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RESEARCH ARTICLE

Analysing barriers of digitalization in apparel sector: a fuzzy DEMATEL approach

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ABSTRACT
The digital transformation process entails the creation of new business models, processes, software, and technologically advanced systems. This study aims to analyze the barriers that businesses in the apparel sector face during the process of digitalization. So far, no comprehensive study has been found in the literature that analyses how these barriers interact with each other to make better decisions for digital transformation. This study initiates by conducting an identification of the barriers faced by companies operating in the apparel sector during their pursuit of digitalization. Then, prioritizing important barriers and the relationships between these barriers are analyzed using the Fuzzy DEMATEL method. Research results showed that lack of expertise, lack of management support, insufficient financial resources and lack of IT system are the four main barriers. It is thought that the development of digitalization in the apparel clothing industry will increase by keeping these barriers in focus.

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Apparel; digitalization; fuzzy DEMATEL; manufacturing

1. Introduction

It is anticipated that the global market size of the textile and apparel sector will achieve a milestone of around 2.25 trillion USD by 2025, marking a significant shift towards digitalization in the apparel sector's value chain (Pal & Jayarathne, 2022). Digitalization involves establishing a highly adaptable production model for personalized digital products and services, facilitating real-time interactions among individuals, products, and devices throughout the production process (Ha et al., 2018). Digitalization offers substantial benefits to apparel businesses, including real-time monitoring of material and product conditions, enhanced availability and accessibility, efficient data transfer, and a seamless transition towards a circular economy (Happonen & Ghoreishi, 2021). Furthermore, it facilitates the enhancement of sustainability through transparency, real-time communication, and demand forecasting. As an illustration, online business platforms have already initiated shifts in consumer behavior and supplier business models on a global scale (Schumann et al., 2021). Digitalization further enhances the agility of apparel businesses, a significant portion of which comprises SMEs, by promoting their international expansion (Divrik & Baykal, 2022).

Digitalization facilitates the transformation of the apparel industry into a more sustainable and customer-oriented sector (Bertola & Teunissen, 2018). The industry may transition from a paper-based approach to a totally digital one in product design and development thanks to digitalization (Weinswig, 2017). Using big data, the apparel industry may forge new connections with its customers, suppliers, competitors, and staff. As a result, businesses can utilize the data and relationships acquired through these connections to optimize their production and decision-making processes (Gangoda et al., 2020). Furthermore, digitalization enables apparel businesses, predominantly composed of small and medium-sized enterprises (SMEs), to adopt modern production methods such as flexible mass customization (Turkyilmaz et al., 2021). Furthermore, there is a forecast that digitalization will lead to an average reduction of two to eight weeks in order delivery times within the apparel industry. This transformation will equip businesses with the agility required to thrive in a demand-driven market, concurrently yielding cost reductions of at least 2.5% (Rudolf et al., 2019). As evident, digitalization exerts a significant impact on the apparel industry, and it is anticipated that this influence will continue to intensify in the future. Hence, it is crucial for businesses to adopt a proactive stance towards digitalization instead of waiting (Parviainen et al., 2022).

Despite the numerous opportunities that digitalization offers to businesses, there are also several barriers that hinder their digital transformation efforts (Gangoda et al., 2020). This study aims to unveil the relationships between barriers to analyze the obstacles hindering the digitalization process in the apparel industry. Decision-makers face limitations due to incomplete knowledge and subjective human choices, which constitute a complex phenomenon that is challenging to fully comprehend, thus impeding the identification of relationships. The problem of expressing the opinions of decision makers with crisp numerical values can be overcome with the fuzzy logic method (Zadeh, 1965). In

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this study, firstly, a comprehensive model is created for the analysis of the barriers on the way to digitalization in the apparel industry. Then, the Fuzzy Decision Making Experiment and Laboratory Evaluation (Fuzzy DEMATEL) method based on fuzzy logic was used (Lin & Wu, 2008). It is aimed to determine the effect and cause barriers between the model criteria by using the fuzzy DEMATEL method.

Limited researcher's attention has been given to Multi-Criteria Decision-Making (MCDM) studies addressing the barriers associated with the implementation of digital transformation in businesses at large, rather than specifically focusing on the textile sector (Javaid et al., 2022; Kumar et al., 2022; Raj et al., 2020; Shang et al., 2022; Surange et al., 2022).

Upon reviewing the literature, no comprehensive study has been found that specifically addresses the challenges and barriers encountered in the integration of digital transformation in the textile sector using MCDM approach. Limited research has been conducted on the application of MCDM methods to analyze the challenges and opportunities arising from digital transformation in the textile industry. Hence, there is a gap in the literature regarding comprehensive studies that investigate the integration of MCDM techniques within the context of digital transformation in this particular sector. In this study Fuzzy DEMATEL method is used to find out the cause-and-effect relationship among the barriers of implementation of digital transformation to the textile sector identified by experts.

Following a review of the literature, Table 1 presents research on the barriers to digitalization identified and the challenges encountered by businesses.

The most identified barriers to digitalization are Lack of Industry 4.0 Management Policy (Government Policy), Insufficient Financial Resources/Investments, Lack of Management Support (Leadership), Lack of Expertise, Insecurity of Data Sharing and Lack of Incentive according to Table 1.

The initial digitalization applications in the apparel industry resulted in the creation of digital human models, which brought about a transformation in the industry's conventional planning, production, and sales processes. Consequently, this led to the production of distinctively differentiated garments (Bas et al., 2022). However, conventional, well-known apparel brands and businesses are hesitant and sluggish to accept digitalization (Bertola & Teunissen, 2018). German textile companies, in particular, exhibit hesitancy in commencing the digital transformation process due to significant barriers in implementation. These barriers include uncertainties regarding financial benefits and a lack of specialized knowledge (Küsters et al., 2017). Table 2 presents the research and findings about the apparel sector's digitalization hurdles.

The research on digitalization in the apparel sector focuses on several digitalization problems as can be observed by examining Table 2. The current state highlights that the number of studies in the apparel sector is insufficient. This is the primary motivation of this study.

2. Fuzzy DEMATEL

In 1972, the Battelle Memorial Institute Research Center introduced the DEMATEL method to the literature. This method aims to analyze complex problems by determining the relationships between various factors of the problem (Gabus & Fontela, 1972). The DEMATEL method is an effective tool for interpreting complex problems visually and numerically. It enables analysts to understand the degrees to which various factors influence and affect one another. This understanding is critical for making informed decisions and identifying potential solutions to complex problems (Lin & Wu, 2004). The DEMATEL approach has been used in several investigations across many different domains as energy (Sun et al., 2022; Yin et al., 2022; Zhao et al., 2021), health (Maqbool & Khan, 2020; Singh et al., 2020), manufacturing (Ganji et al., 2018; Mirzaaghabeik & Abbaspour Esfeden, 2021), and environment (Shamsadini et al., 2023).

The fuzzy DEMATEL method is an extension of the traditional DEMATEL method that integrates fuzzy numbers to provide more accurate and realistic results for real-world problems. This method is particularly useful in complex decision-making processes that involve a high degree of uncertainty. To apply the fuzzy DEMATEL method, a group of experts provide their opinions, which are then analyzed based on a set of operational steps specific to the fuzzy environment. These steps are as follows (Lin & Wu, 2008):

- Determining the decision target of the problem and assembling a group of experts who have knowledge about the problem in this direction.
- Identifying the factors of the problem and fuzzy linguistic variables to evaluate the factors.

Table 1. Barriers of the digitalization.

Barriers	(Fernando et al., 2023)	(Majumdar et al., 2021)	(Dahooie et al., 2022)	(Pavan et al., 2022)
Lack of Industry 4.0 Management Policy (Government Policy)	x	x	x	x
Insufficient Financial Resources/Investments	x	x	x	x
Lack of Management Support (Leadership)	x	x	x	x
Lack of Expertise	x	x	x	x
The Insecurity of Data Sharing	x	x	x	x
Lack of Incentive	x	x	x	x
Level of Dependence of the System on Suppliers			x	
Fear of Failure		x	x	
Lack of Risk Management Tools for Investments		x		
Competitive Pressure			x	
Lack of IT Systems (Infrastructure etc.)				x
Inadequate Maintenance Support System				x
Lack of Clarity in Defining ROI		x	x	x

Table 2. Barriers of the digitalization in apparel industry.

Barriers	(S.-E. Lee et al., 2021)	(S. Lee et al., 2021)	(Waibel et al., 2017)	(Robodk, 2020)	(Petrick & McCreary, 2019)	(Özbek & Pekinalp, 2021)
Insufficient government support	x					
Being a labor-intensive industry		x				
No standardized processing steps yet			x			
The fact that fabrics are an unstable environment and they stretch and deform when touched				x		
Lack of interoperability between protocols, components, products, and systems					x	
Apparel products are constantly changing due to their wide variety and fashion factor						x
Apparel manufacturers still have access to a low workforce						x

Table 3. Linguistic terms.

Linguistic terms	Triangular fuzzy numbers
No influence	(0 0 0.25)
Very low influence	(0 0.25 0.50)
Low influence	(0.25 0.50 0.75)
High influence	(0.50 0.75 1.00)
Very high influence	(0.75 1.00 1.00)

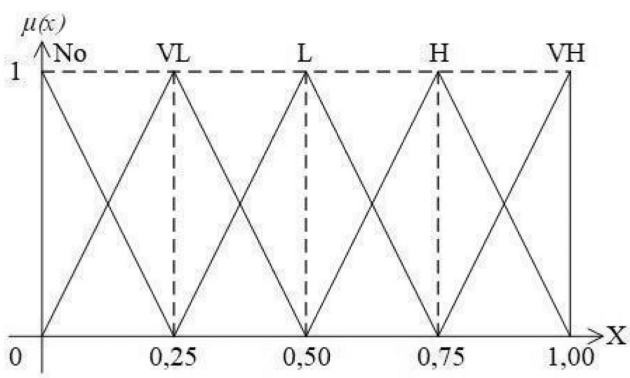

Figure 1. Triangular fuzzy membership functions.

- Unlike the traditional DEMATEL method, linguistic variables are used in group decision making to deal with the uncertainties of expert evaluations in the fuzzy DEMATEL method (Li, 1999). The fuzzy numbers of linguistic variables are given in Table 3 and their membership functions are given in Figure 1.
- Obtaining the averages by taking the evaluations of the experts. At this step, p experts are asked to evaluate the relations between factors in pairs with linguistic terms. A fuzzy matrix $\tilde{F}^1$, $\tilde{F}^2$, . ., $\tilde{F}^p$ is created for each expert. Then the $\tilde{F}$ matrix (Eq. 1) is obtained by finding the averages. $\tilde{F}$ matrix is also called direct relation matrix.

$$\tilde{F} = \frac{\tilde{F}^1 + \tilde{F}^2 + \ldots + \tilde{F}^p}{p} \quad (1)$$

$\tilde{F}$ direct relationship matrix is as follows. The $\tilde{f}_{ij}$ values correspond to the fuzzy numbers (l_{ij}, m_{ij}, u_{ij}). n represents the number of factors.

$$\tilde{F} = \left[0\ \tilde{f}_{12}\ \tilde{f}_{21}\ 0\ \cdots\ \tilde{f}_{1n}\ \tilde{f}_{2n}\ \vdots\ \ddots\ \vdots\ \tilde{f}_{n1}\ \tilde{f}_{n2}\ \cdots\ 0\right]$$

- Obtaining the normalized direct relationship matrix. The normalized direct relationship matrix $(\tilde{X})$, which is formed as a result of the normalization of the direct relationship matrix, is as follows. Using Eq. 2 and Eq. 3, fuzzy numbers $\tilde{x}_{ij}$ are calculated.

$$\tilde{X} = [0\ \tilde{x}_{12}\ \tilde{x}_{21}\ 0\ \cdots\ \tilde{x}_{1n}\ \tilde{x}_{2n}\ \vdots\ \ddots\ \vdots\ \tilde{x}_{n1}\ \tilde{x}_{n2}\ \cdots\ 0\ ]$$

$$\tilde{x}_{ij} = \frac{\tilde{z}_{ij}}{r} = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r}\right) \quad (2)$$

$$r = \max_{1\le i\le n}\left(\sum_{j=1}^{n} u_{ij}\right) \quad (3)$$

- Obtaining of the total relation matrix $(\tilde{T})$. While calculating the total relation matrix, a separate matrix is created for each $(l'_{ij},\ m'_{ij},\ u'_{ij})$ values of the normalized direct relationship matrix $\tilde{X}$ and Eq. 4-6 are applied.

$$\tilde{X}_l = [0\ l'_{12}\ l'_{21}\ 0\ \cdots\ l'_{1n}\ l'_{2n}\ \vdots\ \ddots\ \vdots\ l'_{n1}\ l'_{n2}\ \cdots\ 0\ ]\ \tilde{X}_m = [0\ m'_{12}\ m'_{21}\ 0\ \cdots\ m'_{1n}\ m'_{2n}\ \vdots\ \ddots\ \vdots\ m'_{n1}\ m'_{n2}\ \cdots\ 0\ ]$$

$$\tilde{X}_u = [0\ u'_{12}\ u'_{21}\ 0\ \cdots\ u'_{1n}\ u'_{2n}\ \vdots\ \ddots\ \vdots\ u'_{n1}\ u'_{n2}\ \cdots\ 0\ ]$$

$$\tilde{T} = [\tilde{t}_{11}\ \tilde{t}_{12}\ \tilde{t}_{21}\ 0\ \cdots\ \tilde{t}_{1n}\ \tilde{t}_{2n}\ \vdots\ \ddots\ \vdots\ \tilde{t}_{n1}\ \tilde{t}_{n2}\ \cdots\ 0\ ],\ \tilde{t}_{ij} = \left(l''_{ij}, m''_{ij}, u''_{ij},\right)$$

$$\left[l''_{ij}\right] = \tilde{X}_l \times \left(I - \tilde{X}_l\right)^{-1} \quad (4)$$

$$\left[m''_{ij}\right] = \tilde{X}_m \times \left(I - \tilde{X}_m\right)^{-1} \quad (5)$$

$$\left[u''_{ij}\right] = \tilde{X}_u \times \left(I - \tilde{X}_u\right)^{-1} \quad (6)$$

- Obtaining of $(D + R)$ and $(D - R)$ values. First, the defuzzification method is applied for each $\tilde{t}_{ij} = (l''_{ij}, m''_{ij}, u''_{ij},)$ value of the total relation matrix. The value of D, which is the sum of rows in the $\tilde{T}^{CFCS}$ matrix found as a result of the defuzzification process, illustrates the total effect of each criterion, and R indicates the total effect of each criterion on other criteria.

$$\tilde{T}^{CFCS} = \left[t_{11}^{CFCS} \; t_{12}^{CFCS} \; t_{21}^{CFCS} \; t_{22}^{CFCS} \; \cdots \; t_{1n}^{CFCS} \; t_{2n}^{CFCS} \vdots \ddots \vdots \; t_{n1}^{CFCS} \; t_{n2}^{CFCS} \; \cdots \; t_{nn}^{CFCS} \right],$$

$$t_{ij}^{CFCS} = \left(l''_{ij}, \; m''_{ij}, u''_{ij} \right)^{CFCS}$$

Defuzzification is the process of converting fuzzy numbers into crisp numbers. One of the most popular defuzzification methods in the literature is the Center of Gravity method (Yager & Filev, 1994). However, in the centroid method, it cannot distinguish two symmetric fuzzy numbers with the same mean. In this study, CFCS (Converting Fuzzy Data into Crisp Scores), which enables to distinguish two symmetric fuzzy numbers with the same mean with higher membership functions, was chosen as the defuzzification method (Opricovic & Tzeng, 2003).

The steps of the clarification process are as follows. Let f_{ij}, $(l_{ij}, \; m_{ij}, \; u_{ij})$ and t be the matrix elements in the total relationship matrix.

- Applying the normalization process with the operations in Eq.7 and Eq. 8.

$$R = u_{ij} \; , L = l_{ij} \; , \text{ and } \Delta = R - L \tag{7}$$

$$t_{lj} = (l_{ij} - L)/\Delta, \;\; t_{mj} = (m_{ij} - L)/\Delta, \;\; t_{uj} = (u_{ij} - L)/\Delta \tag{8}$$

- Obtaining the right (rs) and left (ls) normalized values with Eq. 9.

$$t_j^{rs} = \; t_{uj}/(1 + t_{uj} - t_{mj}), x_j^{ls} = \; t_{mj}/(1 + t_{mj} - t_{lj}) \tag{9}$$

- Calculation of the total normalized net worth using Eq. 10.

$$t_j^{net} = \; \left[t_j^{ls} \times \left(1 - t_j^{ls}\right) + t_j^{rs} \times t_j^{rs} \right] / \left[1 - t_j^{ls} + t_j^{ls} \right] \tag{10}$$

- Obtaining f_{ij}^{net} defuzzified values with Eq. 11.

$$f_{ij}^{net} = L + t_j^{net} \times \Delta \tag{11}$$

3. Implementation

As noted on various platforms, digitalization is already having an impact on business environments and the operating processes of companies. Falling behind in the race towards digitalization can pose a significant risk, especially in highly competitive markets. Digitalization has the potential to significantly impact a company's business processes by creating new job opportunities, altering the roles of operators within a value chain, and even resulting in the displacement of existing jobs. In this section of the study, we will explain the methodology used to assess the degree of barriers to digitalization within the apparel sector and group them accordingly.

3.1. Identification barriers of digitalization

In the apparel industry, there are several barriers to the development of digitization. These barriers might be specific to the industry or widespread across several industries. As a result, it's critical to recognize and address the apparel industry's digitization challenges. Using the findings from the research on the subject, an extensive set of criteria has been created, including barriers to digitalization in the apparel business. Determining the prominence of these barriers will help understand the issues impeding the digitization process in the industry and devise solutions accordingly. Model barriers, explanations, and criterion notation are given in Table 4.

3.2. Application of the fuzzy DEMATEL

In this study, expert opinions were used to evaluate the relationships between barriers. The academician database of the Turkish Council of Higher Education was utilized while identifying these experts. Through a comprehensive search of the relevant database, we identified and reached out to academicians specializing in textile and digitalization. Out of the contacted academicians, 16 participated in the study, and their qualifications are as follows: 7 are professors, 5 are associate professors, and 4 are doctoral faculty members. Additionally, 7 of these academicians are engaged in Fashion Design, 7 are Textile Engineers, 1 is an Industrial Engineer, and 1 is involved in the field of business administration. The professional experience among these academicians ranges from 6 years for those with the least experience to 36 years for the most experienced, with an average of 21.3 years across all participants. The barriers of digital

Table 4. Barriers of the digitalization.

B1	Lack of government policy
B2	Insufficient financial resources
B3	Lack of management support
B4	Lack of expertise
B5	The insecurity of data sharing
B6	Dependency of the system on suppliers
B7	Fear of failure
B8	Competitive pressure
B9	Lack of IT systems
B10	Inadequate maintenance support system
B11	Being a labour-intensive and low-cost industry
B12	Lack of standardization in processes
B13	Inconveniences in product features
B14	Lack of interoperability between protocols, components, products, and systems
B15	Lack of clarity in defining return on investment
B16	Product variety and rapid change in demand

Table 5. The first expert's evaluations.

	B1			B2			....			B15			B16		
First Expert	l	m	u	l	m	u	....			l	m	u	l	m	u
B1	0.00	0.00	0.00	0.75	1.00	1.00	...	...	...	0.50	0.75	1.00	0.75	1.00	1.00
B2	0.25	0.50	0.75	0.00	0.00	0.00	...	...	...	0.75	1.00	1.00	0.00	0.25	0.50
B3	0.25	0.50	0.75	0.25	0.50	0.75	...	...	...	0.50	0.75	1.00	0.50	0.75	1.00
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
B14	0.25	0.50	0.75	0.25	0.50	0.75	...	...	...	0.50	0.75	1.00	0.50	0.75	1.00
B15	0.50	0.75	1.00	0.50	0.75	1.00	...	...	...	0.00	0.00	0.00	0.50	0.75	1.00
B16	0.00	0.00	0.25	0.00	0.25	0.50	...	...	...	0.25	0.50	0.75	0.00	0.00	0.00

Table 6. Direct relation matrix.

	B1			B2			....			B15			B16		
	l	m	u	l	m	u	....			l	m	u	l	m	u
B1	0.000	0.000	0.000	0.719	0.969	1.000	...	...	...	0.438	0.688	0.922	0.391	0.609	0.766
B2	0.406	0.641	0.781	0.000	0.000	0.000	...	...	...	0.438	0.672	0.859	0.313	0.531	0.750
B3	0.297	0.531	0.766	0.563	0.813	0.969	...	...	...	0.484	0.719	0.906	0.281	0.469	0.688
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
B14	0.313	0.531	0.750	0.328	0.531	0.766	...	...	...	0.297	0.531	0.766	0.234	0.406	0.625
B15	0.375	0.609	0.828	0.500	0.750	0.906	...	...	...	0.000	0.000	0.000	0.250	0.422	0.656
B16	0.109	0.297	0.547	0.250	0.453	0.672	...	...	...	0.313	0.547	0.781	0.000	0.000	0.000
Sum U	11.031			12.203						11.718			10.718		
R (maxu)	12.640														

transformation adaptation shown in Table 4 were used in the study. The data collected from the experts constitute the input for the fuzzy DEMATEL method stages.

The experts evaluated the relationships between the barriers using linguistic variables and the corresponding triangular membership functions given in Table 1. Depending on the structure of the model, the types of membership functions that express linguistic variables can be used. Although there is no consensus in the literature on the specific number of experts required for the method to function efficiently, a considerable number of studies have utilized five or more experts. The linguistic variable values corresponding to the evaluations of the first expert are given in Table 5 as an example.

The direct relation matrix is found by taking the average of the opinions of all experts using Equation 1. The direct relation matrix is presented in Table 6.

The normalized direct-relation matrix is calculated using the Equation 2 and 3. The normalized direct-relation matrix is given Table 7.

The total relation matrix is calculated using Equation 4, 5 and 6 and given in the Table 8.

The defuzzified process of the total relation matrix is provided by using Equation 7-11 respectively and it is found as in Table 9. The threshold value is determined as 0.22 according to the experts opinion, and it is shown with bold and the values remained above the threshold value. The representation of the relations between the barriers according to the values above the threshold value in Table 9 is given in Figure 2.

4. Results and discussion

The sum of rows (D) and the sum of columns (R) of the Defuzzified Total Relation Matrix are calculated. (D + R) values are named "Significance" and (D - R) values are named "Relation". (D + R) and (D - R) values are used to construct a causal diagram. The (D + R) values indicate the importance of a barrier, while the (D-R) divides the barriers into two groups: cause and effect. A barrier is classified as part of the cause group when the (D - R) value is positive, and considered as part of the effect group when it is negative. Causal diagrams provide a clear visual representation of complex causal relations and this can be used to gain valuable insights for problem solving. By recognizing the distinctions between cause and effect barriers, a causal diagram can facilitate making well-informed decisions. Calculated values are given in Table 10.

Table 7. Normalized direct relation matrix.

	B1			....			B16		
	l	m	u	....			l	m	u
B1	0.00	0.00	0.00	...	...	...	0.03	0.05	0.06
B2	0.03	0.05	0.06	...	...	...	0.02	0.04	0.06
B3	0.02	0.04	0.06	...	...	...	0.02	0.04	0.05
...	...	...	...	...	...	...	...	...	...
B14	0.02	0.04	0.06	...	...	...	0.02	0.03	0.05
B15	0.03	0.05	0.07	...	...	...	0.02	0.03	0.05
B16	0.01	0.02	0.04	...	...	...	0.00	0.00	0.00

Research results indicate that there are four key barriers, each with an importance value of 7.30 or higher: Lack of expertise (B4), Lack of management support (B3), Insufficient financial resources (B2), and Lack of IT systems (B9). These criteria hold greater importance compared to other barriers. The least significant barrier is the insecurity of data sharing (B5) indicated by its lowest (D - R) score of 6.34. According to the findings, the most significant barrier impeding progress toward digitalization was identified as Lack of expertise (B4). Previous studies have centered their attention on the barrier of a lack of expertise along the journey toward digitalization in the textile industry (Fernando

Table 8. Total relation matrix.

	B1			B2			. . . .			B15			B16		
	l	m	u	l	m	u	. . . .			l	m	u	l	m	u
B1	0.02	0.09	0.65	0.08	0.18	0.78	…	…	…	0.05	0.15	0.75	0.05	0.13	0.68
B2	0.05	0.13	0.68	0.02	0.10	0.68	…	…	…	0.05	0.14	0.72	0.04	0.12	0.66
B3	0.04	0.13	0.68	0.07	0.16	0.76	…	…	…	0.06	0.15	0.73	0.04	0.12	0.66
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
B14	0.04	0.12	0.66	0.05	0.14	0.72	…	…	…	0.04	0.13	0.69	0.03	0.11	0.63
B15	0.04	0.12	0.66	0.06	0.15	0.72	…	…	…	0.02	0.08	0.63	0.04	0.11	0.63
B16	0.02	0.12	0.60	0.04	0.12	0.67	…	…	…	0.04	0.07	0.65	0.01	0.07	0.54

Table 9. Defuzzified total relation matrix.

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16
B1	0.19	**0.28**	**0.26**	**0.26**	0.21	0.21	**0.26**	**0.24**	**0.26**	**0.22**	**0.23**	**0.25**	0.21	**0.26**	**0.25**	**0.23**
B2	**0.23**	0.20	**0.26**	**0.26**	0.20	0.21	**0.25**	**0.24**	**0.26**	**0.24**	0.21	**0.23**	0.21	**0.23**	**0.24**	0.21
B3	**0.22**	**0.26**	0.21	**0.27**	0.21	0.21	**0.25**	**0.23**	**0.26**	**0.23**	0.21	**0.24**	0.21	**0.25**	**0.25**	0.21
B4	**0.24**	**0.27**	**0.28**	0.21	**0.22**	**0.22**	**0.27**	**0.25**	**0.27**	**0.25**	**0.23**	**0.26**	**0.23**	**0.26**	**0.26**	**0.23**
B5	0.20	**0.22**	**0.24**	**0.23**	0.15	0.19	**0.22**	0.21	**0.23**	0.20	0.18	0.21	0.19	**0.22**	0.21	0.18
B6	0.20	**0.22**	**0.23**	**0.23**	0.19	0.15	**0.22**	**0.22**	**0.23**	0.19	0.18	**0.23**	0.20	**0.23**	**0.22**	0.20
B7	0.21	**0.25**	**0.26**	**0.25**	0.19	0.20	0.19	**0.24**	**0.23**	0.21	0.19	**0.22**	0.21	**0.24**	**0.23**	0.21
B8	0.20	**0.24**	**0.23**	**0.23**	0.19	0.20	**0.25**	0.18	**0.23**	0.20	0.20	**0.22**	0.20	**0.22**	**0.22**	**0.22**
B9	**0.22**	**0.25**	**0.26**	**0.26**	**0.22**	0.20	**0.24**	**0.23**	0.20	**0.23**	0.21	**0.23**	0.21	**0.25**	**0.23**	0.20
B10	0.18	**0.22**	**0.22**	**0.23**	0.17	0.17	0.21	0.20	**0.22**	0.15	0.18	0.20	0.19	0.21	0.19	0.18
B11	0.21	**0.23**	**0.23**	**0.24**	0.18	0.19	**0.22**	**0.22**	**0.23**	0.20	0.16	**0.22**	0.20	**0.22**	0.21	0.20
B12	0.22	**0.24**	**0.25**	**0.26**	0.20	0.21	**0.24**	**0.23**	**0.24**	**0.22**	**0.22**	0.19	0.23	**0.25**	**0.23**	**0.22**
B13	0.18	0.21	**0.22**	**0.23**	0.17	0.19	**0.22**	**0.22**	**0.22**	0.19	0.19	**0.22**	0.15	0.21	0.20	0.20
B14	0.21	**0.23**	**0.25**	**0.25**	0.20	0.20	**0.24**	**0.22**	**0.24**	**0.22**	0.20	**0.23**	0.20	0.19	**0.22**	0.20
B15	0.21	**0.25**	**0.25**	**0.24**	0.19	0.20	**0.24**	**0.22**	**0.23**	0.20	0.20	**0.22**	0.20	**0.23**	0.18	0.20
B16	0.20	0.21	0.21	0.19	0.19	0.21	0.22	0.21	0.20	0.19	0.21	0.21	0.20	0.21	0.17	0.15

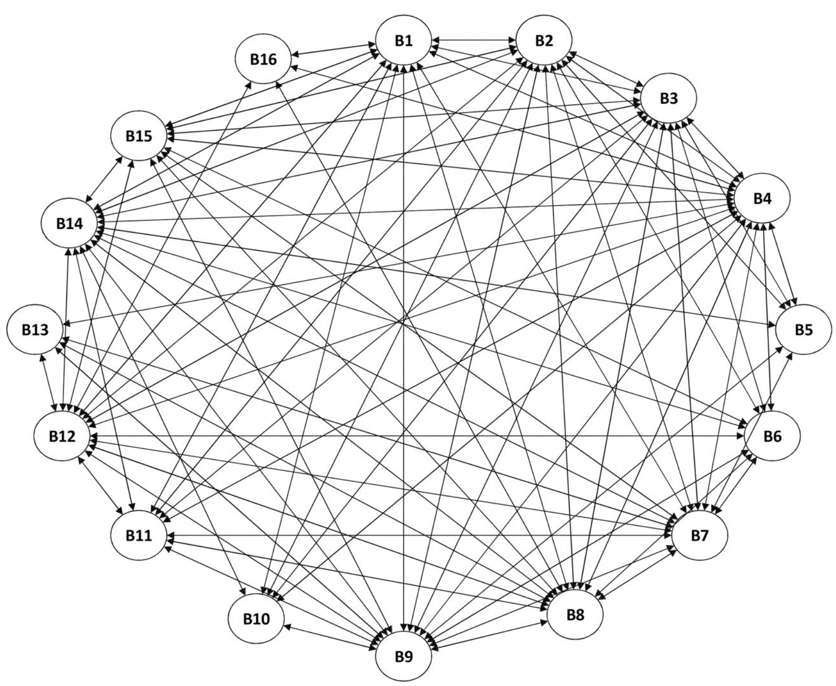

Figure 2. Causal diagram.

et al., 2023; Majumdar et al., 2021; Dahooie et al., 2022; Pavan et al., 2022). Geissbauer et al. (2014) contend that the second most significant hurdle in achieving Industry 4.0 is the shortage of adequately qualified employees, especially as businesses become increasingly data-driven and agile, necessitating a more skilled workforce. Making lifelong learning an integral part of an organization's strategic goals is crucial for enhancing expertise. It is equally essential for individuals and businesses to emphasize reskilling and upskilling, thereby elevating career development as a pivotal element of the evolving workforce. To ensure the accessibility, availability, and affordability of such learning opportunities, significant efforts must be invested (Li, 2022). The study identified the lack of management support (B3) and insufficient financial resources (B2) as the second and third most significant barriers, respectively. Notably, these barriers have also been recognized as barriers to digitalization in various other sectors, as documented in Table 1 (Fernando et al., 2023; Majumdar et al., 2021; Dahooie et al., 2022; Pavan et al., 2022). The fourth significant barrier identified in the study is the lack of IT systems. Gökalp et al. (2019) comprehensively addressed the significance of IT systems in the context of digitalization, encompassing innovative approaches, technologies, production systems, and managerial activities.

As shown in Table 8, the strategic barriers are classified into two groups. The first group is the cause group, which includes Lack of government policy (B1), Lack of expertise (B4), The insecurity of data sharing (B5), Dependency of the system on suppliers (B6), Being a labour-intensive and low-cost industry (B11), and Lack of standardization in processes (B12). Lack of government policy (B1) has the highest D-R value of 0.48. This high value underscores the significant influence of the barrier represented by the absence of government policy on the overall system. Simultaneously, the D + R value, signifying the degree of importance, is also notably high. The report published by OECD identifies seven policy dimensions through which governments can influence digital transformation. It also highlights significant opportunities, challenges, and policies associated with each dimension, providing fresh insights, evidence, and analysis. Furthermore, the report offers recommendations aimed at improving policies in the digital age (OECD, 2019). The barrier with the least impact within the group is the lack of standardization in processes (B12), with a value of 0.07. Despite having a low score in terms of its impact on the system, it is evident that this barrier holds substantial importance, boasting a D + R value of 7.19.

Table 10. Total causal relations.

	D	R	D + R	D-R
B1	3.81	3.34	7.15	0.48
B2	3.67	3.78	7.45	−0.11
B3	3.72	3.88	7.61	−0.16
B4	3.98	3.86	7.83	0.12
B5	3.27	3.07	6.34	0.20
B6	3.36	3.17	6.52	0.19
B7	3.54	3.74	7.28	−0.20
B8	3.42	3.56	6.98	−0.32
B9	3.63	3.74	7.38	−0.11
B10	3.13	3.34	6.47	−0.21
B11	3.34	3.20	6.55	0.14
B12	3.63	3.56	7.19	0.07
B13	3.23	3.25	6.49	−0.02
B14	3.51	3.68	7.19	−0.17
B15	3.46	3.50	6.96	−0.04
B16	3.19	3.23	6.42	−0.04

The second group is Insufficient financial resources (B2), Lack of management support (B3), Fear of failure (B7), Competitive pressure (B8), Lack of IT systems (B9), Inadequate maintenance support system (B10), Inconveniences in product features (B13), Lack of interoperability between protocols, components, products, and systems (B14), Lack of clarity in defining return on investment (B15), and Product variety and rapid change in demand (B16) barriers. When examining the barriers within the effect group, it becomes apparent that managers should prioritize addressing financial obstacles within organizations to overcome these challenges effectively. Consequently, there is a pressing need to fortify investment plans in suitable resources to maximize the benefits. Figure 3 shows the graph of cause and effect barriers.

Consequently, even though some of the digitalization barriers identified may be new to the apparel industry, they do not appear to be exclusive to other industries. Thus, it can be asserted that the endeavours made to tackle these obstacles in related sectors can offer valuable guidance for the apparel industry.

5. Conclusion

Today, the apparel sector has begun to witness a digital transition that will significantly change how it does business. In the highly competitive apparel market, labour comprises a significant portion of the overall costs. Furthermore, due

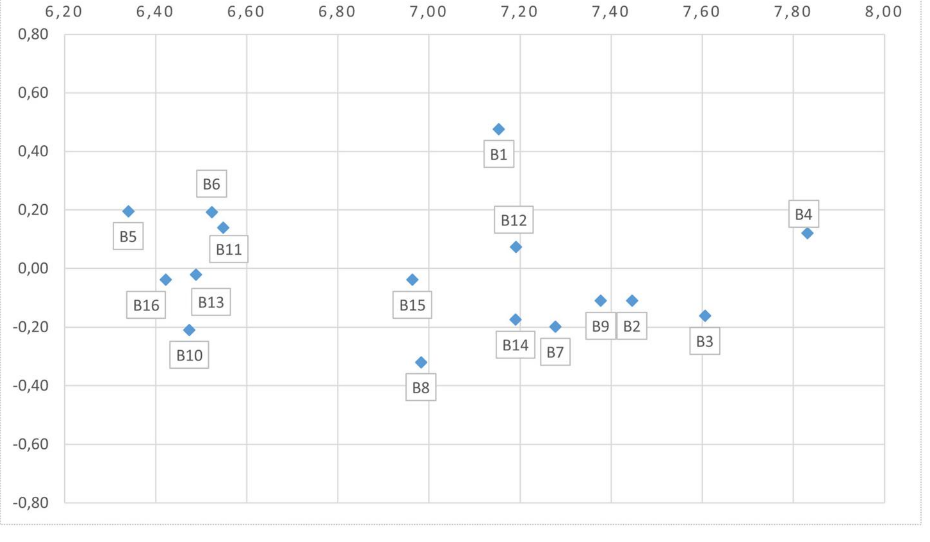

Figure 3. Cause and effect diagram.

to the predominance of small and medium-sized enterprises (SMEs) in the industry, there are limitations on the budgets allocated for hiring qualified personnel as well as advertising and promotional expenses. Given the circumstances under which the apparel sector operates, it is predicted that digitization will revolutionize and transform the industry by minimizing the cost of advertising efforts and the labour-intensive workforce. This makes it obvious that apparel manufacturers who can embrace digital transformation early would have a competitive edge.

This study's objective is to give analyses that will help businesses in the apparel sector be ready for the challenges that come with digital transformation. It is crucial to identify the challenges facing the apparel industry's adoption of digital transformation applications and to make policymakers, practitioners, and decision-makers aware of these issues. The study utilized the fuzzy DEMATEL approach to evaluate critical barriers and cause-effect relationships between them. Expert opinions are needed to obtain relevant analysis for evaluation purposes. The study's model includes 16 obstacles that stand in the way of digital transformation. The results revealed that the four most important barriers to apparel companies' digital transformation are a lack of competence, a lack of managerial support, a lack of financial resources, and lack of IT systems. Prioritizing the most significant barriers identified will empower businesses to expedite their journey toward digitalization. While there is a wealth of informative literature on these obstacles, there is a scarcity of numerical analysis studies utilizing comprehensive models within the textile industry. According to the results of the study, the struggle of businesses against the most important barriers will accelerate the achievement of digital transformation.

The barriers outlined in this research will serve as focus points for policymakers and managers as they address potential challenges. The analysis highlights the most critical barriers in the manufacturing industries, as well as the least significant ones, shedding light on the interactions among these barriers. The barriers attributed to the causal group include "Lack of Government Policy (B1)", "Lack of Expertise (B4)", "The Insecurity of Data Sharing (B5)", "Dependency of the System on Suppliers (B6)", "Being a labour-intensive and low-cost industry (B11)", and "Lack of standardization in processes (B12). Managers' investments in cause group barriers may also have a positive impact on the barriers affected by them.

This research will facilitate businesses operating in the apparel sector in achieving their digital transformation goals. The observations, findings, and insights made can help businesses overcome the barriers that stand in the way of their digital transformation, allowing them to thrive in the marketplace. By applying inclusive models and integrating multi-criteria decision making methodologies for the digital transformation of the apparel business, future study can reinvent the literature.

Disclosure statement

No potential conflict of interest was reported by the authors.

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