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The effect of digital supply chain on lean manufacturing: A structural equation modelling approach

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This study aimed to test the impact of digital supply chains on lean manufacturing, the digital supply chain was a multidimensional measurement composed of seven dimensions: Digital performance management, digital information technology and digital manufacturing, digital human resources, digital suppliers, digital logistics and inventory and digital clients. The electronic industries companies were targeted to represent the research population and collect the primary necessary data. According to the research budget and time constraints, a convenience sampling method was implemented in the data collection process. Structural equation modeling (SEM) was applied to test the research hypotheses through AMOS software. The results indicated that most of the digital supply chain dimensions had a positive impact on lean manufacturing, except digital suppliers and digital clients, which had no effect on lean manufacturing. Findings from this research help organizational managers make multiple decisions related to investing and allocating resources to increase profit and reduce expenses along digital supply chains.

1. Introduction

Digital transformation refers to "the increasing prevalence of digital technologies in society and the associated changes in people's communication and behaviour" (Gimpel et al., 2018). It creates new opportunities for organizations and supply chain practices (Al-Alwan et al., 2022; Tariqa et al., 2022a; Eldahamsheh et al., 2021). The fourth-generation industrial revolution through digital transformation allows organizations to achieve high flexibility when formulating their supply chain strategies and practices, thus creating greater organizational value (Tariq et al., 2022b; Büyüközkan and Göçer 2018). The digital transformation of supply chains also facilitates the application of end-to-end communications along the supply chain, which creates a competitive advantage for organizations to be able to deal with changing customer needs efficiently (Khajavi et al., 2015; Porter & Heppelmann 2015). The digital transformation of supply chains creates great opportunities to increase the availability of information and improve logistics between organizations, and work on transparency and clarity of information along the supply chain by providing the ability to access timely information and the ability to control it; efficiency

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of operations and maintenance; integration and collaboration; product innovation and design; and efficient inventory management (Kache & Seuring 2017).

Digital supply chains are beginning to take on greater importance in industrial organizations (Büyüközkan & Göçer, 2017) because they directly affect the way retailers, manufacturers, distributors, and logistics providers run their operations and, in particular, manage inventory across their sales channels (Yearling, 2018). The term "digital supply chains" has begun to pique the interest of industry experts and managers. Its popularity has corresponded with the rise of words such as "big data" and other recent subjects of academic concern (Alshawabkeh et al., 2022). However, a review of the theoretical literature on digital supply chains reveals a lack of clarity in the field's evolution, indicating that this area needs additional research. It has become evident that there is a void in the managerial literature about digital supply chains, and the topic still requires clarification of its basic structure, clarification of concerns linked to it, and identification of the variables that affect it. Technological and digital developments support the way for more integrated activities and a clear and rapid flow of information between the organization, its suppliers and potential customers. The digital supply chain can be defined as an integrated smart tool that uses new digital information and technologies to provide products of greater value that are more accessible and at the lowest prices (Bhargava, Ranchal & Othmane 2013, Büyüközkan & Göçer 2018).

Digital supply chains have been associated with many benefits, including speed, resilience, global connectivity, intelligence, transparency, scalability, and many more (Hanifan et al., 2014, Al-khawaldah et al., 2022; Aityassine et al., 2021; Schrauf & Berttram 2016). Kittipanya-In Ngam, & Tan (2020) Study of Digital Supply Chains in the Food Sector confirms that the use of digital transformation technologies makes supply chains connected, efficient, and responsive to customer needs. However, the transition to digital supply chains instead of the traditional supply chain has many challenges and requires organizations to specialize resources. Despite the benefits of digital technology in supplying big data systems, they posed numerous obstacles to food supply chains as the final consumer became more informed and aware of news and information via digital media (Song et al. 2018). There is also a lack of consensus among supply chain participants on mechanisms for decreasing costs through the use of digital supply chain technology (Al-Nawafah et al., 2022; eFoodChain, 2017) or the digital integration of supply chain activities to decrease waste, labor, and inventory (Song et al., 2018).

The concept of lean manufacturing is used by many organizations today with the aim of reducing manufacturing waste to improve the productivity and quality of manufactured goods in proportion to what customers pay (Sharma et al., 2021). Lean manufacturing seeks to maintain a continuous flow based on strategy withdrawal to demonstrate value from the customer's point of view and eliminate manufacturing waste (Saxby et al., 2020). Lean manufacturing uses various practices such as production on time (JIT), total production maintenance (TPM), autonomy, value flow mapping (VSM), and kaizen/continuous improvement (CI). All of these practices are used when organizations want to operate their production lines in a flexible manner (Andreadis et al., 2017; Belekoukias et al., 2014; Garza-Reyes et al., 2018; Rocha-Lona et al., 2013). The researchers found limited research on the relationship between digital supply chains and the application of the five lean manufacturing practices that aim to reduce waste. von Haartman et al. (2021) highlight that lean manufacturing is achieved through the application of digital technologies in production. Lean manufacturing, also known as production flexibility, is a method of workplace arrangement aimed at continuous improvement and improvement of the production system by eliminating processes and activities that do not add any value to the process (Maama et al., 2021), which facilitates operations and reduces their costs.

2. Theoretical foundations any hypotheses development

2.1 Digital supply chains

Digital technologies are a new concept, as they are technologies that are still in their development stage. The application of these technologies changes the way business is performed and thus affects the business environment. Digital supply chains have great capabilities to process information and communications through digital platforms, which makes them cooperate with supply chain partners in an optimal way. The transformation of supply chains into digital form gives a standard character to products and processes because digital technologies and tools help simplify and standardize those processes, products, and even the activities that they practice along the supply chain, generating new value for products that make them more sought-after by digital customers (Agrawal & Narain, 2018). The goal of the digital supply chain is the integrated planning and management of logistics systems and networks based on digital models, methods, and tools based on a common information and communication platform. The introduction of digital transformation technology innovates new business activities, making the mobility and physical movement of goods faster. Therefore, it ultimately affects the supply chain activities.

The term "digital supply chain" falls within the e-supply chain concept (Shahin et al., 2022). Digital tools facilitate business supply chain activities (Castorena et al., 2014; Dim & Ezeabasili, 2015; Wang & Lu, 2016; Vendrell-Herrero et al., 2017). Therefore, digital transformation tools are among the most important elements in the supply chain. However, organizations may face many challenges and risks when implementing digital supply chain arrangements to manage collaboration with their partners (Xue et al., 2013). Digital transformation depends on e-commerce (Chaudhuri & Mukhopadhyay, 2014; Nauwelaerts & Chakri, 2016; Tanoos, 2017; Chowdhury et al., 2018), which is an expensive tool to develop and implement. Organizations also face a financial obstacle to the cost of adopting digital tools in implementing their supply chain activities.

Digital supply chain management can be defined as new technologies that are changing the old ways in which business was done along the supply chain, such as supply chain planning, carrying out activities, and interacting with partners in the supply chain, which achieves integration with them and creates a new business model. Due to the metamorphosis, digital is a collaborative effort comprising numerous projects that work together to enable organizations to change. Queiroz et al. (2019) defined “a digital supply chain” as “a set of information and communication technology resources that an organization uses to interact on its network for the purpose of shifting from physical activities to digital activities and applying an integrated model of physical and digital activities to reduce resource consumption and improve productivity, including production allocation tools”. and cooperate with suppliers along the supply chain, while managing data with high technology and skill. Ahmed (2020) defines it as the intelligence of the appropriate technical system that depends on getting rid of big data and effective cooperation and communication with hardware, software, and digital networks to support interaction between partners in the supply chain by giving products and services more value that makes them reach customers quickly and at a lower price (Büyüközkan & Göçer, 2018, p.165). Many researchers have highlighted the importance of a deep understanding of the term “digital supply chains”. Kurpjuweit et al. (2021) confirm that the transition to digital supply chains through the application of block chain leads to security and cost reduction.

Farhani et al., (2017) classified digital supply chain dimensions into seven categories: digital performance metrics, digital information technology, digital human resources, digital suppliers, digital manufacturing systems, digital inventory and logistics, and digital customer. While Meier, C. (2016) identified seven other dimensions of digital supply chains, which are mobile technologies, big data, cloud computing, social media, predictive analysis, the Internet of things, and 3D printing. Bigliardi et al. (2022) define it as ten dimensions: Internet of Things (IoT), advanced analytics, artificial intelligence (AI), and machine learning (ML) technologies. Augmented reality (AR), virtual reality (VR), blockchain technology, robotics, 3D printing, and drones. As identified by Farahani et al. (2017), there are six dimensions of digital supply chains: digital performance measurement; digital information technology; Digital suppliers; digital production systems; digital logistics and inventory; and digital clients.

To achieve the study's objectives, the researchers chose to rely on the dimensions proposed by Farhani et al. (2017), which is the **measurement of digital performance**, which is the method by which standards are established to measure the performance of activities when they are carried out using digital technologies. Digital information technology, which is the tools that provide information and sources based on the Internet for individuals, enables them to access and manage information related to them easily and without additional costs. **Digital information technologies** require the presence of a smart mobile phone, computer, or tablet; the ability to use the Internet to obtain information from websites; the use of e-mail; the ability to send and receive text messages; and the ability to use applications on a Smartphone. **Digital HR** is the use of web technologies to implement human resource management policies and procedures (Shamout et al., 2022). Digital transformation requires new skills for employees because it creates new ways of doing work and may provide new job opportunities that did not exist before. Therefore, it is necessary to train employees on how to perform activities in a new way using information technology and digital applications. This requires the support and commitment of senior management to all parties involved in the implementation of this concept (Berber et al., 2018). The digital transformation of the supply chain also requires an amendment to the rules for each organizational function (Deloitte, 2017). Organizations are working hard to find new tools and opportunities to help them adapt to the digital transformation of human resources.

Digital Suppliers facilitate agreements and transactions along the supply chain using digital technologies such as cloud computing, big data, wireless, etc. A **Digital Manufacturing** System is one of the supporting technologies for carrying out tasks and making decisions using virtual models and simulations without resorting to any physical models, and accordingly, this system can design, re-design, and analyze the factory permanently and effectively in order to improve its performance. (IoT) and modern manufacturing technologies contribute to the development of a digital manufacturing system that supports energy and resource efficiency, which facilitates manufacturing processes and enables factories to deliver on time. **Digital logistics** is one of the processes of planning and managing supply chains directed to customers that works to create and transfer value to the customer through the use of new information and communication technologies with robots to unify logistics operations, which helps in accelerating the movement of materials and reducing errors when handling them, as well as optimizing the use of warehouses and improving the transmission of information, and it arrived on time. Successful implementation of the Internet of Things in logistics requires high levels of cooperation and participation by partners along the supply chain (Montoya-Torres et al., 2021). **Digital customer**, digital transformation helps to find good pronunciation. The digital shopping experience creates more value for the customer, which makes him more satisfied, as the digital customer is the customer who uses digital technologies when shopping and buying to fulfill his needs (Bolton et al., 2018; Klaus, 2014). The transformation of the traditional customer into a digital customer fundamentally affects the mental image of the products. The Internet allows customers to share their opinions, ideas, and experiences regarding the goods and services provided by organizations, which may positively or negatively affect the mental image of the products (Mihardjo et al., 2019).

2.2 Lean manufacturing

Lean management is a technical social management system that deals with efficiency and aims to eliminate any waste by reducing the discrepancy between internal and external sources (Shah & Chauhan, 2021). This systematic reduction enables the organization to improve its procedures and results across the supply chain, which helps it achieve a competitive advantage (Moyano-Fuentes et al., 2020). Organizations today use the concept of Lean Manufacturing to express their ability to create new value for their activities and get rid of all forms of costs and redundancies, which makes them more competitive (Novais et al., 2020). Flexible thinking in organizations is one of the most effective strategies for improving operations (Nicoletti, 2013). The term Lean Manufacturing dates back to World War II, specifically to the Japanese car manufacturer Toyota.

Toyota developed a system to find the best way to carry out activities and integrate manufacturing processes into integrated and comprehensive operations, and since then it has been called the Toyota Production System (Osman et al., 2019).

The Lean Manufacturing strategy uses a number of tools to improve organizational performance, including JIT, TPM, autonomy, VSM, and kaizen/CI, which are the most important tools when applying concepts of Lean Manufacturing (Andreadis et al., 2017; Belekoukias et al., 2014; Garza-Reyes et al., 2020;). One of the most prominent practices of Lean Manufacturing, which was addressed in this study, is the **JIT production system**, It is a modern management philosophy to deal with and control production activities (Filippini and Forza, 2016) and has been applied for long periods as a management approach. (Kurilova-Palisaitiene and Sundin, 2018) emphasizes that JIT is one of the process improvement strategies that deals with inefficient, lengthy, and random processes and minimizes them. JIT makes it easier for organizations to share information in a timely manner, build decisions based on it, and act in a coordinated manner along the entire supply chain (Hofmann and Rüsch, 2017).

Value stream mapping (VM) is one of the most important practices of production flexibility (Kurpjuweit et al., 2021), and a simple mechanism that helps to monitor the current situation and compare it with pre-established standards and uses a variety of signs and signals to control and manage people and processes (VM) (Thomas et al., 2018). **Total productive maintenance** (TPM) is also a system that takes care of the maintenance of equipment to maintain an optimal and defect-free production environment, reduce downtime, and reduce accidents (Pandey et al.,2021). A simple tool is a way to reduce waste to make better use of equipment (Gidwani and Dangayach, 2017) and can help solve cost, technology, and ergonomics problems (Habidin et al., 2018). Continuous improvement CI is the operating strategy (Mirihagalla, 2020). It includes a set of methods that are keen on developing processes and taking care of them; training employees continuously; innovating new working methods; and working on the search for errors to discover and correct them quickly. And finally, **autonomy** (failure prevention) and poka-yoke (mistake-proofing). They are fundamental and critical practices in Lean Manufacturing (Garza-Reyes et al., 2018; Kolos, 2017). The automation system is automatic or manual and stops the production process when any defect or defect appears (Aslan et al., 2016). While Poka-Yoke is a mechanism that allows the application of simple mechanisms that prevent errors or defects during the performance of various activities (Mancosu et al., 2018).

2.3 Digital supply chain and lean manufacturing

The term Industry 4.0 has been closely associated with the digital transformation of industrial processes and equipment and the ability to process large amounts of data in a timely manner, and the application of this term has begun to change the business environment (Battaa et al., 2018). Supply chains and how to manage them have become a critical factor in improving the performance and competitiveness of organizations (Kerdpitak, 2022; Ataseven & Nair, 2020). Because when appropriate supply chain management strategies are adopted, positive results and improvements begin to appear in the outputs of operations in terms of increasing their efficiency, reducing inventory levels, increasing customer satisfaction, improving quality, reducing costs, and accelerating delivery (Sharma, et al. 2021). Many organizations are using supply chain intelligence to overcome their problems by equipping their supply chains with a technological infrastructure that enables an easy and integrated flow of information and materials in supply chain operations (Abdel-Basset et al., 2018). Several studies have found a positive effect of the application of digital supply chains in organizations on the improvement of both the internal efficiency of business sectors and the external efficiency of the supply chain as a whole (Marodin et al. 2017; Tortorella et al., 2017). In their study, Büyüközkan and Göçer (2018) suggest a detailed method for implementing digital supply chains and suggest a number of their advantages, weaknesses, and challenges that may face their implementation. Six success components were identified by Quiierez et al. (2019) to allow digital supply chain capabilities in Industry 4.0. Nasiri et al. (2020) investigated the impact of digital transformation and smart technology on digital supply chain performance. In a study of food supply networks, Kittipanya-Ngam and Tan (2020) provided a viable paradigm for digital supply chains.

Previous studies highlighted the need to use digital technologies in supply chains and the transition to so-called digital supply chains. They added that many organizations are working to improve their capabilities and performance through the use of digital supply chains, but the concept of digital supply chains is still in its early stages of development. The administrative literature related to production management is full of research on the opportunities and risks resulting from digital transformation in production processes. The results of the studies also indicate the use of digital technologies in production that work to develop production proofs and prototypes for products in terms of increasing the possibility of testing products in an accurate and virtual manner without any additional risks or costs, and many studies also confirmed that this topic needs further research (Meissner et al., 2018). Tay and Loh (2021) found in their study that there is an effect of digital supply chains in improving operations using LSS DMAIC strategies. He stressed that the possibilities of solving problems in Lean Six Sigma increased when (LSS's DMAIC) used digital transformation techniques used in supply chains. Organizations use JIT technology in supply chains to reduce waste and excess inventory, with the aim of reducing transportation and inventory costs by delivering repetitive orders in small quantities (Goodarzi & Zegordi, 2018). Organizations have an increased reliance on digital transformation tools in their supply chains, which certainly affects the way they implement JIT strategies (Nowicka, 2017).

Martinez (2019) confirmed that organizations seek to transform their supply chains into digital form and Ia is working to enhance their technological capabilities in operating their supply chains on an ongoing basis, as these new improvements include many digital tools thanks to the efforts of CI (Martinez, 2019). Integrating digital technology processes with flexible production processes provides factories with the ability to reduce costs, improve production, meet delivery commitments, and benefit from all the benefits of digital transformation (Vo et al., 2019).

Industry 4.0 technologies and the digital transformation that organizations are adopting in their digital supply chains provide new ways to help them predict and locate errors in various processes. Thomas et al. (2018) add that organizations are still searching for the adoption of techniques to improve their performance, including improving their performance. The performances of the supply chain and among the most prominent of those techniques that improve performance are automation and Poka-Yoke. Poka-Yoke adopts a set of practices, devices, or methods that make the process of errors impossible or clarify the error that actually occurred as soon as it occurs. The Haddud and Khare (2018) study revealed the impact of digital supply chains on the six lean manufacturing tools. The results of the study showed that digital supply chains contribute positively to making lean manufacturing tools more effective. Because digital supply chains employ tools of great value that help organizations mitigate wastage in manufacturing processes. Several previous studies confirmed that there is a gap in studies examining the relationship between digital transformation technologies and the application of lean manufacturing strategies in industrial companies (Gjeldum et al., 2016; Kolberg et al., 2017; Al-Alwan et al., 2022; Landscheidt & Kans, 2016). Accordingly, the study hypothesis can be formulated as follows:

Main Hypothesis: *There is an impact of digital supply chains on lean manufacturing.*

3. Study model

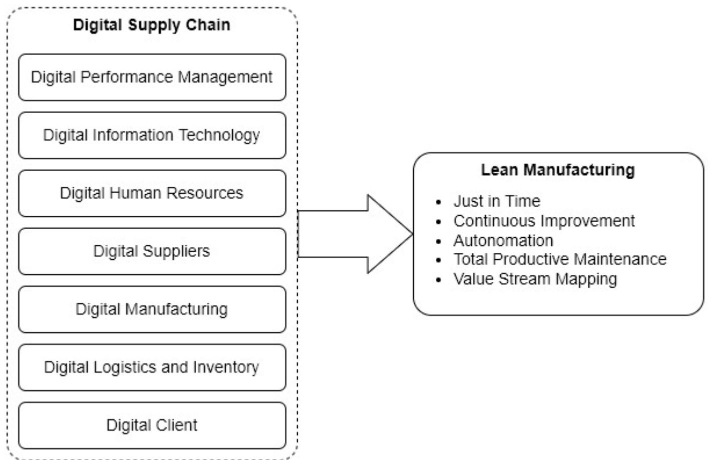

Fig. 1. Conceptual model

4. Methods

4.1 Participants and procedure

The electronic industries companies were targeted to represent the research population and collect the primary necessary data. Before asking individuals to participate in the survey, we obtained permission from the senior management of those companies to obtain the contact information of employees and their managerial levels. According to the research budget and time constraints, a convenience sampling method was implemented in the data collection process. This process continued from May 8, 2022, until June 12, 2022, which included distribution and retrieval activities. The research questionnaire was distributed electronically via e-mail to employees. The research targeted middle and operational management employees, where 580 questionnaires were sent. The number of responses received was 455 questionnaires. However, during its examination, it was found that 29 of them were marked incorrectly or with incomplete data, thus they were excluded from the total responses received. Finally, the correct and usable questionnaires were 426, which made a response rate of 73.44 per cent of distributed questionnaires.

Among the 426 correct responses, it was found that 350 males represented 82.16% of responses, in contrast, there were 79 females who formed 17.84 of the rest responses. The educational level of most of the respondents was 66.90% who hold a bachelor's degree, followed by 24.41% who hold a diploma or less, while 8.69 of them hold postgraduate degrees. The results of the age group analysis indicated that 48.12% of the sample belonged to the category “30-less than 40” which is the dominant category, while 5.16% belonged to the category “50 or older”, which ranked fourth and last. However, the results of the experience level indicated that 36.85% of the respondents have job experience “10-less than 15”, followed by 31.69% have experience “15 or more”, then 25.82% have experience “5-less than 10”, and those with experience “less than 5” constituted 5.64% and they were the least percentage of the research sample.

4.2 Measurement

A developed questionnaire was used as the main instrument for collecting research data, as it was disseminated on the research sample in its electronic form designed by Google Forms. The items of this questionnaire were originally in English; thus, they were fully translated into Arabic so that respondents could understand them. After completing the data collection, the questionnaire items were returned to English with the help of specialists and through the reverse translation method. The research questionnaire included a cover letter that ensured the anonymity and confidentiality of the responses, as well as an explanation that the participation is voluntary. A section was devoted to categorical control variables (gender, age, education, experience). Besides, two sections included items for measuring digital supply chains and Lean Manufacturing. A five-point Likert scale was used for determining the responses with a minimum limit of 1 “strongly disagree” and the highest limit of 5 “strongly agree”, while the middle limit of 3 was reserved for the response of “moderately agree”.

Digital supply chain: it was a 24-item measure adopted by Queiroz et al., (2021). The digital supply chain was a multidimensional measurement composed of seven dimensions. Digital performance management was measured by four items, as was digital information technology and digital manufacturing, each of them was measured by four items. On the other hand, digital human resources, digital suppliers, digital logistics and inventory, and digital clients were measured by only three items.

Lean manufacturing: it was a 15-item measure developed by Santos Bento and Tontini(2018). The lean manufacturing was a multidimensional measurement composed of five dimensions. Just in time, continuous improvement, automation, total productive maintenance, and value stream mapping, each of these variables was measured through three items.

5. Results

5.1 Confirmatory factor analysis

To assess *convergent validity, discriminant* validity, and reliability of measurement model, confirmatory factor analysis was used as recommended by Barnes et al. (2021) and Gana and Broc (2019). The items loading and the average variance extracted (AVE) were used to determine convergent validity. The comparison between the AVE and the maximum shared variance (MSV), as well as the comparison between the square root of AVE and the correlation coefficients were applied to measure the discriminant validity. Regarding reliability, McDonald's omega coefficients were extracted to determine the composite reliability (CR). The results in Table 1 reported the achieved results from these tests.

Table 1
Reliability and validity of measurement model

Variables	Items	Loadings	AVE	MSV	√AVE	CR
Digital performance management (DPM)	DPM1	0.716	0.575	0.461	0.759	0.844
	DPM2	0.794				
	DPM3	0.772				
	DPM4	0.750				
Digital information technology (DIT)	DIT1	0.728	0.567	0.315	0.753	0.839
	DIT2	0.711				
	DIT3	0.806				
	DIT4	0.764				
Digital human resources (DHR)	DHR1	0.813	0.564	0.267	0.751	0.795
	DHR2	0.734				
	DHR3	0.702				
Digital suppliers (DSP)	DSP1	0.715	0.572	0.304	0.756	0.800
	DSP2	0.764				
	DSP3	0.788				
Digital manufacturing (DMA)	DMA1	0.695	0.612	0.430	0.783	0.863
	DMA2	0.781				
	DMA3	0.831				
	DMA4	0.816				
Digital logistics and inventory (DLI)	DLI1	0.713	0.569	0.336	0.754	0.798
	DLI2	0.755				
	DLI3	0.792				
Digital client (DCL)	DCL1	0.729	0.588	0.317	0.767	0.810
	DCL2	0.746				
	DCL3	0.822				
Just in time (JIT)	JIT1	0.831	0.624	0.455	0.790	0.833
	JIT2	0.763				
	JIT3	0.775				
Continuous improvement (CIM)	CIM1	0.681	0.602	0.392	0.776	0.818
	CIM2	0.854				
	CIM3	0.783				
Autonomation (AUT)	AUT1	0.753	0.584	0.266	0.764	0.807
	AUT2	0.820				
	AUT3	0.715				
Total productive maintenance (TPM)	TPM1	0.704	0.580	0.341	0.761	0.805
	TPM2	0.786				
	TPM3	0.791				
Value stream mapping (VSM)	VSM1	0.733	0.630	0.477	0.794	0.836
	VSM2	0.851				
	VSM3	0.793				

The item loadings on their latent constructs according to what was mentioned in Table 1 ranged within (0.681-0.854). Barnes et al., (2021) indicated that the item loading above 0.50 required keeping it, hence all research items were acceptable. AVE for all constructs was greater than 0.50 as the minimum threshold. Hence, the measurement model is characterised by convergent validity (Howard, 2018). The results indicated that AVE was superior to MSV among all research constructs, as well as that the square root of AVE exceeded all correlation coefficients. According to these results, the measurement model was considered to have discriminant validity (Alhalalmeh et al., 2022; Franke&Sarstedt, 2019). Furthermore, the composite reliability was verified using McDonald's Omega coefficients that ranged within the domain (0.795-0.844). Goodboyand Martin (2020) considered that McDonald's omega values which are higher than the minimum value of 0.70 are evidence of the composite reliability achievement of the measurement model. Therefore, the measuring model for examining the impact of the digital supply chain on lean Manufacturing was valid and reliable.

5.2 Descriptive analysis

Mean was used as one of the central tendency indicators for determining the respondents' attitudes about the dimensions of the digital supply chain and lean manufacturing. Standard deviation is considered a dispersion indicator for identifying the variance of the responses on their mean. Moreover, Pearson's correlation coefficients were extracted to verify the multicollinearity among the dimensions of the digital supply chain and the intercorrelation between the research variables. Table 2 reported the results of descriptive statistics related to the current research

Table 2
Correlation and descriptive statistics

Variables	M	SD	1	2	3	4	5	6	7	8	9	10	11	12
1. DPM	3.56	0.764	1											
2. DIT	3.62	0.912	0.335	1										
3. DHR	3.53	0.814	0.415	0.474	1									
4. DSP	3.48	0.711	0.425	0.468	0.432	1								
5. DMA	3.60	0.855	0.402	0.428	0.461	0.452	1							
6. DLI	3.65	0.902	0.356	0.459	0.395	0.488	0.399	1						
7. DCL	3.51	0.725	0.468	0.458	0.425	0.387	0.447	0.385	1					
8. JIT	3.63	0.803	0.512	0.532	0.519	0.495	0.522	0.662	0.591	1				
9. CIM	3.72	0.924	0.623	0.602	0.503	0.527	0.608	0.418	0.645	0.472	1			
10. AUT	3.59	0.866	0.514	0.612	0.516	0.538	0.487	0.589	0.577	0.538	0.552	1		
11. TPM	3.41	0.658	0.503	0.551	0.559	0.534	0.528	0.532	0.568	0.622	0.517	0.549	1	
12. VSM	3.69	0.758	0.511	0.584	0.571	0.560	0.618	0.548	0.595	0.581	0.615	0.582	0.588	1

Note: all correlation coefficients were significant at a level less than 0.05.

From the mean values listed in Table 2, it was found that all dimensions of the digital supply chain were at a moderate relative importance level. The first rank was for digital logistics and inventory (M= 3.65, SD= 0.902), while the last rank was for digital suppliers (M= 3.48, SD= 0.711). Otherwise, the dimensions of lean manufacturing were within moderate and high relative importance levels. The results indicated that continuous improvement (M= 3.72, SD= 0.924) ranked first, and value stream mapping (M= 3.69, SD= 0.758) ranked second, both at a high relative importance level. The rest dimensions were of moderate relative importance level, as just in time (M= 3.63, SD= 0.803) was in the third rank, followed by autonomation (M= 3.59, SD= 0.866) in the fourth rank, then total productive maintenance (M= 3.41, SD= 0.658) which was in the fifth and last rank.

The correlation between the digital supply chain dimensions and the lean manufacturing dimensions was at a moderate level, where Pearson coefficients ranged within the domain (0.418-0.662). Furthermore, the correlation coefficients between the digital supply chain dimensions ranged from r= 0.335 to r=0.468. Shrestha (2020) mentioned that the Pearson correlation coefficients among the independent variable dimensions whose value does not exceed 0.80, the upper limit of the acceptable correlation, represent an indication of the integrity of the multicollinearity problem. Accordingly, the digital supply chain dimensions were free from this problem and autonomous among themselves.

5.3 Effect testing

Structural equation modeling (SEM) was applied to test all the research hypotheses through AMOS software. Fig. 2 illustrated the structural model used to test the impact of digital supply chain dimensions on lean manufacturing.

Through the goodness of fit indices reported in Figure 2, the chi-squared ratio to the degrees of freedom (CMIN/DF) was 2.045, which exceeds 3 the minimum acceptable threshold for this ratio. CFI and TLI were respectively 0.925 and 0.946, which is greater than 0.90 the minimum limit for these indicators. Besides, value RMSEA reached 0.053, where 0.08 is the upper bound for this indicator. According to these results, the study data was considered suitable for the structural model of the effect test (Savalei, 2021; Padgett & Morgan, 2021). Furthermore, it could rely on the effect coefficients listed in Table 3 to verify the research hypotheses and indicate the size of the effect between the variables.

Table 3
Standardized and unstandardized effect coefficients

Variables	B	S.E.	β	t	P
Digital performance management→ Lean manufacturing	0.509	0.053	0.486	9.604**	0.002
Digital information technology → Lean manufacturing	0.527	0.048	0.511	10.979**	0.004
Digital human resources → Lean manufacturing	0.427	0.056	0.395	7.625*	0.02
Digital suppliers → Lean manufacturing	0.074	0.064	0.058	1.156	0.088
Digital manufacturing → Lean manufacturing	0.625	0.045	0.601	13.888***	0.000
Digital logistics and inventory → Lean manufacturing	0.453	0.050	0.433	9.060**	0.006
Digital client → Lean manufacturing	0.065	0.052	0.041	1.250	0.155

Note: * $P< 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.

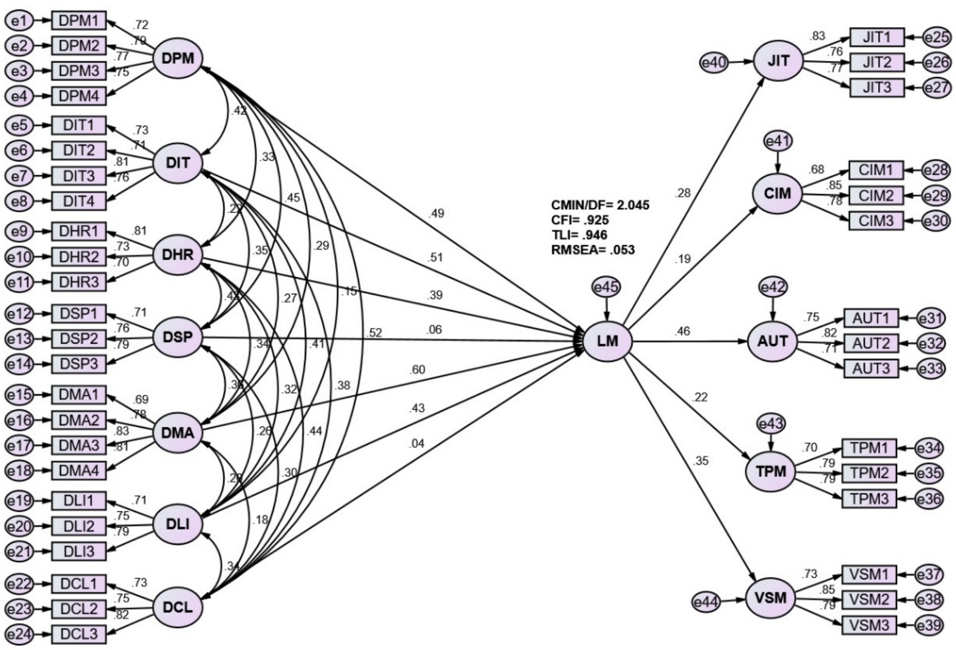

Fig. 2. SEM for testing the impact of DSC on LM

The results in Table 3 indicated that most of the digital supply chain dimensions had a positive impact on lean manufacturing, except digital suppliers and digital clients, which had no effect on lean manufacturing. However, the biggest impact was digital manufacturing (β= 0.601, t= 13.888, p= 0.000), followed by digital information technology (β= 0.511, t= 10.979, p= 0.004), then digital performance management (β= 0.486, t= 9.604, p= 0.002). Moreover, the results demonstrated that digital logistics and inventory (β= 0.433, t= 9.060, p= 0.006) ranked fourth in effect term, while digital human resources (β= 0.395, t= 7.625, p= 0.02) ranked fifth and last in their effect on lean manufacturing.

6. Discussion

This study aimed to test the impact of digital supply chains on lean manufacturing processes by measuring the impact of digital tools used by digital supply chains on the five principles of lean manufacturing. The results of the research showed that digital supply chains add positive value to the five principles of Lean Manufacturing that were adopted in this study. The results of this study also added to the previous literature that examined digital supply chains and Lean Manufacturing or both, when they identified the way to improve digital supply chains from the principles of manufacturing, which are JIT, VM, TPM, CI, and Poka-Yoke.

The study sample confirms that the use of digital technologies in their supply chains has increased their capabilities and worked to facilitate the flow of information and materials along their channels, which made the performance of business and activities in them easier, and that digital technologies facilitated communication between the parts of the supply chain, which increased its integration and flexibility. The results also showed that the application of lean manufacturing techniques in their manufacturing operations came to speed up the process of adapting to customer demands and demand fluctuations and that these techniques were the biggest helpers in allocating production and reducing costs and losses from all activities and operations in factories. The use of digital technologies in the supply chains of organizations supports lean manufacturing practices because digital technologies will improve the processes of communication and transfer of raw materials from stores or finished manufactured materials to warehouses, and this supports the on-time production system, which is one of the most important dimensions of lean manufacturing. The digital technologies, according to the results of the study, also support production proofs by enabling designers in factories, especially product engineers, to test the product virtually without any losses or costs, which improves the process of proposing and testing prototypes.

The digital technologies used in supply chains also support continuous improvement processes because they may help to discover errors as they occur, identify their causes, and propose appropriate solutions to them, which supports the mechanisms of lean manufacturing and prevents delays in operations due to the accumulation of invisible errors, as it identifies and solves them and makes operations performed better a way for managers to choose the best method and update their operations accordingly. These results are consistent with Liu & Chiu's (2021) emphasized that digital supply chain integration has a positive impact on performance in organizations. And the specific use of digital technologies in supply chains determines the development in performance, as agreed with Haddud & Khare's study (2020), whose results confirmed the existence of a positive impact of digital supply chains on manufacturing flexibility and its practices, and the study of Montoya et al. (2021), who confirmed that digital supply chain practices contribute to supporting the implementation of the production strategy on time. And the study of Haddud, A., & Khare, A. (2018), which revealed that digital supply chains contribute positively to making lean manufacturing tools more effective. Because digital supply chains employ important tools that help organizations reduce waste in manufacturing processes.

7. Managerial implications

The results of the study provide a basis for organizational managers to rely on in assessing the role that Industry 4.0 technologies will play in improving business performance. This study agrees with the recommendations of Singh et al. (2019), who emphasized that new cognitive technology will encourage organizations to adopt various Industry 4.0 technologies such as IoTs, AI, CPS, and ICT in supply chains. This paper makes contributions to fill the need for more studies that explore Lean Manufacturing practices through the use of Industry 4.0 technologies. A study recommended by Mayr et al. (2018) focuses on how to implement Lean Manufacturing practices through Industry 4.0 technologies. And the study of Duarte and Cruz-Machado (2017), which emphasized the need for future research that demonstrates the characteristics of the flexible supply chain or the most important green practices when adopting Industry 4.0 technologies. Findings from this research help organizational managers make multiple decisions related to investing and allocating resources to increase profit and reduce expenses along digital supply chains.

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