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A grey decision-making trial and evaluation laboratory model for digital warehouse management in supply chain networks

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ABSTRACT

Integrating digitalization and warehouse management systems (WMS) is a crucial aspect of enhancing supply chain performance for strategic competitiveness. Multiple technologies promote digital development and supply chain management (SCM) transformation. They include artificial intelligence and robotics, cloud computing, 3D printing, advanced analytics, blockchain, augmented reality, radio frequency identification (RFID), the internet of things (IoT), and cloud technology. This research aims to identify and evaluate the factors of digitalization, WMS, and supply chain performance by combining a comprehensive literature review analysis with the grey decision-making trial and evaluation laboratory (DEMATEL) method. An extensive literature review is conducted to identify the primary determinants of supply chain performance. Subsequently, the expert panel from the textile industry is consulted to obtain expert opinions on these factors' relative importance. The findings of this study demonstrated that by considering the interdependencies on supply chain performance and the uncertainties related to expert judgments, the suggested comprehensive model is highly capable of addressing the digitalization WMS problem

1. Introduction

Supply chains (SCs) have become more susceptible to disruptions as a result of their increased size and complexity as a direct result of globalization and outsourcing [1]. Supply Chains must adopt innovative techniques to adapt quickly and economically to rapidly shifting dynamics in the market that are becoming more chaotic in volume and diversity [2]. Due to large customization, inventory reduction, and global rivalry, controlling cost and quality has made supply chain information flow problematic [3]. Various types of disruptions, such as power outages, system crashes, network failures, or unforeseen events, have the potential to initiate a chain reaction of problems that culminate in critical service continuity SC failure situations. The aforementioned scenarios may entail a diverse array of difficulties, including but not limited to loss of data, interruptions in application functionality, breakdowns in communication, and compromised security [4]. These issues pose a threat to the seamless operation and dependability of critical services and systems [5]. Anticipating and proactively addressing potential disruptions is a critical aspect for organizations to mitigate the risk of supply chain failure and ensure uninterrupted operations, even in the event of adverse circumstances [6]. Materials shortages, capacity limits, labour shortages, quality issues, transportation delays, demand shifts, and supply ruptures are typical SC failure mechanisms [7]. Due to customer demand, the complicated and constantly shifting business environment, and the need for businesses to be flexible and adaptive [8]. The advent of digital technologies, including sensors, RFID chips, cyber–physical systems, and the internet of things (IoT), has brought about significant changes in the manufacturing and services sectors of the supply chain [9].

The term "digitalization" refers to the ongoing trend of digital technology becoming pervasive in all aspects of human existence [10]. The concept of digitalization can be perceived as a response to the constantly evolving demands of both organizations and the broader community, rather than a novel notion. The intricate interdependence of interruptions, digitalization, and service continuity necessitates that businesses acknowledge and strategize for these factors. The advent of digitalization has led to a transformation of the risk landscape, rendering traditional risk management methods potentially insufficient [11]. Consequently, risk management strategies have progressed to

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encompass the proactive forecasting and readiness for such potential disruptions. As the landscape of the digital realm undergoes constant evolution, it is imperative for companies to remain adaptable and poised to confront potential disruptions. In order to ensure the continuous provision of products and services in the contemporary era, businesses must adopt a strategic approach that takes into consideration the dynamic nature of the digital realm and the associated risks [12]. In the current era of digitalization, businesses may not solely achieve success unless they adhere to certain practices [13]. Companies can trace raw materials, components, semi-finished items, and final goods in real time using sophisticated technology. Information flow makes the supply chain more trustworthy and robust [14]. Small and medium-sized enterprises need digitalization even more and need more cautious management than large firms and multinationals [15].

Warehouse management systems (WMS) are commonly utilized by various types of companies, including manufacturers, retailers, wholesalers, and logistics providers. The primary objective of WMS is to enhance the efficiency of warehouse operations by optimizing speed, accuracy, and output. This objective is achieved through the provision of real-time monitoring of stock quantities, locations, and movements, thereby enabling business owners to effectively manage their inventory [16]. The implementation of WMS can potentially enhance inventory management, minimize errors, and improve order accuracy and timeliness for enterprises [17]. The optimization of warehouse architecture and storage tactics results in the maximization of space utilization and minimization of unnecessary motion within the system. This system facilitates the scheduling and monitoring of workforce operations, thereby enhancing productivity and optimizing resource allocation [18]. WMSs handle a high-volume warehouse operation in real time. These devices improve product handling and storage [19]. Some companies still utilize antiquated warehouse management practices, which raises the risk of high operating expenses and lost investments and commodities [20]. WMS maximizes storage space, speeds up ordering and delivery, improves manufacturer services, simplifies data access [19]. A good warehouse management system cuts costs and boosts customer satisfaction [21]. WMS improves supply chain performance, for example, wireless barcodes with management information systems (MIS) may reduce costs, enhance flexibility, minimize inventory, and cut delivery times, improving customer satisfaction [21].

The burgeoning potential and remarkable capabilities of digitalization in enhancing supply chain operations have been underscored by recent research [22]. The aforementioned characteristics, particularly within the industrial domain, present a promising outlook. However, the advantages of a digitalized supply chain have yet to be comprehensively investigated. Rad et al. [23] have demonstrated the favourable aspects of contemporary digital technologies in the context of supply chains. However, they have also expressed their reservations regarding the inadequacy of comprehensive assessments of these advantages. As a result of the increasing level of competition in the business realm, the implementation of digital transformation has transitioned from a desirable option to an essential requirement [6]. Notwithstanding the significance of enhancing their supply chains, numerous enterprises encounter difficulties in determining the appropriate technology to adopt [15]. This underscores the heightened necessity for conducting comprehensive research in this domain. Recently, Aljoghaiman and Bhatti [24] conducted a study that sheds light on the transformative influence of e-business technology on supply chain performance, with a particular focus on the textile sector in emerging economies. The present investigation contributes to our comprehension of the matter under consideration, yet it also underscores the significance of carrying out further inquiry. The review of past literature indicates that the digital transformation of the supply chain industry has garnered some attention but remains an area that has not been extensively researched, particularly with respect to empirical validation. This research aims to investigate the impact of digitalization and warehouse management systems on the performance of the textile supply chain in an emerging country. This study takes into consideration the inconsistent results and overlooked aspects in the current body of literature through he below research question.

RQ: How do digitalization and WMS affect the efficiency of the textile industry's supply chain in a developing nation?

This paper is organized as Section 2 will present a comprehensive literature review of the digitalization and Warehouse Management Systems (WMS) in the context of supply chain performance. Sections 3 and 4 will describe the methodology employed, including variable measurement and questionnaire analysis. In Section 5, the discussion, implications, conclusions, and limitations of the study will be presented.

2. Literature review

2.1. Digitalization

Nowadays, one hears the term "digitalization", which refers to the process of an economy becoming digital [10]. One may think of it as a change in how business operations are conducted that makes use of information technology [25]. Seah et al. [26] assert that one of the key themes that is currently transforming society and business on both a short-term and long-term basis is digitalization. It must be stated that a supportive digital infrastructure underlies the digitalization process. This infrastructure is made up of essential digital inputs, such as digital skills, regulatory frameworks, and innovation mechanisms, as well as digital accelerators such socio-cultural factors [27]. Additionally, the use of sensors, RFID chips, cyber–physical systems, and the Internet of Things are revolutionizing supply chain production and services [9]. RFID has been utilized in a variety of fields, but it can be employed particularly in supply-chain management and logistics systems for identification, tracing, and tracking since it enables accurate system monitoring by employing real-time data [28]. Innovative business models, new production techniques, and the development of knowledge-based goods and services are prevalent as a result of this digital transformation, which is defined by the fusing of cutting-edge technology and the integration of physical and digital systems [29].

Numerous research endeavours have been undertaken to expound upon the concept of digitalization. The phenomenon of digitalization encompasses the utilization of digital technology in both industrial and societal contexts, and the consequent alterations in individuals' interconnectivity with both tangible objects and one another [30]. According to Reis et al. [31], digitalization refers to the utilization of digital technology and data to improve business operations, generate revenue, modify or replace corporate procedures, and create a digital business environment with digital information at its core. This was demonstrated in a study conducted by the authors. A recent investigation portrays digitalization as a phenomenon characterized by an increase in the generation, examination, and utilization of data for the purpose of creating value digitalization is presented as the application of digital technology and data to generate income, enhance operations, replace or modify corporate procedures, and establish a setting for digital business, with digital information at its centre [31]. The integration of information and communication technologies (ICTs) is imperative for digitalization, and it is essential that these technologies are incorporated into diverse facets of a company's operations and products [32]. Drawing upon previous conceptualizations and knowledge within the field, certain scholars characterize digitalization as the utilization of digital technology within industrial ecosystems to facilitate the development of novel business models, generate fresh sources of revenue, and foster opportunities for value generation [33]. The definition presented by Parida et al. [34] underscores the notion that the utilization of diverse digital technologies constitutes merely a single facet of the broader concept of digitalization. Devereux and Vella [35] explicate the phenomenon of digitalization as entailing the widespread adoption of a versatile technology. According to Haoua and Moutahaddib [36], the proliferation of smart devices and mobile applications has contributed to the acceleration of digitization.

2.2. Warehouse management system (WMS)

Due to the dynamic nature of commodities intake and outflow, a warehouse management system (WMS) is needed to effectively manage a warehouse's operations [37]. Baruffaldi et al. [38] assert that the Warehouse Management System (WMS) manages a warehouse's physical and informational flows, including arriving and departing activities. Invoicing, reporting, activity coordination, and cycle counting, are part of modern warehouse management systems. According to Madurapperuma et al. [39], this method improves ERP system interaction. Information on a company's assets, commodities, and activities is collected, stored, and distributed via WMS. The system captures and documents transactions and sends important data to other ERP modules [40]. Warehouse activities are documented by a database-driven warehouse management system to monitor put-away and ensure inventory correctness [41]. An excellent warehouse management system may improve operational efficiency and provide valuable business insights, saving manufacturing and distribution companies money [42].

The advent of WMSs at supply chain nodes simplify information infrastructures for procurement, manufacture, storage, and delivery [38]. WMS may now combine with complex technologies like RFID and speech recognition and be utilized alone or as part of an ERP software [41]. Another research found that WMS helps companies manage inventory and provide reports quickly and accurately [43]. Woźniakowski et al. [19] explain that the WMS program detects third-party vendors, determines internal origin, and allows warehouse delivery and pickup. They assert it controls product quality and quantity and chooses the optimal storage location. A warehouse management system is also used to improve logistical operations [41]. WMS systems let businesses manage, supervise, and regulate products and material transportation and storage [19]. According to Assis and Sagawa [44], identify the system's advantages as administration, process order definition, storage location selection, flow dependability, and operation monitoring.

2.3. Supply chain performance

Supply chain management performance must be evaluated for efficiency and profitability [45]. Performance in supply chain management is organizing operations to fulfil end-user needs [46]. It may also be characterized as information about processes and products' results that can be compared to goals, trends, historical performance, and other processes and goods [47]. This word refers to the company's supply chain functions' operational results. This encompasses all actions, information, and activities related to moving and converting items from raw resources to consumers [48]. Effectiveness optimizes the supply chain by increasing customer satisfaction, whereas efficiency maximizes production while minimizing costs and waste [45]. Supply chain performance and connectivity management depend on information communication [8]. Many companies understand performance evaluation and how to use it for a successful supply chain [49].

Supply Chain Performance (SCP) has been studied extensively. SCP study is growing rapidly on this area [47]. Kurdi et al. [46] describe SCP as a set of operations that put customers first and make products available via speedy delivery. Another research found that it measures how effectively supply chain activities improve company competitiveness [45]. Mubarik et al. [50] define SCP as the measures performed by the extended supply chain to rapidly and efficiently satisfy end-customer needs, such as availability of goods and on-time delivery. Another study defined SCP aspects as delivery speed, quality, affordability, adaptability, and visibility [48]. Supplier-oriented performance, customer-oriented performance, cost-containment performance, time-based performance, and reliability performance have also been found [51]. Another research considers performance metrics for flexibility, efficiency, responsiveness, and quality. It may also be used to measure performance increases by availability, variety, innovation, timeliness, cost, and pricing [8]. Altay et al. [52] claim that agile and resilient methods also affect supply chain effectiveness and competitiveness. Cost, quality, variety, and service level may increase with better integration [53].

The conceptual framework depicts the inter-relationship among the three keywords, which as reviewed as follows. As highlighted in the literature cited above, several researches have been compiled on digitalization, warehouse management system, and supply chain performance. Digitalization has been defined as a change in business processes, using information technology [10]. As for WMS, it is a management information system that controls the physical and information flows within the warehouse, for inbound and outbound operations [38]. Whereas, supply chain performance has been defined as the supply chain's activities in meeting end-customer requirements [50]. In the next section, the methodology of the paper shall be discussed in detail.

3. Methodology

DEMATEL is a systematic method used to build and analyze the structure of complicated causal relations between a set of factors with matrices or digraphs. It is widely used to identify the key factors in various systems. This study uses grey DEMATEL and a literature review to find factors of digitalization, warehouse management and supply chain performance. Conducting a comprehensive review of the literature is necessary to ascertain the most crucial factors that contribute to enhancing the overall performance of the supply chain. Initially, twenty-three factors were selected by the authors from a comprehensive literature review pertaining to digitalization, warehouse management and supply chain performance.

Professionals with expertise in the field of textiles are employed to carry out this form of examination. This study utilizes the expertise and insights of prominent figures in the industry to discern the key determinants that affect the effectiveness of supply chain operations. These experts emphasize the importance of conducting a comprehensive analysis of these components and their interrelationships and narrowed down the factors to sixteen in total (Table A.1 in Appendix). Subsequently, it is imperative to ascertain the causal connections between the aforementioned variables, as this will facilitate comprehension of their impact on the efficacy of the supply chain.

The literature evaluates causality using TISM, ISM, DEMATEL, and ANP [54]. Ocampo [55] use ISM and TISM can identify structural linkages among factors, but they do not indicate strength [56]. DEMATEL can assess relationship quality [57–59]. Traditional DEMATEL has fuzzy expert input. The grey-DEMATEL approach can remove these restrictions [60]. Thus, we determined digitalization, warehouse management and supply chain performance causality using the grey-DEMATEL [61,62]. The experts studied the factors and filled the questionnaires. Their interrelationships, the formation of causal relationships was actualized after the implementation of the grey-DEMATEL method. Khan et al. [63] use a linguistic scale to determine how one factor affects others. Experts' direct-relation matrix completes grey-DEMATEL.

The procedure for the grey-DEMATEL is as follows:

Step 1: Define the grey semantic scale.

A five-level grey semantic scale was used in this study. The scale items were as follows:

- No influence = [0, 0]
- Very low influence = [0, 0.25]
- Low influence = [0.25, 0.5]
- High influence = [0.5, 0.75]
- Very high influence = [0.75, 1]

Step 2: Develop the grey direct-relation matrix X.

Three experts with a deep understanding of a developing country's textile industry were invited to participate in this study. The questionnaires, which contained the definitions of the factors of digitalization, WMS, and supply chain performance with relevant filling rules, were distributed to the respondents to collect the data needed for our study. Table 1 shows the completed direct-relation matrices. The direct-relation matrices were transformed into grey direct-relation matrices based on the grey semantic scale [64].

Step 3: Compute the overall crisp direct-relationship matrix Z.

By referencing previous studies, the crisp matrix was obtained using the modified-CFCS method. Subsequently, the overall crisp direct relationship matrix Z was created using Eq. (1):

$$z_{ij} = \frac{1}{k}\left(z_{ij}^{1} + z_{ij}^{2} + \cdots + z_{ij}^{k}\right) \tag{1}$$

Step 4: Compute the normalized direct-relation matrix N.

The normalized direct-relation matrix N was calculated using Equations. (2) and (3):

$$N = sZ \tag{2}$$

$$s = \frac{1}{\max_{1\le i\le n} \sum_{j=1}^{n} z_{ij}} \tag{3}$$

Step 5: Compute the total relation matrix T.

The total relation matrix T was developed using Eq. (4), where I represent the identity matrix:

$$T = N + N^2 + N^3 + \cdots = \sum_{i=1}^{\infty} N^i = N(I-N)^{-1} \tag{4}$$

Step 6: Compute the prominence and net effect of the factors.

The prominence and net effect of the factors were computed using Eqs. (5)–(8), as Table 4 shows.

$$R_i = \sum_{j=1}^{n} t_{ij}, \forall j \tag{5}$$

$$C_j = \sum_{i=1}^{n} t_{ij}, \forall j \tag{6}$$

$$P_i = \left\{R_i + C_j \mid i = j\right\} \tag{7}$$

$$E_i = \left\{R_i - C_j \mid i = j\right\} \tag{8}$$

Step 7: Plot the prominence–causal diagram.

The prominence $(R_i + C_j)$ is represented on the horizontal axis, and the net effect $(R_i - C_j)$ is represented on the vertical axis in the causal-effect graph.

3.1. Case study

A significant exporting and job-producing industry is textile. Any progress made in this area will raise peoples' standards of living and help fight poverty [65]. Pakistan is a developing country with a high labour intensity that mostly depends on the textile industry for jobs and export revenue. More than 60% of export revenues and 8.5% of GDP are contributed by just this industry [66]. Another research supports this notion by stating that presently, nearly one-fourth of industrial added value, 40% of industrial labour, 40% of bank loans, and 60% of exports are attributed to the textile industry [67]. There are 560 companies listed on the Pakistan stock exchange (PSE), with 35 different industries represented. The textile industry, which comprises all 153 of these businesses and is Pakistan's second-largest industry after agriculture, is dominated by that country [65]. Since the adoption of global supply chains (SCs), the SC in this industry has been exposed to significant risks that have frequently come to pass. Examples of these risks include late deliveries, lengthy lead times between returns and resending to customers, stock-outs or overstocks, etc. McMaster et al. [68]. Sometimes the labour markets are exploited, and firms suffer from heavy wages or strikes, which increase the cost of production for the firm. Political instability has a negative impact on economic development by lowering the rates of productivity growth. Inflation is the result of political unrest [69]. The economy is facing a massive industry drain in the past few years as around 41% of the industry has moved abroad, which become the issue of concern for the state to take effective step to stop further industrial drain [70].

4. Results and analysis

According to the value of net effect $(R_i - C_j)$, the factors could be divided into the following three categories:

The "cause" group: sales and operations planning (F9), RFID (F1), sensors (F3), RF handheld devices/vehicle mounted units (VMU) (F6), cloud computing (F4), and augmented reality (AR) (F2). The $R_i - C_j$ value of these factors was greater than zero, which means that these affected other factors more significantly than they were affected.

The "effect" group: cycle count accuracy (F8), quality (F12), reliability performance (F16), blockchain technology (F5), material planning (F10), customer-oriented performance (F15), barcode label (F7), delivery speed (F11), cost (F13), and flexibility (F14). The $R_i - C_j$ value of these factors was less than zero, which means that they were more affected by other factors.

In addition, a critical line was drawn on the mean value of prominence ($R_i + C_j$), and the factors were further divided into two groups according to prominence value. Factors with a prominence value greater than the mean value were considered central factors, which means that they significantly affected others or were significantly affected by others.

Therefore, the factors in the "cause" group with a prominence value greater than the mean value were considered critical. They significantly affected others more than they were affected, and they represented the core factors in the network. Specifically, sales and operations planning (F9), RFID (F1), sensors (F3), RF handheld devices/vehicle mounted units (VMU) (F6), cloud computing (F4), and augmented reality (AR) (F2) were found to be the key factors. Additionally, the normalized and total relation matrix are mentioned (See Tables 2 and 3.)

The presented tabular data depicts a normalized direct relationship matrix that is commonly utilized in the decision-making trial and evaluation laboratory (DEMATEL) technique. The DEMATEL methodology is a significant analytical approach that assesses the structural interdependencies among various criteria, facilitating the comprehension of intricate systems.

The table denotes the extent of direct impact of the factor "Fi" on "Fj" through each cell (i, j). The range of values spans from 0 to 0.0745, with the former denoting a lack of influence and the latter representing the most significant direct impact. It is noteworthy that the diagonal line consisting of 0s, extending from the upper left corner to the lower right corner, denotes the absence of impact of factors on themselves, as factors do not exert influence on their own outcomes. (See Figs. 1 and 2.)

The aforementioned figure displays the various factors within a given system that were assessed through the utilization of the decision-making trial and evaluation laboratory (DEMATEL) methodology. The rank of each factor is established based on its prominence value, which serves as a metric of its impact within the system. A lower rank denotes greater prominence, implying that the factor in question has a significant impact on other variables. The variable with the highest impact is 'reliability performance', which holds the first position in the ranking. Conversely, the variable with the lowest impact is 'blockchain technology', which is positioned at the 16^{th} rank. The process of ranking aids in comprehending the hierarchical interplay of factors, thereby facilitating the establishment of priorities and informed decision-making.

The presented figure showcases the evaluation and prioritization of various factors utilizing the DEMATEL (decision making trial and evaluation laboratory) methodology. The provided Sankey diagram shows how various factors are connected to and contribute to the "Cause" and "Effect" categories. Causal factors, exemplified by RFID which holds the third rank, exert a substantial impact on other factors. Conversely, effect factors, such as reliability performance which holds the first rank, are predominantly influenced by other factors. This comprehension facilitates the identification of pivotal leverage points for strategic decision-making and interventions.

Table 1
Direct relation matrix.

DRM	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16
F1	[0, 0]	[0.75, 1]	[0.75, 1]	[0.75, 1]	[0.75, 1]	[0.5, 0.75]	[0.75, 1]	[0.75, 1]	[0.25, 0.5]	[0.75, 1]	[0.25, 0.5]	[0.25, 0.5]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]	[0.75, 1]
F2	[0.75, 1]	[0, 0]	[0.75, 1]	[0.75, 1]	[0.5, 0.75]	[0.5, 0.75]	[0.75, 1]	[0.75, 1]	[0.25, 0.5]	[0.75, 1]	[0.25, 0.5]	[0.25, 0.5]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]	[0.75, 1]
F3	[0.75, 1]	[0.75, 1]	[0, 0]	[0.75, 1]	[0.5, 0.75]	[0.5, 0.75]	[0.75, 1]	[0.75, 1]	[0.25, 0.5]	[0.75, 1]	[0.75, 1]	[0.25, 0.5]	[0.25, 0.5]	[0.25, 0.5]	[0.75, 1]	[0.75, 1]
F4	[0.75, 1]	[0.75, 1]	[0.75, 1]	[0, 0]	[0.75, 1]	[0.5, 0.75]	[0.75, 1]	[0.75, 1]	[0.5, 0.75]	[0.75, 1]	[0.75, 1]	[0.25, 0.5]	[0.25, 0.5]	[0.75, 1]	[0.5, 0.75]	[0.75, 1]
F5	[0, 0.25]	[0, 0.25]	[0, 0.25]	[0, 0.25]	[0, 0]	[0, 0.25]	[0.5, 0.75]	[0.5, 0.75]	[0.25, 0.5]	[0, 0.25]	[0, 0]	[0, 0]	[0.75, 1]	[0.5, 0.75]	[0, 0.25]	[0.75, 1]
F6	[0.75, 1]	[0, 0.25]	[0.75, 1]	[0.75, 1]	[0.25, 0.5]	[0, 0]	[0.5, 0.75]	[0.25, 0.5]	[0.25, 0.5]	[0.25, 0.5]	[0.75, 1]	[0, 0]	[0.5, 0.75]	[0.5, 0.75]	[0.75, 1]	[0.75, 1]
F7	[0.75, 1]	[0.25, 0.5]	[0.75, 1]	[0.75, 1]	[0, 0.25]	[0.5, 0.75]	[0, 0]	[0.5, 0.75]	[0.5, 0.75]	[0.5, 0.75]	[0.25, 0.5]	[0.25, 0.5]	[0.5, 0.75]	[0.5, 0.75]	[0.75, 1]	[0.75, 1]
F8	[0.75, 1]	[0, 0]	[0, 0]	[0, 0]	[0, 0]	[0.25, 0.5]	[0.5, 0.75]	[0, 0]	[0.75, 1]	[0.75, 1]	[0, 0.25]	[0, 0.25]	[0.25, 0.5]	[0.25, 0.5]	[0.25, 0.5]	[0.75, 1]
F9	[0.75, 1]	[0.25, 0.5]	[0.75, 1]	[0.75, 1]	[0, 0.25]	[0, 0.25]	[0.5, 0.75]	[0.5, 0.75]	[0, 0]	[0.75, 1]	[0, 0.25]	[0, 0.25]	[0.5, 0.75]	[0.25, 0.5]	[0.75, 1]	[0.5, 0.75]
F10	[0.75, 1]	[0, 0]	[0.5, 0.75]	[0.5, 0.75]	[0, 0]	[0, 0]	[0.75, 1]	[0.75, 1]	[0.5, 0.75]	[0, 0]	[0, 0.25]	[0.5, 0.75]	[0.75, 1]	[0.5, 0.75]	[0.5, 0.75]	[0.5, 0.75]
F11	[0, 0]	[0, 0]	[0, 0]	[0, 0]	[0, 0]	[0.75, 1]	[0.75, 1]	[0.25, 0.5]	[0.25, 0.5]	[0.5, 0.75]	[0, 0]	[0.5, 0.75]	[0.5, 0.75]	[0.5, 0.75]	[0.5, 0.75]	[0.5, 0.75]
F12	[0, 0]	[0, 0]	[0, 0.25]	[0, 0]	[0, 0.25]	[0, 0.25]	[0, 0]	[0, 0]	[0.75, 1]	[0, 0]	[0, 0.25]	[0, 0]	[0.75, 1]	[0.5, 0.75]	[0.75, 1]	[0.5, 0.75]
F13	[0.5, 0.75]	[0.5, 0.75]	[0.5, 0.75]	[0.5, 0.75]	[0, 0.25]	[0.5, 0.75]	[0.5, 0.75]	[0.5, 0.75]	[0.5, 0.75]	[0.5, 0.75]	[0.75, 1]	[0.75, 1]	[0, 0]	[0.25, 0.5]	[0.5, 0.75]	[0.5, 0.75]
F14	[0.25, 0.5]	[0.25, 0.5]	[0.25, 0.5]	[0.25, 0.5]	[0.25, 0.5]	[0.5, 0.75]	[0.25, 0.5]	[0.5, 0.75]	[0.25, 0.5]	[0.25, 0.5]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]	[0, 0]	[0.75, 1]	[0.75, 1]
F15	[0.75, 1]	[0.75, 1]	[0.75, 1]	[0.5, 0.75]	[0.5, 0.75]	[0.25, 0.5]	[0.5, 0.75]	[0.25, 0.5]	[0.5, 0.75]	[0.5, 0.75]	[0.5, 0.75]	[0.75, 1]	[0.75, 1]	[0.25, 0.5]	[0, 0]	[0.75, 1]
F16	[0.5, 0.75]	[0.5, 0.75]	[0.75, 1]	[0.5, 0.75]	[0.75, 1]	[0.75, 1]	[0.75, 1]	[0.5, 0.75]	[0.5, 0.75]	[0.5, 0.75]	[0.5, 0.75]	[0.75, 1]	[0.5, 0.75]	[0.25, 0.5]	[0.75, 1]	[0, 0]

Table 2
Normalized direct relation matrix.

X	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16
F1	0.0000	0.0745	0.0745	0.0745	0.0039	0.0745	0.0745	0.0745	0.0745	0.0745	0.0000	0.0000	0.0510	0.0274	0.0745	0.0510
F2	0.0745	0.0000	0.0745	0.0745	0.0039	0.0039	0.0274	0.0000	0.0274	0.0000	0.0000	0.0000	0.0510	0.0274	0.0745	0.0510
F3	0.0745	0.0745	0.0000	0.0745	0.0039	0.0745	0.0745	0.0000	0.0745	0.0510	0.0000	0.0039	0.0510	0.0274	0.0745	0.0745
F4	0.0745	0.0745	0.0745	0.0000	0.0039	0.0745	0.0745	0.0000	0.0745	0.0510	0.0000	0.0000	0.0510	0.0274	0.0510	0.0510
F5	0.0745	0.0510	0.0510	0.0745	0.0000	0.0274	0.0039	0.0000	0.0039	0.0000	0.0000	0.0039	0.0039	0.0274	0.0510	0.0745
F6	0.0510	0.0510	0.0510	0.0510	0.0039	0.0000	0.0510	0.0274	0.0039	0.0000	0.0745	0.0039	0.0510	0.0510	0.0274	0.0745
F7	0.0745	0.0745	0.0745	0.0745	0.0510	0.0510	0.0000	0.0510	0.0510	0.0745	0.0745	0.0000	0.0510	0.0274	0.0510	0.0745
F8	0.0745	0.0745	0.0745	0.0745	0.0510	0.0274	0.0510	0.0000	0.0510	0.0745	0.0274	0.0000	0.0510	0.0510	0.0274	0.0510
F9	0.0274	0.0274	0.0274	0.0510	0.0274	0.0274	0.0510	0.0745	0.0000	0.0510	0.0274	0.0745	0.0510	0.0274	0.0510	0.0510
F10	0.0745	0.0745	0.0745	0.0745	0.0039	0.0274	0.0510	0.0745	0.0745	0.0000	0.0510	0.0000	0.0510	0.0274	0.0510	0.0510
F11	0.0274	0.0274	0.0745	0.0745	0.0000	0.0745	0.0274	0.0039	0.0039	0.0039	0.0000	0.0039	0.0745	0.0274	0.0510	0.0510
F12	0.0274	0.0274	0.0274	0.0274	0.0000	0.0000	0.0274	0.0039	0.0039	0.0510	0.0510	0.0000	0.0745	0.0510	0.0745	0.0745
F13	0.0274	0.0274	0.0274	0.0274	0.0745	0.0510	0.0510	0.0274	0.0510	0.0745	0.0510	0.0745	0.0000	0.0745	0.0745	0.0510
F14	0.0510	0.0510	0.0274	0.0745	0.0510	0.0510	0.0510	0.0274	0.0274	0.0510	0.0510	0.0510	0.0274	0.0000	0.0274	0.0274
F15	0.0745	0.0745	0.0745	0.0510	0.0039	0.0745	0.0745	0.0274	0.0745	0.0510	0.0510	0.0745	0.0510	0.0745	0.0000	0.0745
F16	0.0745	0.0745	0.0745	0.0745	0.0745	0.0745	0.0745	0.0745	0.0510	0.0510	0.0510	0.0510	0.0510	0.0745	0.0745	0.0000

Table 3
Total relationship matrix.

TRM	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16
F1	0.006	0.235	0.236	0.243	0.072	0.208	0.222	0.165	0.206	0.197	0.094	0.066	0.185	0.142	0.223	0.207
F2	0.177	0.001	0.176	0.181	0.047	0.1	0.128	0.06	0.117	0.086	0.057	0.046	0.136	0.102	0.172	0.151
F3	0.222	0.221	0.001	0.229	0.066	0.199	0.211	0.091	0.194	0.165	0.088	0.067	0.174	0.133	0.213	0.216
F4	0.211	0.209	0.21	0.004	0.061	0.189	0.2	0.084	0.185	0.156	0.081	0.057	0.165	0.124	0.181	0.184
F5	0.167	0.145	0.145	0.17	0.003	0.11	0.094	0.053	0.083	0.072	0.049	0.041	0.082	0.093	0.139	0.161
F6	0.165	0.164	0.167	0.173	0.054	0.001	0.156	0.09	0.097	0.09	0.137	0.05	0.146	0.131	0.138	0.182
F7	0.242	0.239	0.243	0.251	0.116	0.194	0.001	0.144	0.186	0.197	0.163	0.066	0.189	0.144	0.209	0.234
F8	0.224	0.222	0.223	0.232	0.11	0.156	0.187	0.008	0.173	0.186	0.108	0.058	0.173	0.152	0.171	0.194
F9	0.157	0.155	0.157	0.184	0.081	0.134	0.166	0.144	0.001	0.151	0.102	0.124	0.158	0.12	0.171	0.175
F10	0.225	0.224	0.226	0.234	0.067	0.159	0.191	0.158	0.197	0.001	0.132	0.061	0.178	0.133	0.194	0.196
F11	0.135	0.134	0.178	0.182	0.045	0.167	0.128	0.062	0.092	0.087	0.006	0.049	0.161	0.105	0.151	0.154
F12	0.135	0.134	0.136	0.141	0.048	0.097	0.127	0.067	0.093	0.134	0.114	0.004	0.163	0.129	0.175	0.175
F13	0.175	0.172	0.174	0.184	0.131	0.172	0.18	0.109	0.162	0.182	0.136	0.133	0.001	0.176	0.209	0.194
F14	0.174	0.172	0.153	0.203	0.097	0.154	0.161	0.095	0.125	0.142	0.119	0.095	0.131	0.008	0.145	0.149
F15	0.246	0.245	0.247	0.236	0.077	0.22	0.233	0.128	0.211	0.185	0.152	0.143	0.199	0.195	0.001	0.243
F16	0.265	0.262	0.265	0.276	0.148	0.233	0.245	0.176	0.201	0.195	0.157	0.123	0.209	0.205	0.252	0.001

Table 4
Causal-prominence values.

Code	Factors	$R_i + C_j$	$R_i - C_j$	Rank	Prominence
F8	Cycle count accuracy	4.367	−0.943	13	Effect
F12	Quality	3.145	−0.689	15	Effect
F16	Reliability performance	6.405	−0.397	1	Effect
F5	Blockchain technology	2.896	−0.384	16	Effect
F10	Material planning	5.04	−0.35	8	Effect
F15	Customer-oriented performance	6.041	−0.217	2	Effect
F7	Barcode label	5.756	−0.188	4	Effect
F11	Delivery	3.643	−0.141	14	Effect
F13	Cost	5.184	−0.04	7	Effect
F14	Flexibility	4.371	−0.031	12	Effect
F9	Sales and Operations planning (SOP)	4.707	0.143	10	Cause
F1	RFID	5.955	0.219	3	Cause
F3	Sensors	5.729	0.447	5	Cause
F6	RF handheld devices/Vehicle mounted units (VMU)	4.64	0.552	11	Cause
F4	Cloud computing	5.712	0.822	6	Cause
F2	Augmented reality (AR)	4.883	1.197	9	Cause

5. Discussion

The grey-DEMATEL results have divided the factors into cause-and-effects. As per Table 4 and Fig. 3, the importance order of the cause factors is: RFID (F1), sensors (F3), cloud computing (F4), Augmented reality (AR) (F2), sales and operations planning (S&OP) (F9), and RF handheld devices (F6).

Subsequently, the importance order of the effect factors is reliability performance (F16), customer-oriented performance (F15), barcode label (F7), cost (F13), material planning (F10), flexibility (F14), cycle count accuracy (F8), delivery (F11), quality (F12), and block chain technology (F5).

5.1. Top-most cause factors

5.1.1. RFID (F1)

Businesses are keen in RFID technology's benefits whether used independently or in a supply chain. RFID has increased sales by 2% for US clothing business gap by reducing stock-outs [71]. J Crew, a popular US apparel company, uses RFID to speed up inventory keeping from five to eight times. RFID has additional uses. Experts reveal that

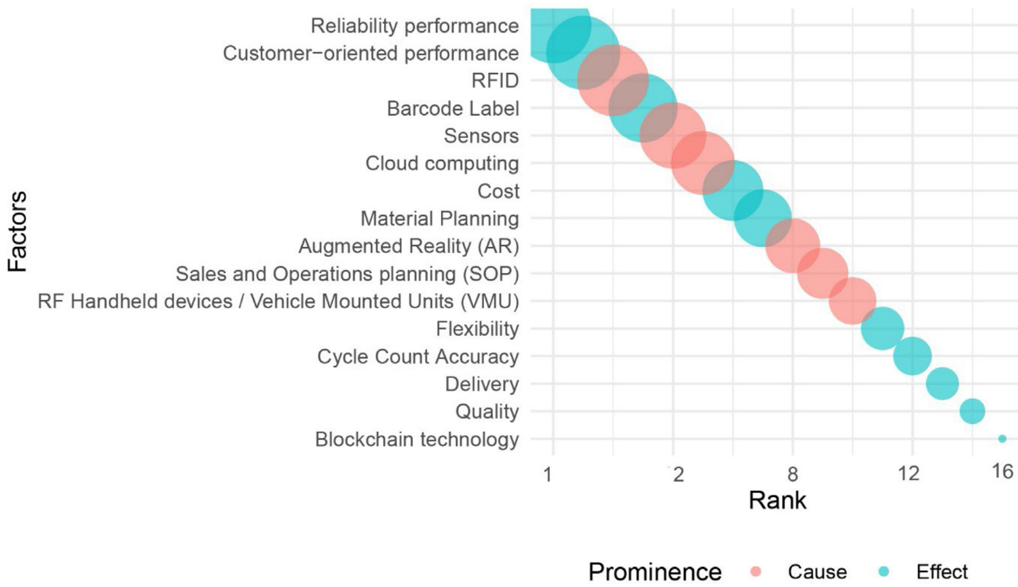

Fig. 1. Ranking of factors.

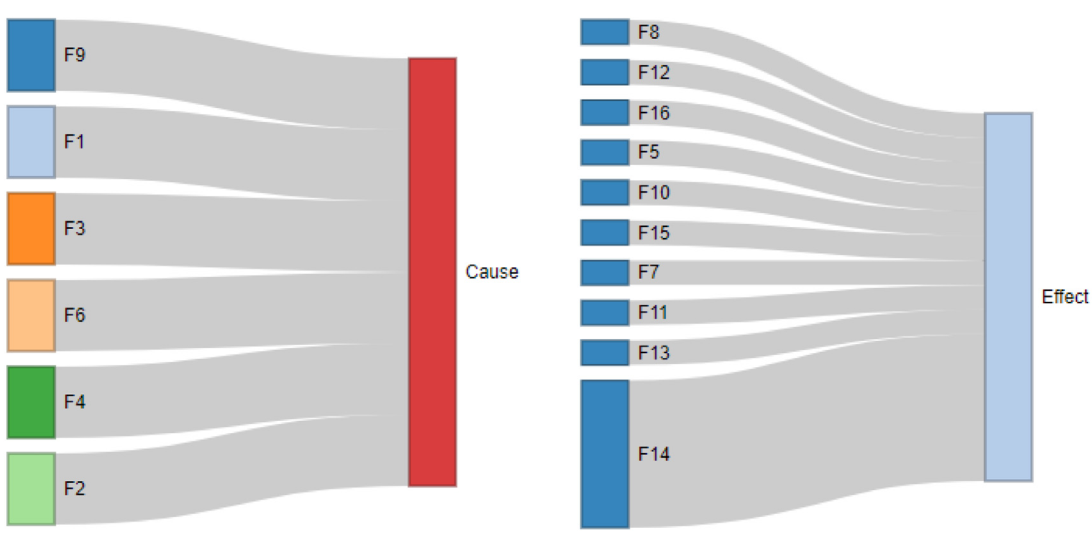

Fig. 2. Cause and effect factors.

it can be used for care labelling by adding washing instructions on it. It can also help improve stock visibility, which has twofold benefits. It simplifies stock inspections that might normally take days. Second, inventory and product monitoring reduce loss and theft. RFID helps warehouses monitor goods and prevent theft [72].

5.1.2. *Sensors (F3)*

Sensors are used in textiles nowadays. Smart sensors automate inventory counts and predictive maintenance, improving efficiency and accuracy. It also boosts machine efficiency, reduces material waste, and lowers costs, according to research [73]. It also prevents machine mishaps. Pakistani firms also use this in machineries like air-jet looms. A sensor stops activities when a thread breaks so a worker may fix it. In finishing facilities, metal-free zones may identify remaining metal fragments in clothing, and sensors can monitor warehouse humidity. Sensors can also automate processes, manage inventory in real time to forecast demand, and save maintenance costs and downtime via improved monitoring [74].

5.1.3. *Cloud computing (F4)*

Cloud computing could save companies cost on servers, internal software, and storage systems. Textile companies may create, manufacture, and invest in other technologies. These are easy to rent and use [75]. This would save a lot of company time and save IT investment costs. Cloud computing improves supply chains by aiding production planning, raw material management, pricing, order processing, and delivery. Cloud computing may also facilitate communication between foreign supply chain partners. Enhanced communication may also alert textile manufacturers to value chain concerns like material receipt delays (decreased on-time delivery) so they can respond quickly.

5.1.4. *Augmented reality (F2)*

Augmented reality (AR) streamlines the supply chain by enabling interactive 3D visualization, item tracking, inventory accounting, and automation. AR headsets let managers swiftly identify, assign, and move about the warehouse to get cost-saving data [76]. AR would automate and improve order picking and sourcing, according to insights.

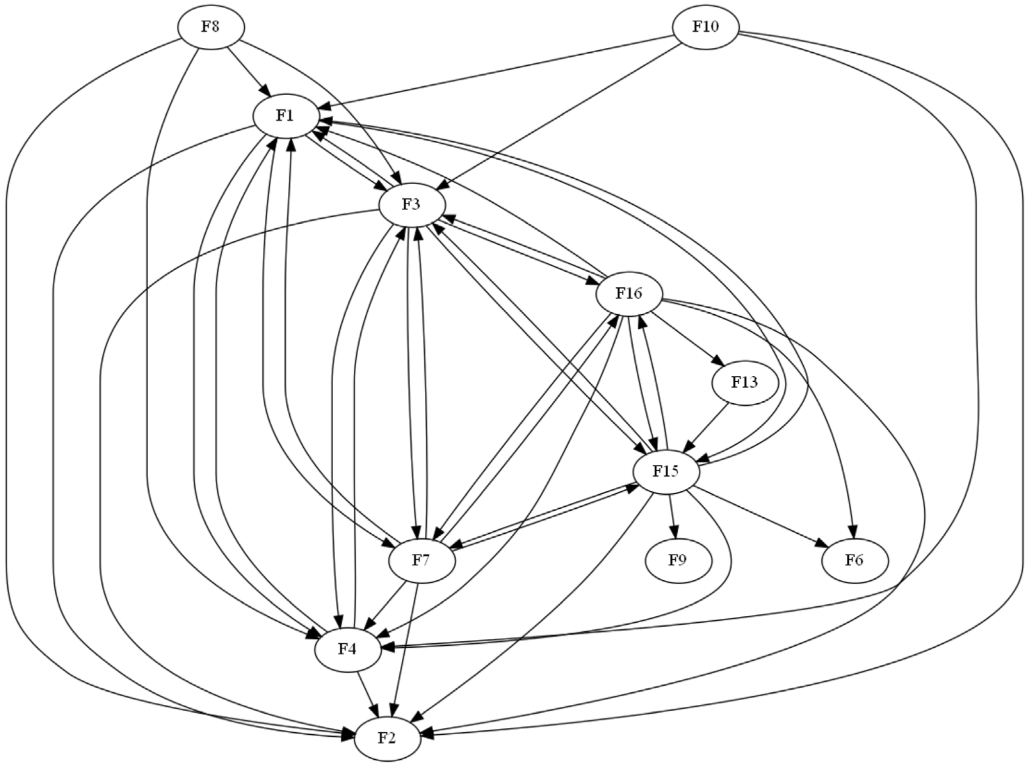

Fig. 3. Inter-relationship diagram.

AR systems will offer a warehouse, logistics, and distribution centre overview, saving time and improving warehouse efficiency. Order selection is another costly warehouse activity. AR headsets attached to mobile devices let employees choose at the proper areas quickly. Visual recognition AR systems will detect and validate the merchandise [77].

5.2. Top-most effect factors

5.2.1. Reliability performance (F16)

The results have ranked reliability as one of the top-most effect factors. It has been identified that this dimension reflects the output of supply chain operations and its capability to meet customer requirements [78]. The role of reliability performance in the supply chain of a textile sector is important. A textile firm in an emerging country experienced high reliability due to the country's logistic capabilities being well established which helps facilitate the flow of goods, information, and raw materials [78]. This leads to the insight that if other developing countries also improve the logistics' infrastructure, then reliability performance of firms can be improved. Another insight has been found that in textile firms the proximity to suppliers is one of the factors which helps improve reliability performance [79].

5.2.2. Customer-oriented performance (F15)

The second important effect factor is customer-oriented performance. Experts reveal that successful companies use this dimension of supply chain performance at the corporate level. It includes measures like cost, environment, quality, and delivery [80]. These measures are associated with the external system as they express the link of an organization with its customers and suppliers. In today's competitive environment, it has been found essential for textile firms to understand the increasingly dynamic needs of customers [81]. These evolving demands may include sustainability, reusing resources (partly due to increasing inflation), employing sea-weed-based textiles, and so on. More findings show that clients may want to pre-order certain designs online with their preferred fabric before they are made [82]. This gives them custom-made designs, which may boost customer-oriented performance. The client obtains the final product with the desired design and fabric at the desired cost and quality [83].

5.2.3. Barcode label (F7)

Barcode labels assist monitor product location and identity and are cheaper than other automated identifying systems. It may improve textile supply chain traceability and transparency by storing sustainability information from a product's whole value chain. Product information must be lightweight, on-demand, and dependable [84]. Barcode-scanning mobile phones are one illustration of this rising need. Barcode labels also save man-hours, inventory management problems, paperwork loss, and organizational mobility. This low-cost method may be adopted on a big scale, benefiting textile enterprises that deal in enormous product volumes. As they progress towards Warehouse Management Systems, Pakistani textile manufacturers are focusing more on barcode labels in the warehouse to manage inventory [85].

5.2.4. Cost (F13)

A textile supply chain's distribution, inventory keeping, and overhead expenses (such energy and labour) are high. With consumer brand awareness rising, corporations must cut expenses and pass the savings on to customers [86]. This also shows good supply chain performance. Many textile companies compete in Pakistan's market. It also attracts more clients since developing countries consumers have less buying power. Therefore, lowering these prices allows customers to get greater value from a firm's goods. In addition, the cost of living is growing due to the economic crisis, thus more customers are deferring textile purchases because this is an expense that can be avoided as long as essential physiological demands are met [87].

5.3. Practical implications and managerial implications

This paper has found some digitalization technologies, namely RFID, sensors, cloud computing, and augmented reality are prominent cause factors that affect supply chain performance factors like reliability, customer-oriented performance, and cost [88]. The study also fails to relate WMS to supply chain performance variables. This contradicts prior research that linked these technologies to quality, flexibility, and delivery speed (main impact variables) of an organization [89]. This study also examined how these technologies may be used in Pakistan. Firms use RFID and sensor-based technologies, while the rest are rare [90]. Cloud computing and AR may still be beneficial. According to this research, the government should first raise knowledge of these technologies and their ROI so enterprises might consider them [33]. Building IT infrastructure in the nation may also help textile manufacturers use new technology and improve their operations. Further research should examine if bigger textile enterprises are more likely to profit from such technologies than smaller firms since they demand substantial expenditures. This requires quantitative and qualitative study and may have implications for textile sector.

Digitalization technologies appear to improve textile firms' supply chains the most [91]. This research identified emerging technologies that may impact textile supply chain performance. Organizations may face security issues with this technology. However, their efficient usage may save costs (connected to distribution, inventory, storage, waste, theft, etc.), boost customer satisfaction with high order fulfilment rates, and so on. WMS did not affect supply chain performance, either. Such organizations may lack advanced WMS [92]. Managers may need to examine a system to reap its advantages. Technology-related systems are the future, thus managers should invest in them [93]. Cloud computing will become more important. However, smart warehousing, cloud computing, AR, and others are understood in many nations [94]. In this regard, firms which take lead in their adoption may reap the benefits first and become industry leaders. This is because achieving higher supply chain performance is one of the factors essential for not only success, but also survival.

5.4. Conclusion

Supply chain has become complex as the product life cycle has shortened owing to frequently changing customer demand. Although, this evolution like the supply chain has enabled firms to perform and compete efficiently in their business environment. In the modern business environment, competition has shifted from single organization to supply chains and effective supply chain management has become increasingly significant in securing competitive advantage and improving organizational performance. With a WMS, supply chain managers can track inventory levels in real-time, allowing for better inventory control and management. This helps reduce the risk of stock outs and overstocking, which improves the operation's efficiency and reduces storage costs. The findings help the textile industry to identify key factors and get the best advice to improve their supply chain performance and competitive advantage. The literature highlights the transformative impact that such technology-related systems can have on a firm's supply chain performance. However, the results have highlighted that although digitalization technologies have a significant relationship with the dependent variable, but WMS is not an important cause factor. Nevertheless, these are future avenues which still need to be explored by academicians, government, and managers alike in order to maintain pace with the current competitive landscape.

5.5. Limitations and future direction

The limitations of this study are several. This paper focused on the analysis of only textile industry for supply chain performance. Other industries may also be explored in the context of a developing country in order to attain broader insights. Hence, future researchers may conduct this study for other industries as well. This may also help conduct a comparative analysis among different industries to explore individual industry differences. Moreover, the research question was explored using cross-sectional data. In this regard, a longitudinal study may provide further in-depth understanding of the study objective. Moreover, due to limited time and resources, the authors have used only the free literature article available online. Access to latest paid articles may have resulted in a richer understanding of the topic. Finally, the respondents of the study belonged to two textile firms. In the future, more respondents may be sought to generalize the results further.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data used is available in manuscript

Appendix

See Table A.1.

Table A.1
Key factors influencing digitalization, warehouse management system, and supply chain performance.

Sr. No.	Factors	Description
Digitalization		
1	RFID (F1)	RFID stands for the radio frequency identification, a generic term for technologies and systems that use radio waves to transmit and automatically identify people or objects.
2	Augmented reality (AR) (F2)	An interactive digital experience of a real-world environment where objects are augmented by computer generated perceptual data which may include visual, auditory, haptic, somatosensory and olfactory perceptions.
3	Sensors (F3)	Detect physical phenomenon (i.e., pressure, force, acceleration, temperature, etc.) can convert data into an output typically in the form of an electronic signal.
4	Cloud computing (F4)	A massively scalable computing paradigm that offers software, infrastructure and platforms as a service, providing real time data sharing capability throughout the supply chain.
5	Blockchain technology (F5)	Incorruptible digital ledgers of transactions that are programmed to record value of any type of transaction, allowing for a secure and transparent form of sharing transactional data.
Warehouse management system		
6	RF handheld devices/vehicle mounted units (VMU) (F6)	These devices help performing the day-to-day warehouse activities much faster and with very low user error. As, these are integrated with the WMS, it helps in validating the data that the user is attempted to scan from the product.
7	Barcode label (F7)	Barcode label is a visual that consists of a composition of bars that have a set of numbers underneath it. It is a representation of a data that can be translated by a certain type of machine.
8	Cycle count accuracy (F8)	Cycle count accuracy represents how closely the system stock matches to the physical stock. Higher accuracy means the WMS system stock location and the physical stock location are closely matched.

(continued on next page)

Table A.1 (*continued*).

9	Sales and operations planning (SOP) (F9)	The ability to read the reports on production output and inventory to effectively plan the sales and operations.
10	Material planning (F10)	The ability to plan long-term purchasing contracts, just in time purchasing, effectively do the stock transfers, manage offsite material storage, and manage subcontracting.
Supply chain performance		
11	Delivery speed (F11)	Delivery speed comprises producing and delivering products/services much faster than others. The dimensions of delivery speed include response customer-time, on-time delivery, lead-time, and fill-rates.
12	Quality (F12)	Quality considers getting orders from customers and making sure that the agreed standards are met at all times. Customer satisfaction is enhanced when their preferred standards are met in the supply chain operations; failure to achieve this will dip performance.
13	Cost (F13)	The cost implication around distribution, manufacturing, inventory, warehousing, incentive cost and subsidies, intangible cost and overhead cost. When these costs are managed efficiently, firms in the supply chain operation turn to be more competitive and have an overall enhanced SCP.
14	Flexibility (F14)	Firms with high flexibility are largely innovative and serve customers appropriately. It also allows for the production of goods and services that move along with changing times.
15	Customer-oriented performance (F15)	The performance of producers in servicing customers in the context of quality, flexibility, delivery in the downstream supply chain
16	Reliability performance (F16)	The order fulfilment rates, inventory turnover rate, safety stocks, obsolete inventories and the number of product guarantee claims

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