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A Fuzzy AHP Analysis of the Barriers to Digital Transformation in Turkish SMEs

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Abstract: In the era of the Fourth Industrial Revolution, digitalization emerges as a key driver reshaping societal norms and business models, particularly for Small and Medium-sized Enterprises (SMEs). This paper aims to identify and prioritize the barriers SMEs face in their digital transformation journey. Utilizing the fuzzy analytic hierarchy process, a method adept at handling the uncertainties and complexities in prioritizing barriers, this study identifies 26 sub-barriers grouped into five main categories through literature review and expert consultation. The analysis reveals organizational barriers as the most significant, suggesting the need for strategic planning to navigate digital transformation challenges. The research underscores the risk of a widening digital divide, where SMEs lagging in digital adoption may exacerbate employment and regional economic disparities. This study examines the digital transformation challenges of SMEs within Industry 4.0, with a focus on Turkey, providing new insights for strategic planning and policy-making to address these barriers.

Keywords: SME, Digital transformation, Fuzzy AHP

Introduction

The criticality of digital transformation for SMEs to achieve sustainable growth is paramount, particularly in the milieu of the Industry 4.0 revolution. This transformation is a cornerstone for business expansion, as noted by (Philbin et al., 2022). By embracing digital technologies, SMEs can expedite the development of sustainable products and services, cultivate an innovative culture, enhance user experiences, and engage more effectively with customers. This transition not only augments capital efficiency but also opens strategic avenues for market expansion (Chen et al., 2021). For SME managers striving to ensure their businesses' resilience and prosperity in competitive landscapes, adapting to digital transformation across all business operations emerges as an optimal strategy. Through digital transformation, businesses can reshape their organizational structures, amplify operational efficiency, enrich customer experiences, reinforce competitiveness, innovate business models, and reduce operating costs. SMEs, these advantages are crucial in the successful execution of digital transformation initiatives. They play a significant role in augmenting managerial effectiveness and in providing superior products and services to their customer base. Nonetheless, SMEs encounter several challenges, including capital limitations, difficulties in accessing skilled human resources, a dearth of competent ICT personnel, insufficient digital infrastructure platforms, and disparities in digital standards. Research underscores the necessity for SMEs to embrace digital transformation in a competitive milieu (Eller et al., 2020).

The digital transformation journey for SMEs is impeded by technological, organizational, human resource, customer-related, and environmental barriers. In this context, it is crucial to prioritize these barriers in the digital

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transformation process, enabling SMEs to effectively allocate their limited resources. However, there is a discernible research gap concerning the prioritization of these barriers for SMEs undergoing digital transformation. This study employs the Fuzzy Analytic Hierarchy Process (FAHP) technique to identify and rank the barriers confronting SMEs in Turkey during the digital transformation process, thereby bridging existing research gaps and enhancing both theoretical and practical understanding of digital transformation. FAHP is a method employed to ascertain the most significant criteria in multi-criteria decision-making (MCDM) scenarios. This technique leverages fuzzy numbers in pairwise Analytic Hierarchy Process (AHP) comparisons, incorporating the perspectives of academics, digital transformation experts, and SMEs managers, thus enabling the precise articulation of subjective preferences. The prioritization process involves pairwise comparison of barriers, assisting SMEs in pre-emptively recognizing impediments to digital transformation.

This research is aimed at scrutinizing the identification and ranking of barriers in the digital transformation process of SMEs in developing countries. The introductory section, constituting the paper's onset, provides a comprehensive overview of the subject and is succeeded by a research framework. The third section delves into a detailed exposition of the FAHP approach. Subsequent to this, the fourth section systematically presents the research findings, followed by in-depth discussions in the fifth section. The paper culminates with a conclusion summarizing the results and providing an overarching evaluation of the study.

Research Framework

In the ambit of their developmental strategies, nations in the developing world have gleaned pivotal insights from the sequence of industrial revolutions commencing in the early 18th century, spanning from Industry 1.0 through to Industry 4.0. This progression delineates a transition from the advent of steam power, through the advent of electrical energy, to the emergence of electronics and computer technologies, culminating in the advent of cutting-edge technologies such as digitalization, the Internet of Things, and Artificial Intelligence. These sequential industrial revolutions have been instrumental in the metamorphosis of business processes, yielding substantial enhancements in production efficiency and quality.

Figure 1. Industry 4.0 keywords

For SMEs in developing nations, these technological shifts are imperative for securing competitive edges and fostering sustainable growth. The developmental blueprints of these countries incorporate policies and mechanisms designed to facilitate the SMEs' acclimation to these digital transformation processes, thereby broadening their access to novel business domains and technological proficiencies. This stratagem is deemed a vital catalyst in hastening the economic advancement of developing countries and augmenting the prominence of SMEs in the global economic arena.

Within the context of national development strategies, a paramount driver of the transition towards Industry 4.0 is recognized as the enhancement of awareness. Consequently, a thorough exploration of nations' engagement with and consciousness of industrial revolutions assumes significance. The ramifications of Industry 4.0, particularly for SMEs, are regarded as an integral aspect of the technical evolutions and innovations delineated in scholarly discourses. During the transition phase to Industry 4.0, variegated levels of awareness and expectations of adaptation among SMEs in both developed and developing countries are observable (Table 1).. For SMEs in the developing world, this heightened awareness is especially crucial in terms of their adaptation to digital transformation processes and the cultivation of technological capabilities. Hence, differing degrees of awareness are posited as a critical determinant impacting the efficacy of SMEs in the digital transformation trajectory.

In this vein, a comprehensive literature review focused on Industry 4.0 was undertaken to ascertain these varying levels of awareness. This review, spanning the period from 2010 to 2023 and utilizing the Web of Science database, facilitated the identification of the most prevalently employed keywords in conjunction with Industry 4.0. Subsequently, these keywords were systematically organized into eight distinct clusters and further subdivided into 37 sub-clusters, providing a nuanced understanding of the thematic concentration within this domain.

Table 1. Development plans of developing countries

Country	Plan timeframe	Country	Plan timeframe	Country	Plan timeframe
Africa		Asia		Middle East	
Angola	2018-22	Bangladesh	2020-25	Algeria	2013-30
Benin	2018-25	Bhutan	2018-23	Bahrain	2017-20
Botswana	2017-23	Brunei	2018-23	Egypt	2020-30
Burkina Faso	2016-20	China	2021-35	Lebanon	2016-40
Burundi	2018-27	India	2012-17	Oman	2021-25
Chad	2017-21	Laos	2021-25	Palestine	2021-23
Congo	2019-23	Malaysia	2021-25	Qatar	2018-22
Ethiopia	2021-30	Myanmar	2018-30	Iraq	2018-22
Ghana	2022-25	Pakistan	2013-18	Saudi Arabia	2018-30
Guinea	2016-20	Papua New Guinea	2008-50	Tunisia	2022-25
Guinea-Bissau	2020-23	Philippine	2023-28	Latin America	
Kenya	2018-22	Thailand	2023-27	Argentina	2023-25
Lesotho	2018-23	Timor Leste	2011-30	Barbados	2013-20
Liberia	2018-23	Vietnam	2015-35	Belize	2010-30
Madagascar	2019-23	Europe		Bolivia	2021-25
Malawi	2017-22	Albania	2015-20	Chile	2014-18
Mali	2019-23	Armenia	2014-25	Colombia	2018-20
Mozambique	2020-24	Azerbaijan	2022-26	Costa Rica	2023-26
Namibia	2017-22	Belarus	2018-25	Dominica	2020-30
Nigeria	2021-25	Bosnia	2021-27	Ecuador	2023-27
Rwanda	2017-24	Estonia	2018-20	El Salvador	2014-19
R. of Congo	2018-22	Georgia	2014-20	Guatemala	2021-24
Sierra Leone	2019-23	Kazakhstan	2018-25	Haiti	2018-30
Somaliland	2023-27	Kosovo	2016-21	Honduras	2010-38
South Africa	2012-30	Kyrgyzstan	2018-26	Jamaica	2018-21
South Sudan	2021-24	Lithuania	2011-30	Mexico	2019-24
Swaziland	2019-22	Moldova	2018-30	Nicaragua	2019-23
Tanzania	2021-26	Mongolia	2016-30	Panama	2019-24
Togo	2018-22	Tajikistan	2021-25	Peru	2016-21
Uganda	2015-20	Turkey	2019-23	Tobago	2020-30
Zambia	2022-26	Ukraine	2017-30	Venezuela	2020-23
Zimbabwe	2021-25				

In this study, the method of document analysis, a fundamental approach in qualitative analysis, was employed to scrutinize information derived from the national development plans of 92 countries. This research necessitated a meticulous examination of the concepts related to the characteristics of Industry 4.0, as outlined in these nations' national development strategies. The most recent iterations of these development plans were considered, with each country's plan being directly obtained from the relevant official web portals.

The analytical process involved the use of MaxQda 2020, a software package specifically designed for qualitative data analysis, to code features related to Industry 4.0. During this analytical phase, primary codes were established, followed by the addition of corresponding sub-codes that aligned with each main code. The process of analyzing each country's development plans entailed aligning the same or closely related expressions with predetermined codes. The emerging codes and sub-codes related to Industry 4.0 are illustrated in Figure 1. The frequencies and percentages obtained from this analytical scan are also presented, providing a measurable perspective on the data. The coding of concepts in the development plans was meticulously conducted at various levels including paragraphs, sentences, and words, resulting in the identification of 8 primary codes and 37 sub-codes. Following the coding of the national development plans, a word cloud visually representing the characteristics of Industry 4.0 compiled from these documents was created. The concluding sections of the findings depict the codes of the sub-codes and their emergence frequencies in a comprehensive graphic format, thereby offering a detailed overview of the prevalence and significance of Industry 4.0 features within the context of national development strategies.

The national development plans of 92 countries underwent a comprehensive analysis. Within this context, the 25 most frequently occurring words pertaining to the concept of Industry 4.0 were identified. These words have been prominently displayed in a word cloud, as depicted in Figure 2.

Figure 2. Industry 4.0 code cloud

Frequency and percentage values of the first 5 words are also shown (Table 2). The word cloud was created by taking into account the number of repetitions in the development plans.

Table 2. Word frequency distributions of Industry 4.0 features

Keyword	Frequency (f)	Percentage (%)
Digitalization	70	10,7
Digital Technology	59	9,0
Digital Transformation	56	8,6
Internet of Things	51	7,8
Artificial Intelligence	50	7,7

The code cloud analysis shows that the term "digitalization" is the most prominent and used term among the Industry 4.0 concepts. The terms "digital technology", "digital transformation", "internet of things" and "artificial intelligence" are also listed as important concepts respectively. The total frequency of the codes discussed in the study was determined as 653. According to the code frequencies, "Bangladesh" 93, "'Malaysia" 58, "Philippine" 52, "China" 44 and "Azerbaijan" 36 are among the prominent countries, while "Turkey" appears 28 times. The digitalization focuses in the national development plans of countries can be associated with various dimensions such as cultural, economic, communication and international competition and the importance of these factors can be emphasized. In particular, the impact of these findings on the digital transformation processes of SMEs can be decisive in terms of their technology adaptation, innovation capacities and their position in the international competitive environment. By adopting these digital transformation foci in national development plans, SMEs can become more competitive and innovative in both local and global markets. The study then proceeds within the framework of digital transformation, which ranks third in the development plans of nations.

Digitalization

Digitalization is conceptualized as leveraging digital technologies and data to enhance efficiencies, evolve, refine, and revolutionize business processes, thereby fostering a digital-centric business model where digital information is fundamental (Schallmo & Williams, 2018). According to (Digitalization and Digitization – Culture Digitally, 2014), digitalization means "the integration of digital or computer technology by a business, industry, country, etc., or the expansion of its use in business processes". Although the importance of the concept of digitalization is increasing day by day and accepted by businesses, it can be stated that businesses cannot easily integrate and face difficulties against the change process that the digital transformation process will bring (Parviainen et al., 2022). This transformation poses distinct hurdles for manufacturing SMEs, which must either align with larger corporations or risk exclusion from the evolving digital framework (SMEs - European Commission, n.d.). Digitalization opens significant avenues for SMEs to penetrate new markets, yet the journey towards digital transformation is complex, characterized by barriers that impede manufacturing SMEs in their digital adoption strategies. The integration of digital technologies in business models, product offerings, and service delivery within cloud-based systems heralds innovative prospects for service innovation (Zheng et al., 2018). Emerging digital technologies, including mobility, social media, and smart devices, are reshaping customer engagement, internal business operations, and value creation processes (Henriette et al., 2015; Pagoropoulos et al., 2017). Digitalization fosters value-creation structures, catalyzing the reformation of existing business models and the development of new ones (Pagoropoulos et al., 2017; Vendrell-Herrero et al., 2017). Furthermore, the synergy of services and digital technologies introduces novel capabilities, such as enhancing process efficiency, enriching managerial decision-making through comprehensive and rapid data, forging robust customer relationships, adding value to products, personalizing offerings, and creating shared value (Paschou et al., 2018). With the digital revolution, the concepts of digitalization and digital transformation have undoubtedly become a trending topic in recent years. In fact, it is obvious that the concept of transformation, which is much older, is more talked about today (Alcácer et al., 2016; Sommer et al., 2017; Tekic & Koroteev, 2019). The main reason for this is the recent developments affecting information technologies such as electronic data processing, personal computers, communication technologies, internet and social media. Big data, artificial intelligence and information technologies have also heralded the arrival of a new era in information technologies, leading to the emergence of common words such as digitalization and digital transformation (Downes & Nunes, 2013). Thus, it is evident that digital transformation is pervasive, impacting all organizations, with many businesses still grappling to adapt to this paradigm shift. The permanence and ubiquity of information, knowledge, and processing capabilities, coupled with the growing interconnectedness of people, objects, devices, and systems, are transforming the operational landscapes of individuals, businesses, and societies.

Digital Transformation

Digital transformation is not about a single technology, but about major changes based on a "combination of information, computing, communication and connectivity technologies" (Bharadwaj et al., 2013), i.e. a "combination of advanced technologies" that integrate physical and digital systems (SMEs - European Commission, n.d.). Today's digitalization trend has radically changed the business processes of companies by pressuring them to integrate and incorporate digital technologies into their operations (Zangiacomi et al., 2020). Digital technologies such as IoT, Cloud Computing and Big Data and Analytics (Paschou et al., 2018), especially applied in manufacturing, bring significant changes to traditional manufacturing systems where inter-company connectivity (Mueller et al., 2017) and process integration between different stakeholders in the supply chain (Khan & Turowski, 2016) are realized, thus improving the overall efficiency of the company. The changes brought by Industry 4.0 are mainly focused on information technologies (Lasi et al., 2014), digital technologies of this nature are enablers of a digital industrial transformation, often referred to as the fourth industrial revolution or Industry 4.0. The implementation of Industry 4.0 leads to process optimization, resulting in improved operations for the entire organization. This is recognized as the main advantage of supporting the decision to implement Industry 4.0 (Sony & Naik, 2020).

Small and Medium-Sized Enterprises (SMEs)

An additional focal point of the literature review encompasses SMEs, a distinct category of organizational entities. Since its inception in 2011, Industry 4.0 has been at the forefront of industrial digital transformation, exploring innovative methods to interconnect devices and systems, thereby yielding novel data insights, facilitating the customization of products, and advancing technological independence. In this milieu, the digital transformation, as influenced by Industry 4.0, is becoming increasingly significant across various sectors. This is particularly pertinent in Europe, where it is imperative to ensure that SMEs, which constitute 99% of businesses, are not marginalized from these evolving opportunities. (Grooss et al., 2022). The definition of SMEs is not a universally accepted standard worldwide. These definitions vary depending on various factors such as economic data and differences in the distribution of enterprises across countries. SMEs are generally enterprises with a limited number of employees and a limited amount of income. Such enterprises are recognized as an important source of economic growth and employment. SMEs are recognized for their distinct advantages, including adaptability, innovation, and their substantial contribution to local economies, as elucidated by (Management Association, 2013). These enterprises represent a considerable segment of the global business landscape, encompassing over 95% of businesses (Malesios et al., 2020). Their role is particularly vital in supporting the supply chains of larger corporations. The European Commission has categorized SMEs based on employee count, distinguishing small-sized enterprises (employing fewer than 50 individuals) from medium-sized ones (with fewer than 250 employees). (Zaied & Mohmed, 2021) note that both formal and informal SMEs collectively contribute between 60% and 70% to the Gross Domestic Product. In the realm of open innovation processes, while larger firms often prioritize research and development, especially in the discovery phase, SMEs tend to focus more intently on commercialization aspects (Van Hemert et al., 2013). Nevertheless, SMEs frequently grapple with challenges such as constrained resources, complicating their capacity to innovate and compete effectively (Carias et al., 2020). The dynamic and heterogeneous nature of SMEs necessitates a variety of support mechanisms to navigate their specific challenges and harness their potential for sustainable economic development. In the Turkish context, SMEs constitute a majority of businesses, providing approximately 66% of employment and playing a pivotal role in the economy, significantly contributing to import and export rates (Aydin & Yildiz, 2023). However, the operational efficiency and competitiveness of Turkish SMEs are often lower compared to many European counterparts. This disparity stems from factors such as difficulties in accessing finance, growth challenges, struggles with technology adaptation, innovation lags, and deficiencies in institutional regulation. The literature of recent years has extensively discussed SMEs, particularly within economic domains. Yet, specific challenges inhibiting SMEs from actively participating in the economic process- like resource limitations, absence of formal planning, and financing hurdles (Klewitz & Hansen, 2014)- warrant further scholarly attention. Additionally, SMEs encounter various barriers in the digital transformation journey. Addressing these barriers and proposing solutions is critical for the economic development of nations, emphasizing the need for a focused discourse in this area.

Barriers to Digital Service Provision for SMEs

The implementation of digital transformation is articulated as a multifaceted process fraught with numerous impediments, complicating the successful progression of related initiatives. Presently, numerous enterprises continue to grapple with realizing the full potential of their digital transformation endeavors, hindered by a spectrum of barriers (Vogelsang et al., 2019). For this reason, identifying barriers and understanding their basic structure and origins is an important step in combating them. Although the importance of digitalization is well known, companies often struggle to understand the potential impacts and benefits of digitalization. According to (Henriette et al., 2015), a digital transformation project involves the application of digital capabilities to support business model transformations that affect entire organizations, especially operational processes, resources, internal and external users. Initially, the foundational technologies enabling the provision of digital services encompass the Internet of Things (IoT), big data and analytics, cloud computing, cybersecurity, augmented reality, advanced manufacturing solutions, additive manufacturing, simulation, and artificial intelligence. These technologies are characterized by their heterogeneous and intricate compositions (Paschou et al., 2018). The fact that SMEs are financially limited and do not currently have technical resources creates an barrier to easy adoption and implementation of digital technologies (Mittal et al., 2018). Barriers to digital transformation need to be well defined and necessary precautions must be taken. As a result of the literature review, it was concluded that there are many studies on the barriers to digital transformation. These studies were carried out to identify barriers and can be listed as follows: (Ahmed et al., 2022; Chatterjee et al., 2022; Cichosz et al., 2020; Jones et al., 2021; Kutnjak, 2021; Lammers et al., 2019; Raj et al., 2020; Scuotto et al., 2021; Troise et al., 2022). There are three most basic studies conducted specifically in Turkey regarding digital barriers. These studies can be listed as follows; (Bolat & Temur, 2019; Demirbas et al., 2011; Mutluturk et al., 2021). In the study conducted by (Demirbas et al., 2011), the barriers faced by SMEs operating in Turkey were examined. In this context, 224 SMEs were examined empirically and as a result of the research, it was concluded that the lack of government incentives and research and development policy is the most critical barrier encountered within the scope of change and transformation in Turkey. In another research conducted, the relationships between the possible barriers that industrial development in Turkey will encounter with the data obtained from the literature using the ISM method and a survey conducted with 14 experts in the sector were investigated. As a result of the research, it was concluded that lack of vision is the most fundamental deficiency and affects other factors (Bolat & Temur, 2019). Table 3 includes selected studies conducted in the manufacturing and service sectors on the barriers and success factors of digital transformation.

Table 3. The hierarchical structure of barriers and sub-barriers

Barriers	Sub-barriers	References
Technical/ technological barriers (B1)	Digital tools are both diverse and complex (B11) Limited financial resources of SMEs (B12) Lack of a stable and reliable technical infrastructure (B13) Product incompatibility with tech transformation (B14) Difficulties in selecting and implementing the right technology (B15) Lack of integration (incompatibility between different systems) (B16)	(Kane et al., 2015)
Organizational barriers (B2)	Decision makers' resistance to digital change and risk aversion (B21) Employees' reluctance or indifference to change (B22) Lack of experimentation and iteration process (B23) Coping with uncertainty and constant change (B24) Reluctance to outsource (B25) Failure to support relevant training of employees (B26) Lack of time (B27) Lack of cooperation between departments (B28) Lack of strategy (B29)	(Kane et al., 2015; Vogelsang et al., 2018, 2019)
Human resources barriers (B3)	Lack of employees with digital competence (B31) Fear of job loss (B32) Loss of control (B33)	(Vogelsang et al., 2018, 2019)
Customer-related barriers (B4)	Unclear customer needs (B41) Ineffective customer communication of digital benefits (B42) Customers closed to innovation (B43) Privacy and security breaches (B44)	(Plekhanov et al., 2023)
Environmental barriers (B5)	Lack of standards and laws (B51) Industrial purchasing culture and relationships (B52) Inadequate brand image (B53) Lack of investors (B54)	(Töytäri et al., 2017)

Digital transformation must be underpinned by a robust strategic framework. The efficacy of digital technologies does not reside in the technologies themselves but in how firms integrate them to reformulate business processes and accrue advantages (Kane et al., 2015). Digital transformation entails integrating digital technologies to modify fundamental business operations, products, services, processes, organizational structures, and managerial concepts (Matt et al., 2015). Digitization of service processes amplifies the factors involved in value creation, elevating the complexity of products and escalating the requirements for resources and competencies essential for their creation and support. This shift often necessitates novel competencies, resources, and collaborations, demanding an innovation management approach that synergizes traditional research and development services with information technology systems, contemporary management systems, and robust customer service (Lerch & Gotsch, 2015).

Digitalization represents a profound shift, yet the cultural resistance to change and transformation, or the indifference to its necessity, is cited as a significant cultural barrier; this aspect is often overlooked or underestimated by companies (Von Leipzig et al., 2017). Alterations in service delivery frequently imply substantial and radical cultural transformations within SMEs (Dubruc et al., 2014; Peillon et al., 2018). Transitioning to digital structures in service delivery is a complex endeavor for manufacturing SMEs, with digitalization introducing an additional layer of complexity and deepening the cultural shift required.

In the context of digital transformation, the literature highlights issues related to qualifications and skills. (Lerch & Gotsch, 2015), identify the absence of sufficiently qualified personnel within organizations as a primary impediment to the digitalization of services during the development and delivery of digital business processes. Digitalization considerably heightens the complexity, abstraction, and problem-solving skills required of all employees. Furthermore, those involved in direct service provision must possess technical competencies encompassing engineering, mechatronics, and information technology. Digital competence, defined as the effective utilization of digital technology, is deemed essential for the evolution of digital service delivery and the overarching process of digitalization (Süße et al., 2018). A deficiency in digital competencies poses a significant challenge for SMEs. (Coreynen et al., 2017) also highlight the need for acquiring new sales competencies or developing customer interface skills as potential barriers in digital servitization.

Klein et al., (2018) have identified several primary obstacles in the realm of digital transformation, which include the uncertainty in ascertaining customer needs, the vagueness in articulating value propositions, and the challenges associated with conveying the benefits of digital transformation to customers.. Another critical barrier can be listed as customers' fear of losing control over information, that is, privacy violations, concern about security and security of access to corporate systems (Klein et al., 2018). Additionally, Raja et al. (2017) point out customer proximity as a managerial uncertainty in pursuing service-oriented growth strategies. While businesses gain from and require customer insights to develop complex service offerings, there is often reluctance from customers to provide the necessary information for these insights.

Research Methodology

Research Framework

The aim of this study is to evaluate the relative importance of barriers to digital transformation using the FAHP methodology. The use of the FAHP approach offers several advantages:

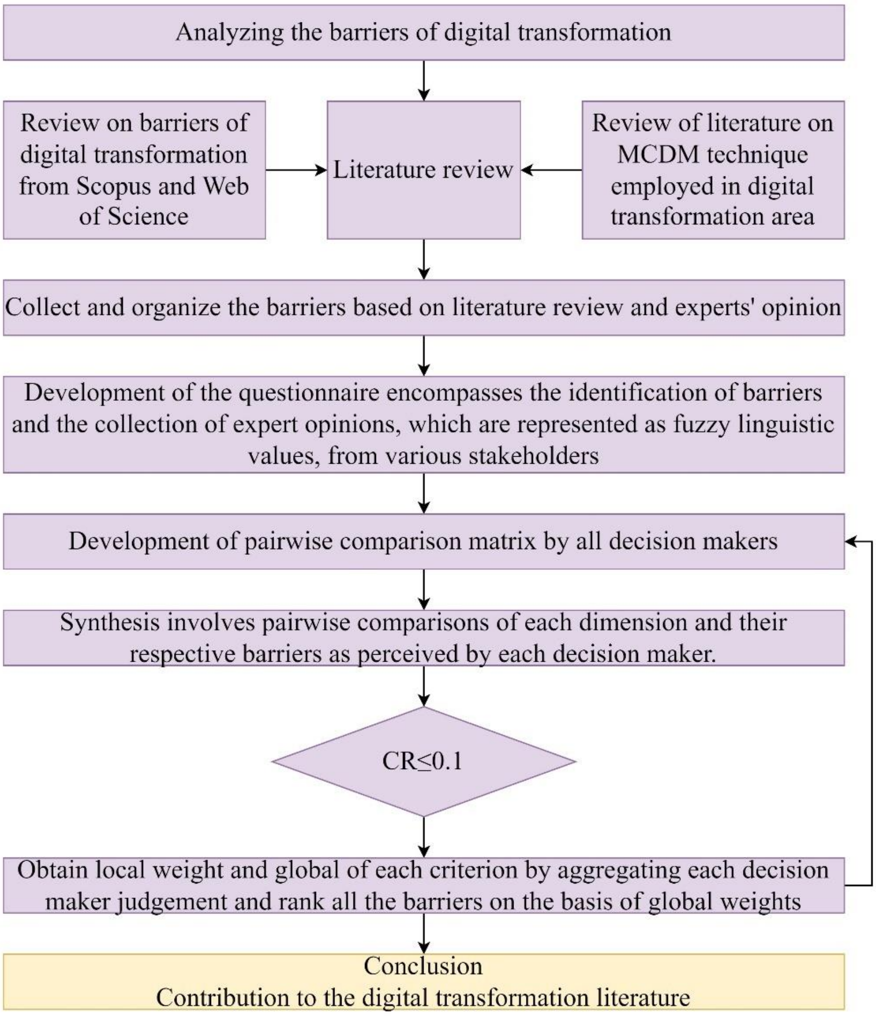

Figure 3. Research framework

- Fuzzy numbers, due to their inherently dispersed structures, are preferred tools in understanding human judgment. These numbers are suitable for modeling ambiguity and uncertainty in decision-making processes.
- The use of fuzzy numbers provides decision-makers with the freedom to estimate their preferences and to evaluate these estimates in a flexible manner. This is particularly useful in complex decision-making processes, as it allows for the consideration of various probabilities and scenarios.
- The fuzzy numbers approach can effectively handle uncertain data; human emotions and preferences are inherently unpredictable and uncertain. In modeling such uncertainties, fuzzy set theory, as an extension of the analytic hierarchy process, can be integrated into pairwise comparisons. This integration ensures a more realistic and accurate representation of decision-making processes.

This study, integrating literature findings with expert opinions, seeks to identify the primary barriers to the adoption of digital transformation. In the next step, we discuss and analyze these barriers with various field specialists. Subsequently, we determine the relative weights and global weights of each dimension using the FAHP. Figure 3 presents the proposed research framework employed for this study.

Fuzzy Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP), originally proposed by (Saaty, 1987), is a widely used method for solving Multiple Criteria Decision Making (MCDM) problems. However, the conventional AHP may not accurately capture human cognitive processes, particularly in situations where problems are not fully defined or where solving them involves uncertain data, often referred to as "fuzzy" problems. Recognizing this limitation, (Van Laarhoven & Pedrycz, 1983) addressed the issue by incorporating the concept of "fuzzy theory" into AHP assessments.

The introduction of "fuzzy AHP" enables the resolution of uncertain and fuzzy problems, providing a framework to rank excluded factors based on their weight ratios. This adaptation enhances the applicability of AHP in scenarios characterized by incomplete problem definitions and uncertainty. The integration of fuzzy theory into AHP contributes to a more realistic representation of decision-making processes, especially when dealing with complex and ambiguous decision environments.

The extent analysis fuzzy AHP method

In this study, (Chang, 1996) extent analysis method was employed due to its widespread usage and its efficiency, requiring fewer operations compared to alternative methods. The rationale behind selecting Chang's extent analysis method lies in its prevalent use and operational simplicity, making it a pragmatic choice for our study. The following are the systematic steps involved in the application of this method

Let $X = \{x_1, x_2, \dots, x_n\}$ be an object set, and $U = \{u_1, u_2, \dots, u_m\}$ be a goal set. According to the extended analysis method, g_i values are generated for each object, considering each target individually. Thus, for each object, m extended analysis values can be obtained as follows.

$$M_{g_i}^1, M_{g_i}^2, \dots, M_{g_i}^m \qquad i = 1, 2, \dots, n \tag{1}$$

where all values of $M_{g_i}^j (j = 1, 2, \dots, m)$ are triangular fuzzy numbers. The steps of Chang's extended analysis are given below.

The fuzzy pairwise comparison matrix $\tilde{A} = [\tilde{a}_{ij}]$ is set as follows:

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1,1,1) & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & (1,1,1) \end{bmatrix} = \begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & (1,1,1) & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \dots & (1,1,1) \end{bmatrix} \tag{2}$$

Step 1. The value of the fuzzy synthetic degree with respect to the ith object is calculated using (Eq. 3).

$$S_i = \sum_{j=1}^{m} M_{g_i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1} \quad (3)$$

To obtain $\sum_{j=1}^{m} M_{g_i}^{j}$ perform the fuzzy addition operation of m extent analysis values for a specific matrix. This operation is essential for comprehensively assessing the performance of the matrix under a given criterion or parameter.

$$\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_j , \sum_{j=1}^{m} m_j , \sum_{j=1}^{m} u_j \right) \quad (4)$$

To obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1}$ perform the fuzzy addition of $M_{g_i}^{j}(\, j = 1, 2, \dots , m)$ values such that

$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_j , \sum_{j=1}^{m} m_j , \sum_{j=1}^{m} u_j \right)$ and then compute the inverse of the vector

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1} = \left(\left(\sum_{j=1}^{m} l_j \right)^{-1} , \left(\sum_{j=1}^{m} m_j \right)^{-1} , \left(\sum_{j=1}^{m} u_j \right)^{-1} \right) \quad (5)$$

Step 2. $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ degree of probability:

$$V(M_2 \geq M_1) = \sup_{y \geq x} \left[min(\mu_{M_1}(x), \mu_{M_2}(y) \right] \quad (6)$$

In the context of the FAHP, after establishing a pairwise matrix predicated on the prioritization among criteria utilizing triangular fuzzy numbers and their inverse counterparts, the methodology advances to the computation of composite scores for each alternative relative to these criteria. These composite scores are articulated as fuzzy values, encapsulating the efficacy of each alternative. This process of aggregation takes into account the fuzzy assessments contributed by various decision maker and the inherent fuzziness in the weights of the criteria. Consequently, the degree of possibility (*V*) is ascertained through the application of (Eq. 6) and (Eq. 7).

$$V(M_2 \geq M_1) = hgt(M_2 \cap M_1) = \begin{cases} 1 & if\ m_2 \geq m_1 \\ 0 & if\ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \quad (7)$$

d, μ_{M_1} and μ_{M_2} between the highest intersection point is the ordinate of D.

weight vector for k≠i ; k=1,2,…,n

$$W' = \left(d'(A_1), d'(A_1), \dots , d'(A_n) \right)^T \quad (8)$$

Step 3. The normalized weight vectors are

$$W = \left(d\,(A_1), d\,(A_1), \dots , d\,(A_n) \right)^T \quad (9)$$

where W is a non-fuzzy number. Table 4 shows the meaning of linguistic expressions in the form of fuzzy numbers (Kannan et al., 2013). Although precise data may not suffice for modeling real-world scenarios in Multi-Criteria Decision Making (MCDM), this study implements linguistic variables to specifically define the grades of a criterion, thereby facilitating decision makers' subjective assessment using fuzzy numbers. A linguistic variable is a variable that employs natural language to describe the degree of value, and the type of expressions used for comparing each criterion is illustrated in Table 4.

Table 4. Linguistic scales and fuzzy scales for importance

Linguistic scale for importance Criterion i and Criterion j	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Ci and Cj are equally strong	(1, 1, 1)	(1, 1, 1)
Ci is slightly more moderately strong than Cj	(2, 3, 4)	(1/4, 1/3, 1/2)
Ci is strongly more important than Cj	(4, 5, 6)	(1/6, 1/5, 1/4)
Ci is very strongly more important than Cj	(6, 7, 8)	(1/8, 1/7, 1/6)
Ci is extremely more important than Cj	(9, 9, 9)	(1/9, 1/9, 1/9)
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)

Fuzzy Analytical Hierarchy Process (AHP)

Turkey is renowned for its rich historical and cultural heritage, serving as a pivotal bridge between the East and the West. Economically, the country is characterized by a dynamic structure predominantly reliant on SMEs. In recent years, these enterprises have accelerated their digital transformation by adopting technology more effectively. Advancements in areas such as e-commerce, digital marketing, and online business processes have enhanced their competitiveness in both local and global markets. This progression in digital transformation plays a crucial role in Turkey's economic growth, and is anticipated to continue its upward trajectory in the future.

Application and Results

This section is dedicated to the presentation of the numerical outcomes. In the study, the FAHP methodology was employed for expert assessments, and all computations were conducted using an Excel spreadsheet. Details regarding the experts involved are provided in Table 5.

Table 5. Profile of the Ten Decision-Making Experts

Code	Gender	Age	Education Level	Experience (Years)	Job Title	Job Responsibility
E1	Male	34	PhD in operation research	>7	Research Assistant	Managing the budget university.
E2	Female	30	PhD in business	>7	Research Assistant	Marketing research
E3	Male	34	Computer engineering	>6	Manager of software development	In charge of all software development decisions.
E4	Male	35	Computer engineering	>6	Manager of software development	Responsible for R&D and new software development.
E5	Female	35	Master’s in Businesses	>5	Manager of company	Director of company
E6	Male	32	Master’s in electronic engineering	>9	Project manager	Managing the engineering team and new projects
E7	Female	42	PhD in management information systems	>15	Academic	Responsible for projects and academic studies
E8	Male	33	PhD in financier	>5	Academician	Accounting and finance specialist
E9	Male	38	Master’s in Industrial Engineer	>10	Manager of company	Director of company
E10	Male	37	Assist. prof. dr	>10	Academician	Marketing research

Table 6. Comparison matrix of the barriers

	B_1	B_2	B_3	B_4	B_5
B_1	(1, 1, 1)	(1.162, 1.356, 1.597)	(0.856, 0.992, 1.149)	(0.736, 0.904, 1.149)	(1.516, 1.871, 2.259)
B_2	(0.626, 0.738, 0.860)	(1, 1, 1)	(1.149, 1.301, 1.490)	(1.886, 2.253, 2.595)	(1.282, 1.778, 2.392)
B_3	(0.871, 1.009, 1.168)	(0.671, 0.769, 0.871)	(1, 1, 1)	(1.267, 1.513, 1.762)	(1.672, 2.141, 2.595)
B_4	(0.871, 1.107, 1.358)	(0.385, 0.444, 0.536)	(0.568, 0.661, 0.789)	(1, 1, 1)	(0.669, 0.823, 0.972)
B_5	(0.443, 0.535, 0.660)	(0.418, 0.563, 0.780)	(0.385, 0.467, 0.598)	(1.029, 1.215, 1.431)	(1, 1, 1)

Table 7. Comparison matrix of the sub-barriers within "Technical/technological barriers" (B1)

	B_{11}	B_{12}	B_{13}	B_{14}	B_{15}	B_{16}
B_{11}	(1, 1, 1)	(0.430, 0.521, 0.660)	(0.789, 0.896, 1.054)	(0.707, 0.803, 0.933)	(0.634, 0.763, 0.933)	(0.616, 0.719, 0.871)
B_{12}	(1.516, 1.918, 2.325)	(1, 1, 1)	(1.182, 1.552, 1.943)	(1.414, 1.763, 2.083)	(1.000, 1.205, 1.414)	(1.072, 1.390, 1.741)
B_{13}	(0.949, 1.116, 1.267)	(0.515, 0.644, 0.846)	(1, 1, 1)	(1.149, 1.344, 1.516)	(0.616, 0.695, 0.812)	(0.475, 0.549, 0.652)
B_{14}	(1.072, 1.246, 1.414)	(0.480, 0.567, 0.707)	(0.660, 0.744, 0.871)	(1, 1, 1)	(0.707, 0.803, 0.933)	(0.545, 0.617, 0.707)
B_{15}	(1.072, 1.311, 1.578)	(0.707, 0.830, 1.000)	(1.231, 1.438, 1.625)	(1.072, 1.246, 1.414)	(1, 1, 1)	(0.699, 0.763, 0.846)
B_{16}	(1.149, 1.390, 1.625)	(0.574, 0.719, 0.933)	(1.534, 1.823, 2.107)	(1.414, 1.621, 1.835)	(1.182, 1.311, 1.431)	(1, 1, 1)

Table 8.Comparison matrix of the sub-barriers within "Organizational barriers" (B2)

	B_{21}	B_{22}	B_{23}	B_{24}	B_{25}	B_{26}	B_{27}	B_{28}	B_{29}
B_{21}	(1, 1, 1)	(1.072, 1.255, 1.431)	(1.072, 1.311, 1.578)	(1.625, 2.019, 2.421)	(1.149, 1.334, 1.534)	(0.728, 0.888, 1.072)	(1.943, 2.273, 2.595)	(2.024, 2.690, 3.383)	(0.461, 0.544, 0.660)
B_{22}	(0.699, 0.797, 0.933)	(1, 1, 1)	(0.860, 1.061, 1.282)	(0.634, 0.782, 0.960)	(0.591, 0.757, 1.012)	(0.836, 0.958, 1.116)	(0.771, 0.903, 1.041)	(0.461, 0.535, 0.634)	(0.469, 0.567, 0.671)
B_{23}	(0.634, 0.763, 0.933)	(0.780, 0.943, 1.162)	(1, 1, 1)	(1.358, 1.633, 1.888)	(0.933, 1.052, 1.196)	(0.679, 0.803, 0.972)	(0.480, 0.549, 0.660)	(0.438, 0.521, 0.634)	(0.530, 0.612, 0.736)
B_{24}	(0.413, 0.495, 0.616)	(1.041, 1.278, 1.578)	(0.530, 0.612, 0.736)	(1, 1, 1)	(0.728, 0.803, 0.907)	(1.103, 1.311, 1.534)	(0.728, 0.896, 1.116)	(0.360, 0.444, 0.574)	(0.430, 0.521, 0.660)
B_{25}	(0.652, 0.750, 0.871)	(0.988, 1.321, 1.692)	(0.836, 0.950, 1.072)	(1.103, 1.246, 1.374)	(1, 1, 1)	(0.641, 0.803, 1.029)	(1.029, 1.390, 1.813)	(0.699, 0.903, 1.149)	(0.370, 0.471, 0.616)
B_{26}	(0.933, 1.126, 1.374)	(0.896, 1.043, 1.196)	(1.029, 1.246, 1.473)	(0.652, 0.763, 0.907)	(0.972, 1.246, 1.560)	(1, 1, 1)	(0.871, 0.943, 1.041)	(0.577, 0.725, 0.896)	(0.530, 0.649, 0.812)
B_{27}	(0.385, 0.440, 0.515)	(0.960, 1.108, 1.297)	(1.516, 1.823, 2.083)	(0.896, 1.116, 1.374)	(0.552, 0.719, 0.972)	(0.960, 1.061, 1.149)	(1, 1, 1)	(0.758, 0.896, 1.072)	(0.660, 0.757, 0.907)
B_{28}	(0.296, 0.372, 0.494)	(1.578, 1.871, 2.169)	(1.578, 1.918, 2.285)	(1.741, 2.253, 2.781)	(0.871, 1.108, 1.431)	(1.116, 1.380, 1.732)	(0.993, 1.116, 1.320)	(1, 1, 1)	(0.536, 0.644, 0.812)
B_{29}	(1.516, 1.838, 2.169)	(1.490, 1.764, 2.132)	(1.358, 1.633, 1.888)	(1.516, 1.918, 2.325)	(1.625, 2.125, 2.702)	(1.231, 1.540, 1.888)	(1.103, 1.321, 1.516)	(1.231, 1.552, 1.866)	(1, 1, 1)

Table 9. Comparison matrix of the sub-barriers within "Human resources barriers" (B3)

	B_{31}	B_{32}	B_{33}
B_{31}	(1, 1, 1)	(1.267, 1.732, 2.945)	(1.516, 2.158, 2.144)
B_{32}	(0.340, 0.577, 0.789)	(1, 1, 1)	(0.922, 1.125, 1.320)
B_{33}	(0.467, 0.463, 0.660)	(0.758, 0.889, 1.084)	(1, 1, 1)

Table 10. Comparison matrix of the sub-barriers within "Customer-related barriers" (B4)

	B_{41}	B_{42}	B_{43}	B_{44}
B_{41}	(1, 1, 1)	(1.966, 2.290, 2.595)	(0.341, 0.408, 0.509)	(0.552, 0.649, 0.780)
B_{42}	(0.385, 0.437, 0.509)	(1, 1, 1)	(0.687, 0.859, 1.103)	(1.000, 1.175, 1.374)
B_{43}	(1.966, 2.451, 2.930)	(0.907, 1.165, 1.455)	(1, 1, 1)	(1.149, 1.256, 1.374)
B_{44}	(1.282, 1.540, 1.813)	(0.728, 0.851, 1.000)	(0.728, 0.796, 0.871)	(1, 1, 1)

Table 11. Comparison matrix of the sub-barriers within "Environmental barriers" (B5)

	B_{51}	B_{52}	B_{53}	B_{54}
B_{51}	(1, 1, 1)	(1.116, 1.356, 1.625)	(1.041, 1.145, 1.282)	(0.907, 1.061, 1.282)
B_{52}	(0.616, 0.738, 0.896)	(1, 1, 1)	(1.217, 1.427, 1.625)	(0.803, 0.950, 1.090)
B_{53}	(0.780, 0.873, 0.960)	(0.616, 0.701, 0.822)	(1, 1, 1)	(0.509, 0.577, 0.679)
B_{54}	(0.780, 0.942, 1.103)	(0.917, 1.052, 1.246)	(1.473, 1.732, 1.966)	(1, 1, 1)

The FAHP was subsequently utilized to ascertain the weights of both factors and sub-factors. Illustratively, utilizing the pairwise comparison matrix of the factors presented in Table 6, the weights of the factors were meticulously computed. In the process of conducting comparative analyses, each sub-barriers was meticulously evaluated in relation to the higher-level barriers. This evaluation was performed by decision-makers operating at the corresponding level, resulting in the formulation of comparison matrices. Subsequently, these matrices were consolidated to form representative matrices, which are comprehensively presented in Tables 7-11. Using Eqs. (3) – (5), we determined TFN values of the six output indicators as follows:

$$S_{B_1} = (5.270, 6.122, 7.153) \otimes \left(\frac{1}{23.472}, \frac{1}{27.436}, \frac{1}{32.010}\right) = (0.165, 0.223, 0.305)$$
$$S_{B_2} = (5.923, 7.069, 8.338) \otimes \left(\frac{1}{23.472}, \frac{1}{27.436}, \frac{1}{32.010}\right) = (0.185, 0.258, 0.355)$$
$$S_{B_3} = (5.481, 6.432, 7.395) \otimes \left(\frac{1}{23.472}, \frac{1}{27.436}, \frac{1}{32.010}\right) = (0.171, 0.234, 0.315)$$
$$S_{B_4} = (3.522, 4.034, 4.655) \otimes \left(\frac{1}{23.472}, \frac{1}{27.436}, \frac{1}{32.010}\right) = (0.110, 0.147, 0.198)$$
$$S_{B_5} = (3.275, 3.779, 4.469) \otimes \left(\frac{1}{23.472}, \frac{1}{27.436}, \frac{1}{32.010}\right) = (0.102, 0.138, 0.190)$$

$$V(S_{B_1} \geq S_{B_2}) = V[(0.165, 0.223, 0.305) \geq (0.185, 0.258, 0.355)]$$

The values of SB_i were individually compared and the degree of possibility of $SB_j=(lj,mj,uj) \geq SB_i=(li,mi,ui)$ were subsequently determined using the equation (Eq. 7). Table 12 shows the values of $V(SB_i \geq SB_j)$.

Table 12. Degree of Posibility of V(SB_i ≥ SB_j) for the barrriers.

$V(S_{B_1} \geq S_{B_j})$	Value	$V(S_{B_2} \geq S_{B_j})$	Value	$V(S_{B_3} \geq S_{B_j})$	Value	$V(S_{B_4} \geq S_{B_j})$	Value	$V(S_{B_5} \geq S_{B_j})$	Value
$V(S_{B_1} \geq S_{B_2})$	0.776	$V(S_{B_2} \geq S_{B_1})$	1	$V(S_{B_3} \geq S_{B_1})$	1	$V(S_{B_4} \geq S_{B_1})$	0.307	$V(S_{B_5} \geq S_{B_1})$	0.232
$V(S_{B_1} \geq S_{B_3})$	0.922	$V(S_{B_2} \geq S_{B_3})$	1	$V(S_{B_3} \geq S_{B_2})$	0.848	$V(S_{B_4} \geq S_{B_2})$	0.107	$V(S_{B_5} \geq S_{B_2})$	0.043
$V(S_{B_1} \geq S_{B_4})$	1	$V(S_{B_2} \geq S_{B_4})$	1	$V(S_{B_3} \geq S_{B_4})$	1	$V(S_{B_4} \geq S_{B_3})$	0.237	$V(S_{B_5} \geq S_{B_3})$	0.165
$V(S_{B_1} \geq S_{B_5})$	1	$V(S_{B_2} \geq S_{B_5})$	1	$V(S_{B_3} \geq S_{B_5})$	1	$V(S_{B_4} \geq S_{B_5})$	1	$V(S_{B_5} \geq S_{B_4})$	0.896

Afterwards, we determined the minimum degree of possibility $d'(i)$ of $V(SB_i \geq SB_j)$ for i, j = 1, 2, . . ., 6 by using Eq. (6).

$d'(1) = \min V(S_{B_1} \geq S_{B_2}, S_{B_3}, S_{B_4}, S_{B_5})$ = 0.776
$d'(2) = \min V(S_{B_2} \geq S_{B_1}, S_{B_3}, S_{B_4}, S_{B_5})$ = 1
$d'(3) = \min V(S_{B_3} \geq S_{B_1}, S_{B_2}, S_{B_4}, S_{B_5})$ = 0.848
$d'(4) = \min V(S_{B_4} \geq S_{B_1}, S_{B_2}, S_{B_3}, S_{B_5})$ = 0.107
$d'(5) = \min V(S_{B_5} \geq S_{B_1}, S_{B_2}, S_{B_3}, S_{B_4})$ = 0.043

The weight vector was obtained by the use of Eq. (8)

$W' = (0.776, 1, 0.848, 0.107, 0.043)^T$

Normalized the weight vectors using Eq. (9) and obtained the relative weights of the five barriers,

$W = \left(W_{S_{B_1}}, W_{S_{B_2}}, W_{S_3}, W_{S_{B_4}}, W_{S_{B_5}}\right)^T$
$W = (0.280, 0.360, 0.306, 0.039, 0.015)^T$, where W is a non-fuzzy number.

Through a comparable calculation, the weight vectors $W_{B1\text{j}}$, $W_{B2\text{j}}$, $W_{B3\text{j}}$, $W_{B4\text{j}}$, $W_{B5\text{j}}$ for sub-factors at the successive level were established. They are delineated below:

$(W_{B11}, W_{B12}, W_{B13}, W_{B14}, W_{B15}, W_{B16})^T = (0.005, 0.387, 0.072, 0.025, 0.199, 0.313)^T$
$(W_{B21}, W_{B22}, W_{B23}, W_{B24}, W_{B25}, W_{B26}, W_{B27}, W_{B28}, W_{B29})^T$

$= (0.248, 0.003, 0.027, 0.006, 0.084, 0.072, 0.077, 0.196, 0.288)^T$

$(W_{B31}, W_{B32}, W_{B33})^T = (0.789, 0.167, 0.044)^T$
$(W_{B41}, W_{B42}, W_{B43}, W_{B44})^T = (0.234, 0.026, 0.547, 0.193)^T$
$(W_{B51}, W_{B52}, W_{B53}, W_{B54})^T = (0.507, 0.384, 0.051, 0.547)^T$

Table 13. Final prioritization of barriers in context of digital transformation

Barriers	Weight (Bi)	Ranking	Sub-barriers	Weight (Bij)	Finalized Weight	Local Rank	Local Weight %	Global Rank	Global Weight %
B_1	0.280	3	B_{11}	0.005	0.001	6	0,1%	23	28,0%
			B_{12}	0.387	0.108	1	10,8%	2	
			B_{13}	0.072	0.020	4	2,0%	13	
			B_{14}	0.025	0.007	5	0,7%	20	
			B_{15}	0.199	0.056	3	5,6%	7	
			B_{16}	0.313	0.087	2	8,7%	5	
B_2	0.360	1	B_{21}	0.248	0.089	2	8,9%	4	36,0%
			B_{22}	0.003	0.001	9	0,1%	25	
			B_{23}	0.027	0.010	7	1,0%	15	
			B_{24}	0.006	0.002	8	0,2%	22	
			B_{25}	0.084	0.030	4	3,0%	9	
			B_{26}	0.072	0.026	6	2,6%	11	
			B_{27}	0.077	0.028	5	2,8%	10	
			B_{28}	0.196	0.071	3	7,1%	6	
			B_{29}	0.288	0.104	1	10,4%	3	
B_3	0.306	2	B_{31}	0.789	0.241	1	24,1%	1	30,6%
			B_{32}	0.167	0.051	2	5,1%	8	
			B_{33}	0.044	0.013	3	1,3%	14	
B_4	0.039	4	B_{41}	0.234	0.009	2	0,9%	16	3,9%
			B_{42}	0.026	0.001	4	0,1%	24	
			B_{43}	0.547	0.021	1	2,1%	12	
			B_{44}	0.193	0.007	3	0,7%	19	
B_5	0.015	5	B_{51}	0.507	0.008	2	0,8%	18	2,3%
			B_{52}	0.384	0.006	3	0,6%	21	
			B_{53}	0.051	0.001	4	0,1%	26	
			B_{54}	0.547	0.008	1	0,8%	17	

As part of the research, decision-makers conducted a comparative analysis of five primary barriers using a pairwise comparison questionnaire. Table 13 presents the weight coefficients assigned to the main barriers. When analyzing the coefficients associated with primary barriers, decision-makers identified "Technical/technological barriers" as the most significant barriers, yielding a value of 0.360. Subsequently, "Human resources barriers" ranked second at 0.306, followed by "Technical/technological barriers" again at 0.280. Other barriers, such as "Customer-related barriers" held a value of 0.039, while "Environmental barriers" were deemed less influential with a value of 0.015. In Table 13, among technical/technological barriers, the most crucial sub-barrier is identified as "Limited financial resources of SMEs." Within organizational barriers, "Lack of strategy" holds the highest significance. Among human resources barriers, "Lack of employees with digital competence" is identified as the most pivotal barrier. In terms of barriers related to customer-related barriers, "Customers closed to innovation" is deemed the most prominent, while within environmental barriers, "Lack of investors" is recognized as the foremost challenge.

Discussion

In order to effectively realize digital transformation, there may be critical factors in overcoming the barriers that SMEs may encounter. Integrating new technologies with existing systems can be difficult. In this case, it is necessary to use technology wisely, improve processes and increase efficiency by creating a flexible and compatible infrastructure. Digital transformation is often costly; Therefore, it is important for businesses to plan their budget carefully and consider costs. Getting support from external sources in this process can facilitate access to technical information and resources.

Barriers in the digital transformation process are not limited to technological advances, but also require changes in business culture and employee attitudes. For this reason, the importance of digital transformation should be emphasized to employees, training opportunities should be provided, flexible working environments should be created and innovative ideas should be encouraged. To create an environment that supports digital transformation in business culture, full support from the leadership level is required. Therefore, SME managers should understand the importance of this process, provide the necessary resources and create a strategic vision. Additionally, communicating effectively with employees, customers, and other stakeholders, soliciting feedback, and involving them at every stage of the process can increase acceptance and support the success of the process. SMEs' progress in their transformation processes step by step and starting with small steps instead of major changes can provide a more manageable digital transformation process.

Governments can take various measures to alleviate the difficulties of SMEs in digital transformation: Applications can be developed to increase the integration of engineering fields and informatics, software and technology disciplines in universities. They can provide tax advantages to encourage businesses to employ IT experts. Policies and supportive practices can be implemented to increase the number of not only male but also female IT specialists. Technology roadmaps can be presented for focus technology areas (cloud computing, big data, artificial intelligence, autonomous robots, etc.). Finally, to accelerate the digital transformation of SMEs, centers of excellence or similar structures can be created and research centers can be strengthened and supported in line with technology roadmaps. These suggestions can contribute to reducing the barriers that may arise during the digital transformation process.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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