existing supply chain models to survive in the competitive market. One of the tools used in the digital supply chain and is becoming increasingly widespread is an augmented reality (Jetter, Eimecke and Rese, 2018).

Augmented Reality (AR) is a technology that has been subject to research and discussed since multiple decades in industrial areas. Technology is expected to play a very important role in the future, particularly in the development of intuitive-machine interfaces (Klein, 1975).

Augmented reality can be defined as all activities whose main purpose is to strengthen the world environment, human senses and abilities with the virtual world. Augmented reality is becoming increasingly common in everyday life. This is due to the possibility of using augmented reality to directly or indirectly complete the real-world environment with visualized assets accrued by specific hardware, software and accessories (Azuma, 1997).

According to X.Wang et al., augmented reality aims to combine real and virtual based objects. It aims to run real-time and virtual-based objects in three dimensions and in real time. AR users have a larger working space by placing the digital content they use and the virtual space they interact with in their workspaces. Such augmented workspace is realized by integrating the power and flexibility of computing environments with the comfort and familiarity of the traditional workspace (Wang, 2009).

Nowadays, developing firms are working to digitalize existing supply chain operations, making them more manageable, faster and more efficient. Augmented reality has been used in many sectors to digitize the supply chain and successful results have been achieved.

With the development of technology, important financial and business processes are turning to digitalization. The digital supply chain is one of the subject of great importance in this area. Experts predicts that digitalization will significantly affect supply chain management.

The digital supply chain is becoming more and more popular and leads to rapid changes and innovations. Some of the digital models that we use today are data centers, online sales, bits. According to digital supply chain approach, supply chains shall be perceived as a business, instead of a department of a business. According to supply chain experts, investments in the digital supply chain will generate significant economic benefits. According to Schrauf and Berttram (2016), organizations with DSC and highly digitalized digitalized operations can expect 4.1% annual efficiency gains while boosting their revenues by 2.9% per year (Büyüközkan and Göçer, 2018).

Companies that want to successfully implement digital supply chain management should use these two basic strategies:

- Reinvent their supply chain strategy,
- Reimagine supply chain as a digital supply network (DSN) that unites not just physical flows but also talent, information and finance (Merlino and Sproge, 2017).

In conjunction with Industry 4.0, emerging companies benefit from some technological developments in order to implement digital supply chain management more quickly and effectively. Some of these are big data, artificial intelligent, internet of things, cloud computing, similation, autonomus robots and augmented reality.

The most important topics mentioned in this study are augmented reality and digital supply chain. We see that the concept of digital supply chain has developed by using technology such as augmented reality and using it in many places where the supply chain is located. In other words, augmented reality and similar technological advances are increasing the applicability of the digital supply chain. At this point, it can be said that literature studies related to concepts such as augmented reality, artificial intelligence, blockcahin are open to development and accordingly there is a gap in the literature about digital supply chain.

In this study, the role and importance of augmented reality in digital supply chain is mentioned and aimed to integrate the augmented reality tools in the most appropriate way to the digital supply chain. On the other hand, selection among augmented reality tools alternatives is a multi-criteria decision making (MCDM) problem and it is necessary to make an assessment in terms of several conflicting criteria. However, the fuzzy sets enable to cope with vagueness of evaluations in decision making process (Çalık, 2020; Koçak and Çalık, 2020).

The aim of this study is to select the most appropriate hardware augmented reality tools for the digitalization of the supply chain with fuzzy and multi-criteria decision making methods. In this study, an integrated Fuzzy Analytic Hierarchy Process (AHP) and Fuzzy Technique for Ordering Preference by Similarity to Ideal Solution (TOPSIS) methods based on the fuzzy sets is proposed for the ranking AR tools in Dijital Supply Chain Management (DSCM). Fuzzy AHP was used to get weight for main and sub-criteria and Fuzzy TOPSIS was used to get ranking of the solutions. Throughout the study, there is an introduction to digital supply chain and augmented reality, followed by a comprehensive literature review, application steps of Fuzzy AHP and Fuzzy TOPSIS methods, and finally a sample application. The sample application consists of 3 experts evaluating a model with 4 main criteria and 12 sub-criteria for 3 different augmented reality tools. This study is a guiding and supportive study on the assessment and selection of augmented reality tools for supply chain management staff.

Finally, this study consists of six different sections. In the next part of the study, there is a literature review section covering augmented reality, digital supply chain and multi-criteria decision making methods. After the literature review, multi-criteria decision making techniques used as the method of the study are introduced. In the fourth part of the study, the detailed introduction of the criteria and alternatives to be used in these methods is given. In the conclusion and discussion section of the study, the results of the applied method and the effects of these results for the practitioners are examined in detail. In the conclusion part of the study, the general evaluation of the study and how the results can be improved are given.

2. Related Work

2.1. About Augmented Reality

The literature studies show that the concept of Augmented Reality has become more widespread nad it is presented in Figure 1. In the literature review of this study, we focused on the applications of augmented reality and the methods used in the literature.

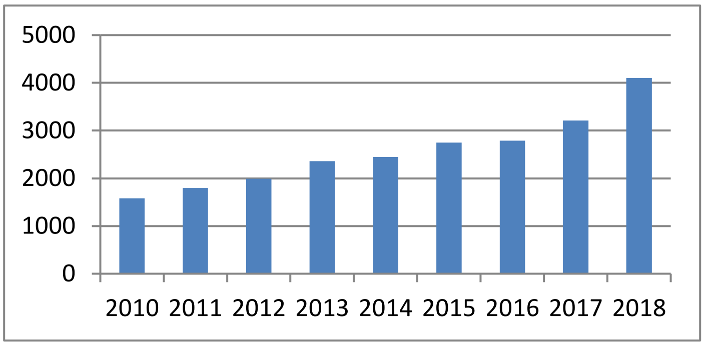

Figure 1. Augmented reality studies according to years.

In the literature, augmented reality studies have been found in many areas such as health, production, marketing, education and warehouse. Azuma tried to introduce AR applications in large industrial areas such as medical visualization, maintenance and repair, robotics and military. It also aimed to introduce AR applications in potential application areas such as the entertainment sector (Jetter et al., 2018).

AR has gained interest in several industrial fields and industries such as manufacturing in the aerospace industry and in shipbuilding, engineering analysis and simulation or architecture and construction (Jetter et al., 2018).

AR technology is envisioned to improve the current practices of architecture visualization, design process, building construction processes and engineering management systems (Wang, 2009).

The manufacturing context is increasingly dynamic due to the high level of integration with advanced information tools, especially with mobile devices. Part of the efficiency depends on an effective and real-time communication between individuals and production departments within a manufacturing system. AR systems are now becoming mature technologies for application in manufacturing production and service systems: the aim is to support an increase in company performance in terms of shorter lead-times and process quality (Caricato, Colizzi, Gnoni, Grieco, Guerrieri and Lanzilotto, 2014).

Augmented reality provides users to relate between virtual objects and real world. Users can view images from different angles around the virtual image. The data transmitted by virtual objects provides users to learn more in a fun and educational way (Kesim and Özarslan, 2012).

With a video output device and a video camera, the user can see an augmented reality object on the object in a real environment. 3D models can be identified using RFID (Cirulis and Ginters, 2013).

Order picking activities cover more than half of the warehouse activities. The current studies focused on how to improve the orientation of people or operators using AR. Stated that one of the most effective ways of showing a storage place to an order collector was voice, via a head mounted display, lights and paper (Beroule, Grunder, Barakat, and Aujoulat, 2017).

One of the tools that can be used effectively for remote maintenance operations is AR. A remote maintenance system or maintenance specialist can complete the task by using the AR by following the instructions. Porcelli et al. proposed an application supporting technicians using an AR tool (a mobile collaborative systems) (Caricato et al., 2014).

AR technology is helpful to make a rapid prototype by seeing 3D models of real-world objects. AR technology also be used to control users' specific features on virtual objects. Caricato et al. has developed a system that can intuitively interact between 3D models and their modifications (Caricato et al., 2014).

In the literature, several studies have used fuzzy AHP and TOPSIS methods to reach a solution.

Junior et al. proposed a study for the problem of supplier selection using fuzzy AHP and fuzzy TOPSIS. In this study, seven factors were used. In order to better solve the problem, he proposed that both methods be applied to supplier selection (Lima Junior, Osiro, and Carpinetti, 2014).

Chen at al. studied the selection of suppliers in fuzzy environments. In this study, it was aimed to reach the best solution by using fuzzy TOPSIS from decision making methods (Chen, Lin, and Huang, 2006).

Tabucanon et al. propose a solution for the development of an intelligent decision support system for flexible manufacturing systems. The AHP approach is used for this intelligent decision support system. This article focuses on the selection process of alternative machines (Tabucanon, Batanov, and Verma, 1994).

Bottani and Rizzi applied fuzzy TOPSIS method and worked on the logistic operations of a dairy company operating under a certain criteria (Bottani and Rizzi, 2006). Çalık (2018), presented an integrated fuzzy AHP and fuzzy TOPSIS method to prioritize and analyze the risks in supply chain management in a company in the automotive supplier industry.

Table 1. Literature review of AR applications areas and methods

Authors	Areas of Augmented Reality Applications						Methods		
	Procurement	Production	Education	Marketing	Warehouse	Logistic	Theoritical	MCDM	Application
Caricato et al. (2014)		✓						✓	
Persaud and Azhar (2012)				✓			✓		
Kesim and Özarslan (2012)			✓				✓		
Cirulis and Ginters (2013)						✓	✓		
Beroule et al. (2017)					✓				✓
Lima Junior et al. (2017)	✓							✓	
Tabucanon et al. (1994)		✓						✓	
Mahony (2015)				✓			✓		
Ginters (2013)					✓				✓
Bacca et al. (2014)			✓						✓
Proposed Model	✓	✓			✓	✓		✓	

The studies presented the applicability of the augmented reality in the processes in the supply chain or in other sectors are examined above. When we look at the processes and sectors applied, we see that augmented reality is an important smart technology that digitizes the supply chain. In the next part, the effect of smart technologies on the concept of digital supply chain is examined in more detail.

2.2. About Digital Supply Chain Management

In the first part of the related works section, literature studies about augmented reality are included. In this part, the studies related to the digital supply chain, which are formed by integrating technological developments such as augmented reality into the supply chain and which are becoming common, are mentioned.

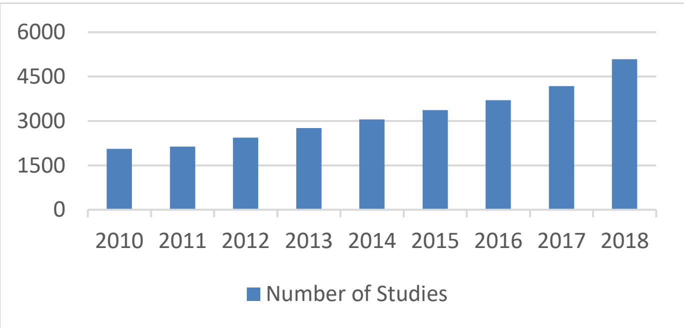

Figure 2. Number of studies related to Dijital Supply Chain according to years (science direct)

Figure 2 shows the increase in the work on digital supply chain management over the years. In this part of the related works section, we focused on the studies related to digital supply chain concept became widespread depending on which technological developments. It is not possible to say that there are many publications in the literature academically by looking at the speed of technological developments and the supply chain processes increasingly benefiting from these technological developments.

Büyüközkan and Göcer (2018), have defined the digital supply chain as a concept that aims to transform the difficulty and complexity of the items that constitute the supply chain (such as suppliers, companies, partners, dealers) into a business opportunity with technological and analytical methods and add value to the work done. According to the authors, digital supply chain applications (such as augmented reality, artificial intelligence, internet of things, big data) make the digital and physical supply chain processes of companies within themselves or with the external environment smart, value-based and efficient (Büyüközkan, Göçer, 2020).

According to Nasiri et al. (2020), Companies should focus on digital transformation, smart technologies and performance relationship to gain competitive advantage in the digital supply chain. In this study, a questionnaire was applied to small and medium-sized enterprises (SMEs). According to the results of these surveys, if companies can manage to apply these three main issues together, they provide a significant competitive advantage in the digital supply chain. This article has revealed that smart technologies will be a network between digital transformation and relationship performance (Nasiri, Ukko, Saunila and Rantala, 2020).

At this point we see the importance of smart technologies in digitizing supply chains. In the literature, examples of digitizing supply chain integrated with smart technologies are found. Below are some studies that can be an example.

Korpela et al. (2017), In their work, they talked about cloud integration with supply chain processes, as the digital supply chain processes are becoming more and more dynamic. The authors stated that important concepts such as accessibility of customer data, storage of data, traceability of supply chain processes have strategic importance for companies in supply chain processes. Companies receive assistance from intermediary companies to provide and store this data, and this is high in cost. The authors have developed a business model that targets the digital supply chain with cloud integration (Korpela, Hallikas and Dahlberg, 2017).

In the article above, while there is a supply chain between the company and the external environment, this article focuses on the digitalization of material transportation, which is one of the supply chain processes within the company. According to

Bechtsis et al., The smart autonomous vehicles to be developed will be easier and more efficient vehicles for sustainability in supply chain operations. The purpose of the authors is to provide software suggestions to develop highly customized simulation tools that support effective integration of Smart Autonomous Vehicles (IAVs) as a rising field in operations in sustainable supply networks. Finally, the authors developed pilot simulations for using these tools for a warehouse (Korpela et al., 2017; Bechtsis, Tsolakis, Vlachos, and Srai, 2018).

2.3 General Evaluation of Related Works

The literature studies show that the concept of Augmented Reality has become more widespread nad it is presented in Figure 1. In the literature review of this study, we focused on the applications of augmented reality and the methods used in the literature.

First, the similarity between graph 1 and graph 2 shows that with the development of intelligent technologies such as augmented reality, the work on digital supply is increasing. In summary, smart technologies enable digital supply chain applications.

When we look at the studies with augmented reality, it is seen that augmented reality is applied in many operational processes and in different sectors. These operational processes and sectors are an indispensable part of the supply chain. It aims to make these supply chain processes more efficient in terms of time, cost, location, labor, quality with augmented reality applications. In essence, the digital supply chain is a form of management that targets the efficiency and sustainability of the processes it covers. Based on these evaluations, selecting the best augmented reality tool to be used in supply chain processes will directly affect the degree of digitalization of supply chain processes.

3. The Proposed Approach

The biggest reason for using fuzzy methods in this study is to ensure that the complex structure formed in supply chain processes is compensated.

With the AHP model, which is another proposed multi-criteria decision making technique, we aim to correctly weigh the criteria to be used in the model. The criteria of our model have been prioritized and weighted among themselves with the AHP method. It is generally unexpected that all the criteria used in a model have the same weight. In this study, these criteria were evaluated with supply chain experts by considering supply chain applications. However, when these criteria are evaluated for other processes, weights are likely to be different. At this point, the importance of weighting the criteria becomes apparent and it is necessary to weight all the criteria by applying AHP model before proceeding to the selection process.

Fuzzy TOPSIS is used for the selection of alternatives. One of the most important reasons for choosing the Fuzzy TOPSIS technique is that the method can evaluate alternatives in terms of benefit and cost. If there is a ranking among the alternatives, the benefits and costs that each alternative will affect the model under each criterion are obtained with this technique.

In this study, fuzzy multi-criteria decision making method is used to solve this complex model. A multi-criteria approach can be a reliable method, as it allows the numerical and effective integration of different criteria. The suggested fuzzy MCDM model combines fuzzy Analytic Hierarchy Process (AHP) and fuzzy TOPSIS methods. Since the fuzzy sets whose membership functions are enable to handle situations that an element has several membership value are more able to model uncertainties in decision making process, in this paper a MCDM methodology based on these two methods are suggested to evaluate augmented reality tools alternatives for Digital Supply Chain Management. The fuzzy AHP method is applied to determine the weights of decision criteria, and the fuzzy TOPSIS method is applied to classified augmented reality tools alternatives. A real case application has been presented via expert evaluations to indicate applicability of the proposed model. The flow chart of the proposed model is presented in Figure 3.

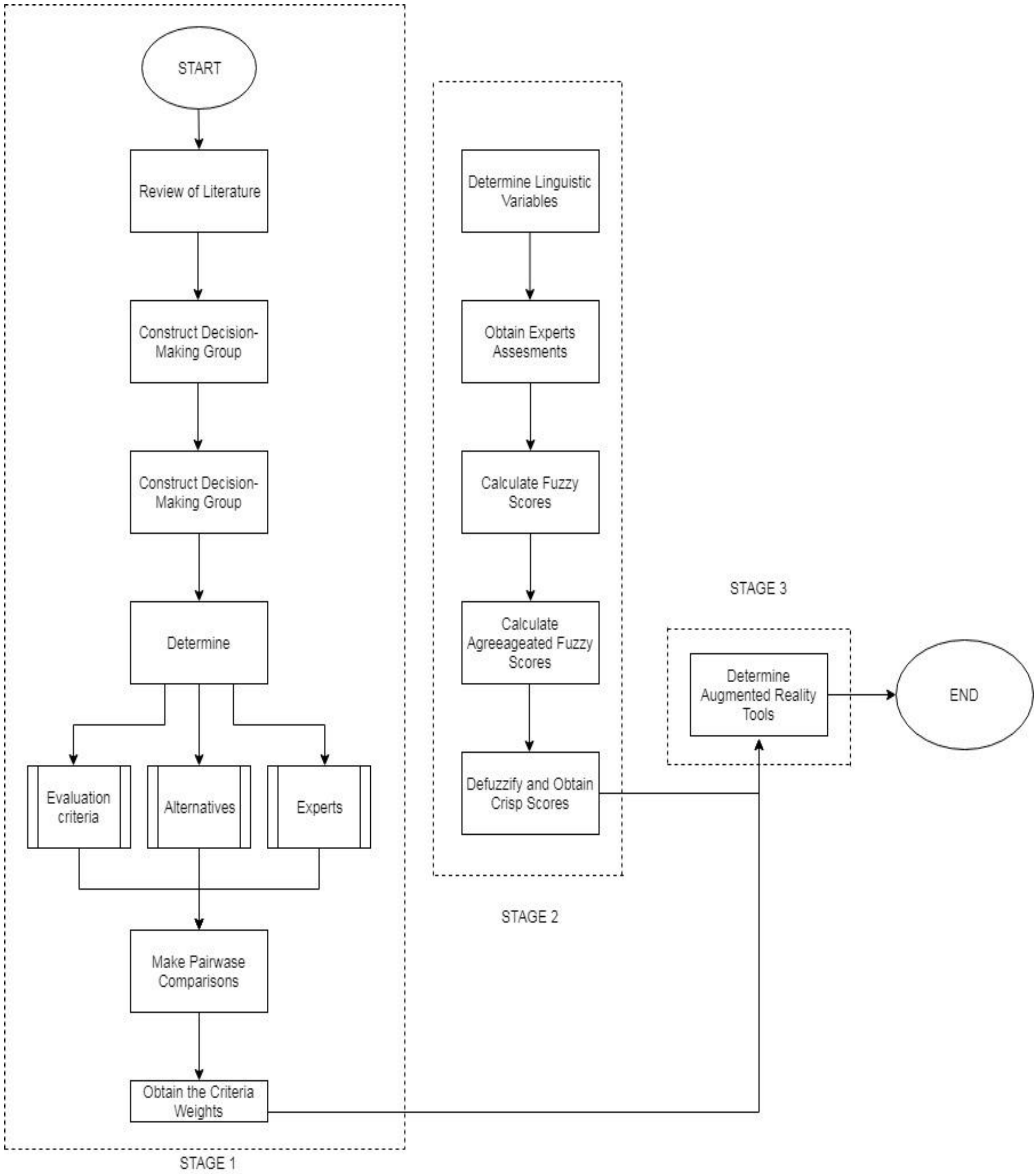

Figure 3. Flow-chart of the model

3.1. Fuzzy Set and Fuzzy Numbers

The mathematical theory developed by Zadeh (1965) to model uncertainty or certainty in processes is called fuzzy set theory. The fuzzy set is usually defined as the functions in which the elements receive membership degrees [0,1]. If the assigned value is 0, it has no membership. If the assigned value is 1, there is full membership. If the value assigned as a different status is between 0-1, there is a certain degree of membership (Yıldızbaşı, Öztürk, Efendioğlu, Bulkan, 2021).

3.2 Fuzzy AHP Methodology

AHP is a quantitative method which is structured as a hierarchical and multi-criteria solution in 1980 by Saaty. The most important feature of this method is that it can make evaluations by considering more than one criterion. Qualitative and quantitative data can be evaluated together effectively (Kahraman, Cebeci and Ruan, 2004; Çalık, 2020; Yıldızbaşı et al., 2021).

Traditional AHP does not fully address the uncertainty in the way people think, even if they are focused on expert opinions on the basis of AHP. Therefore, fuzzy AHP has been developed to take into account these uncertainties (Yıldızbaşı et al., 2021).

First, the scale to be used by experts is determined. The following TFN scale contains 1-9 values.

Table 2. Linguistic scale for weighted matrix [19]

	Triangular Fuzzy Scale	***Triangular Fuzzy Reciprocal Scale***
Equally importance	(1,1,1)	(1/1, 1/1, 1/1)
Moderate importance	(1,3,5)	(1/5, 1/3, 1/1)
Essential importance	(3,5,7)	(1/7, 1/5, 1/3)
Demonstrated importance	(5,7,9)	(1/9, 1/7, 1/5)
Extreme importance	(7,9,9)	(1/9, 1/9, 1/7)
Intermediate values	(1,2,3)	(1/3, 1/2, 1)
	(3,4,5)	(1/5, 1/4, 1/3)
	(5,6,7)	(1/7, 1/6, 1/5)
	(7,8,9)	(1/9, 1/8, 1/7)

Step 1: As seen in Equation 1, pairwise comparison matrix is made for the main criteria and sub-criteria using the above scale.

$$\tilde{A} = \begin{bmatrix} 1 & \cdots & \tilde{a}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \cdots & 1 \end{bmatrix} \quad (1)$$

Step 2: Fuzzy geometric mean is calculated by using equation 2.

$$\bar{r_i} = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \dots \otimes \tilde{a}_{in})^{1/n} \quad (2)$$

The result from the fuzzy geometric mean will be referred to later as local fuzzy number.

Step 3: In this step, the global fuzzy number is calculated for each evaluation dimension.

$$\widetilde{w}_i = \tilde{r}_1 \otimes (\tilde{r}_1 \otimes \tilde{r}_1 \otimes \dots \tilde{r}_1)^{-1} \quad (3)$$

Step 4: Finally, in this step, the global fuzzy number is converted to crisp weight value using the field center in equation 4. The purpose of this is to find the best BNP value of any dimension.

$$BNP_{wi} = \frac{[(u_{wi} - l_{wi}) + (m_{wi} - l_{wi})]}{3} + l_{wi} \quad (4)$$

3.3. Fuzzy TOPSIS Methodology

The fuzzy TOPSIS method is a technique recommended by Hwang and Yoon to solve a problem with multiple criteria and a limited number of alternatives. The purpose of this method is to ensure that the chosen alternative is the furthest to the negative set of solutions, the closest to the positive set of solutions. The fuzzy TOPSIS technique proposed by Chen aims to deal effectively with the uncertainties in the evaluations. In this study, fuzzy TOPSIS is used to evaluate the performance of AR tools in the digital supply chain[20]

Step 1: In this study, fuzzy AHP is used for weighting the evaluation criteria.

Step 2: Construct of decision matrix and selection of linguistic variables for alternatives based on criteria

$$\bar{D} = \begin{vmatrix} \bar{x}_{11} & \bar{x}_{12} & \dots & \bar{x}_{11} \\ \bar{x}_{11} & \bar{x}_{11} & \dots & \bar{x}_{11} \\ \vdots & \vdots & \ddots & \vdots \\ \bar{x}_{11} & \bar{x}_{11} & \cdots & \bar{x}_{mn} \end{vmatrix} \quad (5)$$

$$\overline{W} = (\overline{w}_1, \overline{w}_2, \dots, \overline{w}_n) \quad (6)$$

Step 3: Standardize of decision matrix

$$\overline{R} = [\overline{r}_{ij}]_{mxn} i = 1,2, \dots, m; j = 1,2, \dots, n \quad (7)$$

$$\overline{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \ and\ c_j^* = \max \mathrm{i}\, c_{ij}\ (benefit\ criteria) \quad (8)$$

$$\overline{r}_{ij} = \left(\frac{\overline{a}_i}{c_{ij}}, \frac{\overline{a}_i}{b_{ij}}, \frac{\overline{a}_i}{a_{ij}}\right) \ and\ \overline{a}_i = \min \mathrm{i}\, a_{ij}\ (cost\ criteria) \quad (9)$$

Step 4: Weighted Normalized Fuzzy Decision Matrix

$$\overline{p} = [\overline{p}_{ij}]\ where\ \overline{p}_{ij} = \overline{r}_{ij}\ x\ \overline{w}_j \quad (10)$$

Step 5: Finding Feasible Positive Ideal Solution (FPIS) and Feasible Negative Ideal Solution (FNIS)

$$A^* = (p_1^*, p_2^*, \dots, p_n^*)\ where\ p_i^* = \max i\, \{p_{ij3}\}, i = 1,2, \dots, m; j = 1,2, \dots, n \quad (11)$$

$$A^* = (p_1^*, p_2^*, \dots, p_n^*)\ where\ p_i^* = \min i\, \{p_{ij}1\}, i = 1,2, \dots, m; j = 1,2, \dots, n \quad (12)$$

Step 6: Evaluate FPIS and FNIS for each criteria

$$FPIS(A1) = d(pij, p1+) \quad (13)$$

$$FNIS(A1) = d(pij, p1-) \quad (14)$$

Step 7: Calculate the distance of each weighted alternative

$$d_i^+ = \sum_{j=1}^{n} d(\overline{p}_{ij}, p_j^+) \quad (15)$$

$$d_i^- = \sum_{j=1}^{n} d(\overline{p}_{ij}, p_j^-) \quad (16)$$

Step 8: Calculate closeness coefficent of each alternative

$$CC_i = {d_i^-}/{(d_i^- + d_i^+)}, i = 1,2, \dots, m \quad (17)$$

Step 9: Ranking of each alternative

4. Alternative / Criteria Defition Part

In this study, it is aimed to select the most effective and efficient one of the augmented reality tools that is presented in figure 4 by using fuzzy AHP and fuzzy TOPSIS methods. The main criteria and sub-criteria which is described below were taken into account to achieve the goal.

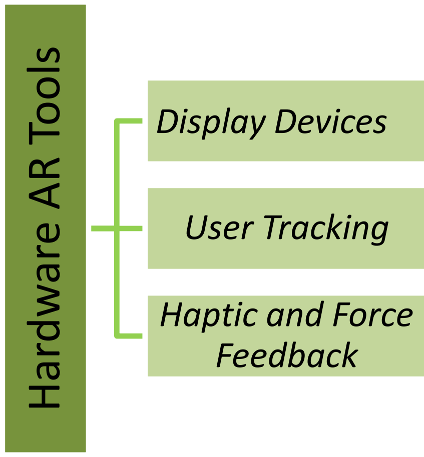

Figure 4. Alternative hardware tools of augmented reality.

Hardware Tools

Display Devices: One of the devices commonly used in AR applications is head-mounted display devices. Recently, researchers have been working on tools such as projectors and handheld devices, as long-term use of head-mounted display devices may be uncomfortable.

User Tracking: Most AR systems use sensor-based monitoring technologies using radio frequency technology. The researchers applied RFID labels and logistics facilities in radio frequency technology.

Haptic and Force Feedback: Haptic and force feedback systems are used to enhance interaction and sensation for the user. Researchers have implemented these devices in applications such as assembly where shares are needed (Nee, Ong, 2013).

Definition of Criteria

Identifying and defining the criteria is one of the most important stages of multi-criteria decision-making methods. Criteria should be determined by experts in the field of study. The selection of effective criteria is one of the key points in order for the decision making method to be successful. In this study, the main criteria for measuring the performance of augmented reality tools on digital supply chain are detailed below (Caricato et al., 2014).

- Reliability: The AR system provides information in a correct and effective manner.
- Responsiveness: The time required for the AR system to be ready for use (based on the operating speed of the AR system).
- Agility: The ability to adapt to changes in the system where the AR system is used
- Asset Management: The ability to interact with the environment outside the system using the AR system (Caricato et al., 2014).

There are many sub-criteria in the 4 main criteria that are generally determined. These sub-criteria help experts to analyze the performance of AR tools in detail. Reliability, responsiveness, agility and assets management are crucial criteria in supply chain processes. These criteria directly affect important issues such as cost, time, accuracy and efficiency in supply chain processes. These main criteria and sub-criteria, which directly affect these issues that we see as the objectives of the digital suppy chain, have been selected to be weighted in order for the model to give successful results. The hierarchical structure for the main and sub criteria is presented in figure 5.

The “reliability” criterion for AR application is examined under two main headings. These are described in detail below as data and software.

Data: The data formats provided for the AR application and are usually provided from 2D or 3D images or audio or text files.

Software: Software is the basic element that supports the interaction of data records for real and virtual objects.

The “responsiveness” criterion has been defined in three main technological sub-criteria as life cycle, manageability and weight.

Life Cycle: Life cycle duration shows the maximum capacity of AR vehicles. Tools suitable for the duration of supply chain processes should be selected.

Manageability: Manageability is focused on the movement of AR tools in the supply chain processes. The mobility of the user and the AR tool must be appropriate for the processes.

Weight: Weight is an important sub-criteria for efficient and easy use of AR tools in supply chain processes.

The “agility” criterion has been divided in three sub-criteria as acces, network, feedback and shape.

Acces: Acces can be defined as the maximum time spent on data collection.

Network: Network be defined as main networks required by AR tools. Examples of these networks are internet and bluetooth.

Feedback: This sub-criteria shows the types of feedback provided by the device during the application such as image acquisition, processing and analysis of information.

Shape: The design of the shapes of the augmented reality tools has been identified as a sub-criterion of agility. The shape designed according to the system to be applied achieves more efficient results.

The “asset management” criterion has been divided in three sub-criteria as places, range and teachability.

Places: This sub-criterion focuses on the places of use of AR tools in supply chain processes. It takes into account factors such as different room temperatures, moisture content, amount of dust, amount of sound and light.

Range: Range is a sub-criterion of the operating range of AR tools. It shows the distance between the work area and the AR tools.

Teachability: Teachability is a sub-criterion that shows the processing time of learning the tools of augmented reality by employee who will use it.

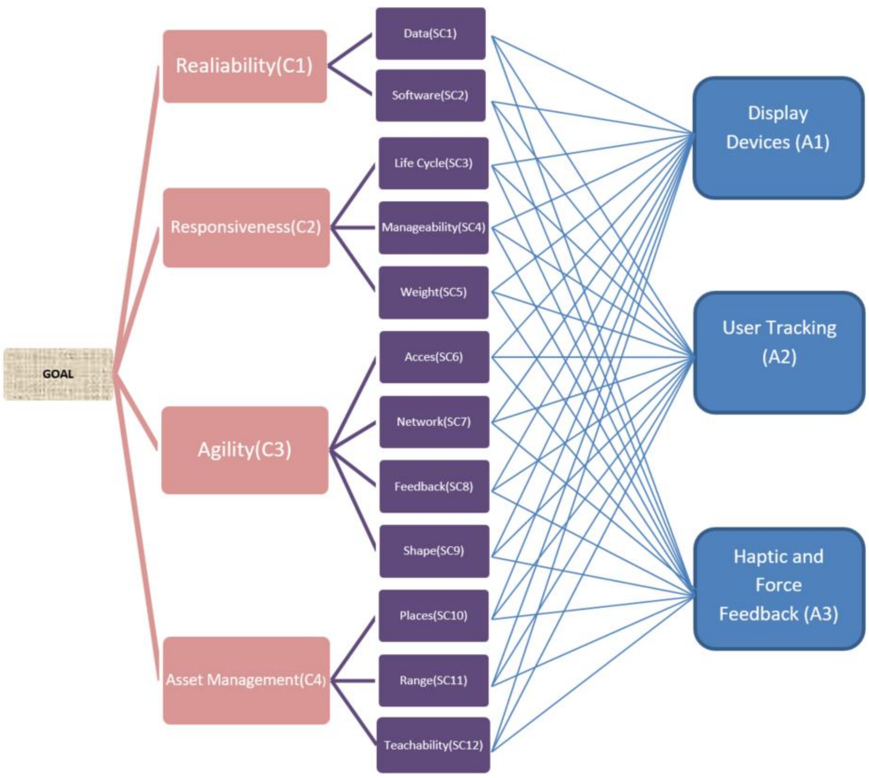

Figure 5. The hierarchical structure of the alternative

5. Result and Discussion

At this stage, interviews were made with 3 experts who were experts in their fields and their opinions were taken by using comparison matrices. The linguistic expressions obtained were converted to Fuzzy AHP and Fuzzy TOPSIS data to obtain the rankings. The results and discussion section include assessments of these transformations and other processing steps. In this study, 4 criteria and 12 sub-criteria were used for ranking augmented reality tools.

5.1. Fuzzy AHP Application

The fuzzy decision matrix and fuzzy aggregated decision matrix of criteria and sub-criteria with calculated weight are given Tables 3-7.

Table 3. Calculated fuzzy aggregated decision matrix of criteria.

	C1	C2	C3	C4	Weight	Rank
C1	(1,1,1)	(1,3,5)	(3,5,7)	(3,5,7)	0,5123	1
C2	(0.20,0.33,1)	(1,1,1)	(1,3,5)	(3,5,7)	0,2936	2
C3	(0.14,0.20,0.33)	(0,20,0.33,1)	(1,1,1)	(1,1,3)	0,1171	3
C4	(0.14,0.20,0.33)	(0.14,0.20,0.33)	(0.33,1,1)	(1,1,1)	0,0767	4

The highest weightage value used to consider the most important criteria for ranking augmented reality tools which were represented such that C1 > C2 > C3 > C4 which is given in Table 4. Reliability is the most important element in the digitalization process in the supply chain. The most important reason for this is that missing data and software applications in the supply chain cause significant damage. Responsiveness has emerged as the main criterion of secondary importance. One of the most important reasons for digitalization in the supply chain is to increase productivity. In order to use the augmented reality tools efficiently in the supply chain processes, they need to meet the important sub criteria such as life cycle, managebilitiy and weiğht. After these two main criteria, agility and assess management appear as the main criteria covering the sub-criteria such as shape, range, network and feedback required for the more functional use of augmented reality tools in digital supply chain processes.

In this study, sub criteria were ranking for each main criteria which are sub-criteria realiability (C1), responsiveness (C2), agility (C3), and assest management (C4) as shown Table 4-7.

Table 4. Calculated fuzzy aggregated decision matrix of sub-criteria (C1).

C1	SC1	SC2	Weight	Rank
SC1	(1,1,1)	(1,1,3)	0,5	1
SC2	(0.33,1,1)	(1,1,1)	0,5	1

As shown in Table 4, the data and software are two equally important criteria for the reliability criterion. Data collection plays a major role in the digitalization of supply chain processes. The software to be implemented according to the collected data will enable the digitalization of the supply chain processes so that the processes can continue more effectively and reliably.

Table 5. Calculated fuzzy aggregated decision matrix of sub-criteria (C2).

C2	SC3	SC4	SC5	Weight	Rank
SC3	(1,1,1)	(1,3,5)	(3,5,7)	0,5966	1
SC4	(0.20,0.33,1)	(1,1,1)	(1,3,5)	0,2847	2
SC5	(0.14,0.20,0.33)	(0.20,0.33,1)	(1,1,1)	0,1185	3

Table 5 shows that life cycle is the most important sub-criterion for responsiveness. Companies which want to use augmented reality tools effectively in the digitalization process give importance to the long life cycle of the tools. The high level of manageability of augmented reality tools is the second important sub-criterion in terms of ease of use of these tools in different processes and by people with different competencies.

Table 6. Calculated fuzzy aggregated decision matrix of sub-criteria (C3).

C3	SC6	SC7	SC8	SC9	Weight	Rank
SC6	(1,1,1)	(3,5,7)	(5,7,9)	(5,7,9)	0,6266	1
SC7	(0.14,0.20,0.33)	(1,1,1)	(3,5,7)	(1,3,5)	0,2173	2
SC8	(0.11,0.14,0.20)	(0.14,0.20,0.33)	(1,1,1)	(1,1,3)	0,0777	4
SC9	(0.11,0.14,0.20)	(0.20,0.33,0.14)	(0.33,1,1)	(1,1,1)	0,0782	3

Table 6 shows the importance of the computational sub-criteria for the main criterion of agility in the process of digitalization. The fact that augmented reality tools meet the sub-criteria such as acces and network directly affects the agility rate.

Table 7. Calculated fuzzy aggregated decision matrix of sub-criteria (C4).

C4	SC10	SC11	SC12	Weight	Rank
SC10	(1,1,1)	(1,1,3)	(1,3,5)	0,4657	1
SC11	(0.33,1,1)	(1,1,1)	(1,3,5)	0,3563	2
SC12	(0.20,0.33,1)	(0.20,0.33,1)	(1,1,1)	0,1778	3

As shown in Table 7, the assest management criterion consists of 3 different sub-criteria. The most important of these 3 criteria are places and ranges. These sub-criteria will affect the efficiency of the supply chain processes of augmented reality products, especially in the production area. Designing augmented reality tools according to these two criteria is important for the active and more efficient use of the tools. Teachability sub-criterion is less important for assest management criterion since it can be provided by trainings.

Due to same process of weight calculation, the weights of remaining criteria and the final results of pairwase comparison of criteria and sub-criteria also illustrated in Table 8.

Table 8. Final weight and rank of all sub-criteria.

Criterion	Weight	Sub-criteria	Weight	Global Weight	Global Rank
Reliability(C1)	0,5123	*Data (SC1)*	0,5	0,2562	**1**
		Software (SC2)	0,5	0,2562	**1**
Responsiveness(C2)	0,2936	*Lifecycle (SC3)*	0,5966	0,1752	**2**
		Manageability (SC4)	0,2847	0,0836	**3**
		Weight (SC5)	0,1185	0,0348	**6**
Agility(C3)	0,1171	*Access (SC8)*	0,0777	0,0091	**11**
		Network (SC7)	0,2173	0,0254	**8**
		Feedback (SC6)	0,6266	0,0734	**4**
		Shape (SC9)	0,0782	0,0092	**10**
Assess Management(C4)	0,0767	*Place (SC10)*	0,4657	0,0357	**5**
		Range (SC11)	0,3563	0,0273	**7**
		Traceability (SC12)	0,1778	0,0136	**9**

5.2. Fuzzy TOPSIS Application

In this section, decision-makers evaluated 3 different augmented reality tools and presented in Table 9, taking into account the 12 sub-criteria weighted previously using Fuzzy AHP. Then, the normalization of the decision matrix determined by the decision makers was performed using eq. 7-9. Presented in Table 10. To calculate weighted fuzzy normalized matrix for the alternatives, weights obtained from Fuzzy AHP method which is presented in Table 5-7. Finally, the distances of the alternatives to fuzyy ideal positivesolutions (FPIS) and fuzzy ideal negative solutions (FNIS) were calculated using equations 15 and 16, and CCi values of the alternatives were obtained by using these FPIS and FNIS values in equation 17 and all of these values shown in Table 11 (Rouyendegh, Yildizbasi, Yilmaz, 2020; Rouyendegh and Can, 2012; Öztürk and Yildizbasi, 2020).

Table 9. Evaluations matrix of solutions.

	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12
A1	(3,5,7)	(5,7,9)	(7,9,9)	(7,9,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(7,9,9)
A2	(7,9,9)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)
A3	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(1,3,5)	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)

Table 10. Normalized fuzzy decision matrix of solutions.

	SC1	SC2	…	SC10	SC11	SC12
A1	(0.20,0.34,0.48)	(0.37,0.52,0.67)	…	(0.40,0.56,0.72)	(0.40,0.56,0,72)	(0.56,0.72,0.72)
A2	(0.48,0.62,0.62)	(0.22,0.37,0.52)	…	(0.24,0.40,0.56)	(0.40,0.56,0,72)	(0.24,0.24,0.56)
A3	(0.48,0.62,0.62)	(0.22,0.37,0.52)	…	(0.08,0.24,0.40)	(0.24,0.40,0.56)	(0.24,0.24,0.56)

Table 11. Closeness coefficient index (CCi) value of alternatives

Code	Tools	d+	d-	CCi	Rank
A1	*Display Devices*	0,2185	0,1127	0,6597	**1**
A2	*User Tracking*	0,1844	0,2078	0,4701	**2**
A3	*Haptic and Force Feedback*	0,0695	0,3486	0,1663	**3**

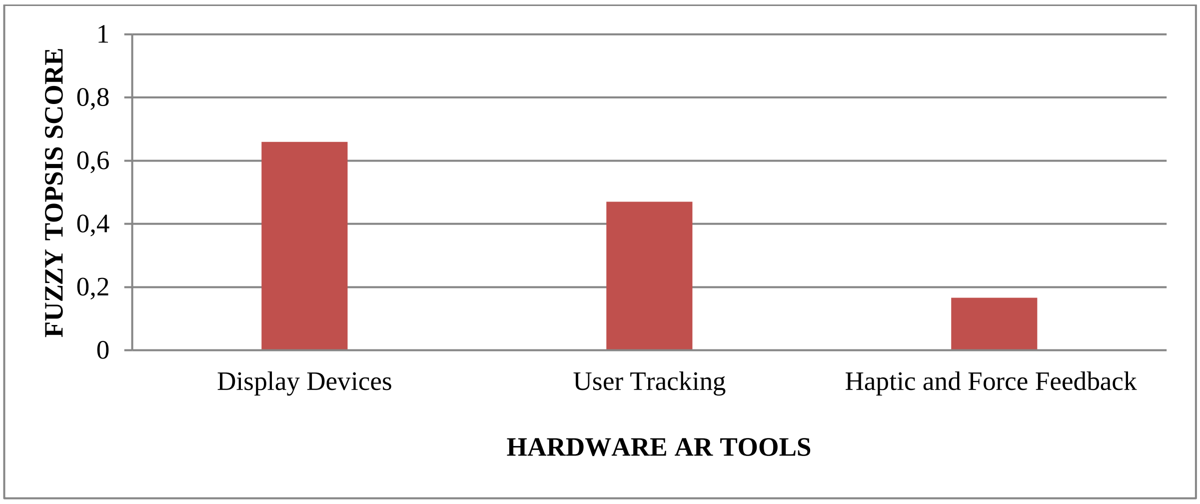

Figure 6. The results according to the Fuzzy TOPSIS methodology

According to the figure 6 display devices with the highest value of 0.65 have been identified as the most important alternative followed by user tracking and haptic and force feedback.

The prioritization of these hardware AR tools to be used in supply chain processes is critical for determining the investments that companies will make. As a result of this study, companies can calculate which criteria are more effective in the supply chain processes they have specifically determined. The ranking of augmented reality tools also shows the ranking of the investments to be made. The right investments of companies have a direct impact on issues such as income and competitive advantage.

In addition, even though the results of the article will vary according to the sectors and processes in which they will be used, the spread of display devices in many sectors supports the ranking of the study among the alternatives. In support of this, the experts whose opinions are taken in the study are selected from different sectors and this situation prevents the margin of error in the ranking. Despite all these positive aspects, there will be situations in which the ranking of the model changes, but the general purpose of this study is to create a structure that will enable this model to be applied effectively in different sectors and under different criteria and alternatives.

6. Conclusion

Nowadays, many companies aim to improve their supply chain processes by using the trends that came into our lives with Industry 4.0. One of the most important applications of Industry 4.0 is the augmented reality that enables us to use high technology effectively in key sectors such as health, education and manufacturing. According to the researches, augmented reality, which is a subject of increasing interest with developing technology, is thought to provide great benefits in terms of time, cost, reliability and quality in digital supply chain processes.

Based on the comparision display devices with the highest value of 0.65 have been identified as the most important alternative. When the criteria that lead to this result are discussed in detail, it is determined that especially life cycle, teachability and manageablity features are prominent. So if any new manufacturer wants to develop a product, or if existing alternative manufacturers are to focus on product development, the areas they need to focus primarily on are life cycle, teachability and manageablity, and then weight, software, and places comes respectively.

In future studies, augmented reality tools can be evaluated using other important multi-criteria decision-making methods such as Fuzzy VIKOR, Fuzzy ANP and Fuzzy ElECTRE. In addition, the number of alternatives can increase the using software augmented reality tools.

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