Towards Circular Economy: A IoT Enabled Framework for Circular Supply Chain Integration

Luay Jum'a[a], Muhammad Ikram[b1], Charbel Jose Chiappetta Jabbour[c]

[a]*Logistic Sciences Department, School of Management and Logistic Sciences, German Jordanian University, Amman, Jordan*

[b]*School of Business Administration, Al Akhawayn University in Ifrane, Avenue Hassan II, P.O. Box 104, 53000 Ifrane, Morocco*

[c]NEOMA Business School, Department of Information Systems, Supply Chain Management & Decision Support, 76130, Mont-Saint-Aignan, France

Abstract

Nowadays, the Internet of Things (IoT) has evolved beyond mere buzzword status, emerging as a pivotal force that can confer a competitive advantage in the market. By facilitating seamless communication between objects and the internet, IoT catalyzes unprecedented connectivity between machines and objects. An inherent advantage lies in its capacity to facilitate real-time information sharing, enabling efficient management of vital aspects within the realm of supply chain management, including inventory, products, and orders. Therefore, this study investigates the impact of IoT on supply chain performance, with a specific focus on the mediating role of interconnected systems in the dynamics of supply and demand, and the performance of supply chain firms within a sustainable circular economy context. A survey involving 268 manufacturers forms the basis of quantitative data analysis. Partial Least Square Structural Equation Modelling (PLS-SEM) was employed to test the relationships between latent and construct factors. The results highlight the significant influence of IoT capabilities on both supply chain performance and the integration of internet-enabled supply and demand processes. Concurrently, the study reveals a reciprocal positive effect, as supply and demand integration within internet-enabled supply chains contributes to enhanced supply chain performance. Moreover, the integration of internet-enabled supply and demand processes emerges as a crucial mediator, amplifying the relationship between IoT capabilities and supply chain performance. This study provides valuable insights for managers, researchers, and policymakers, fostering a deeper understanding of the vital role that IoT plays in cultivating and enhancing superior supply chain management practices and overall performance. The study highlights the significant benefits of IoT in enhancing supply chain performance through improved real-time tracking, inventory management, and resource optimization. It also emphasizes the crucial role of integrating internet-enabled supply and demand processes as a mediator, boosting overall supply chain efficiency and responsiveness.

Keywords: Internet of things; supply chain performance; Internet-enabled supply process integration; Internet-enabled demand process integration; circular economy.

1. Introduction

[1] Corresponding Author (Muhammad Ikram; i.muhammad@aui.ma)

In the 21st century, I4.0 or industry 4.0 has been coined as the 4th industrial revolution, and it encompasses a broad range of cutting-edge technologies. Industry 4.0 is utilizing to create novel equipment and machines, real-time asset tracking, and machine maintenance in aerospace, health care, furniture manufacturing, and agriculture industries. However, the various technologies associated with Industry 4.0, including digital platforms, Internet of Thigs (IoTs), blockchain, 3D printing, and Artificial Intelligence (AI), have hardly been evaluated from a circular economy perspective across the entire supply chain (Sassanelli et al., 2023). There are several branches of smart applications (Hecklau et al., 2016; Qin et al., 2016; Queiroz et al., 2019), which allow objects (products) and machines to interact with one another, supported by technologies such as the internet of things (IoT), cyber-physical systems (CPSs), artificial intelligence (AI), and big data analytics (BDA), among others (Jum'a & Kilani, 2022; I. Lee & Lee, 2015; Qin et al., 2016). Everything in Industry 4.0 is made up of CPS, including field equipment, machinery, production modules, and products (Alzoubi, 2021; Ghazal et al., 2021; K. Lee et al., 2022; Shamout et al., 2022). As technology advances, the IoT or the internet of everything or the industrial internet is on the horizon. The Internet is becoming a ubiquitous global computing network where everything is interconnected (Farooq et al., 2015; Khan et al., 2012). As a result of it, all internet-connected smart objects can be connected at any time and through any network (Borgia, 2014; De Vass et al., 2018) and a wide range of settings, smart devices include sensors, networks, computations, and actuators that make people and things easier to interact (Atzori et al., 2010; Birkel & Hartmann, 2019; Borgia, 2014; De Vass et al., 2018, 2021a, 2021b; Mishra et al., 2016; Whitmore et al., 2015). In IoT-based services and products, a variety of IoT forms are used in an extensive manner such as wireless sensor networks (WSN), radio frequency identification (RFID) tags, sensors, handheld devices, cloud computing, middleware, and IoT application software developing telematics systems for the tracking of vehicles, medical devices, actuators, drones, machines, smartphones, etc.(I. Lee & Lee, 2015; Mishra et al., 2016).

IoT has become such a versatile tool in the 21st century that organizations are adopting it as a platform in a massive way. The IoT is not the only buzzword for business; it creates trends, gives you a sense of direction, and offers a good planning approach. (Ghazal et al., 2021; K. Lee et al., 2022; Tang et al., 2018). Through internet connectivity, ordinary things are "digitally upgraded," adding new functionality (Mattern & Floerkemeier, 2010). Due to their ubiquity, intelligence, and autonomy, IoT capabilities may be different from earlier ICT capabilities (Constantinides et al., 2017). In the business management area, IoT is employed to simplify the new modern needs of such organizations (Madakam et al., 2015; Shafique et al., 2018). Recent research has focused on the relationship between the circular economy (CE) and the IoT, but there is limited research on how IoT can directly benefit the CE (Ding et al., 2023; Jauhar et al., 2023; Sun & Wang, 2022). Jauhar et al. (2023) study focuses on the prevalent utilization of IoT in internet traceability, e-commerce, digitalization in the supply chain, the impact of information technology on the CE, and improving supply chain performance. The integration of cutting-edge information technologies, such as the IoT, offers growth prospects for industries and has the potential to generate sustainable results (Bressanelli et al., 2018). A wide range of IoT applications fall under the supply chain management umbrella, which includes checking and tracking products, managing inventories, enlisting buyers and suppliers, and reducing both mishandling and theft. (Shafique et al., 2018). As a consequence of globalization and the escalating utilization of internet applications, the integration of supply chain activities through the internet has become an increasingly crucial component of the supply chain management process (Flynn et al., 2010; Liu et al., 2013). Agrawal et al. (2022) found that digitalization can support the creation of sustainable circular products and improve the implementation of the CE concept. The paper explores how firms can improve their supply chain performance by adopting digitalization, including IoT, and sustainable CE practices. IoT is thought to promote SC and company performance by improving supply chain integration (SCI) (De Vass et al., 2018). The implementation of the IoT is, however, hampered by social and technological issues (Haddud et al., 2017; Mishra et al., 2016). To the best of the author's knowledge, there is a limited body of empirical research exploring IoT adoption within the supply chain, as the majority of studies in this area tend to be theoretical in nature (De Lima & Seuring, 2023; Attaran, 2020).

The connections among a sustainable CE, IoT capabilities, and supply chain performance are crucial elements for the future of sustainable and efficient contemporary business practices(Ding et al., 2023). A sustainable CE focuses on reducing waste and optimizing the utilization of resources. The IoT played a crucial role by offering real-time data and connectivity throughout the supply chain, encompassing both demand and supply aspects (Sun & Wang, 2022). This integration improved the ability to see, understand, and optimize the use of resources and procedures. The use of IoT sensors and devices allowed for the gathering of important data across the supply chain, which helped in making well-informed decisions. The IoT enhanced supply chain performance by improving production, distribution, and consumption processes (Sun & Wang, 2022). A firm's performance is not only determined by its efficiency but also by its operation or capability. It is not these circumstances that determine the performance of a firm (Abedin et al., 2015). IoT capabilities are those that a supply chain possesses as a result of everyday objects becoming connected to technology and using the internet to communicate with other objects and services. IoT capacity is a crucial component of contemporary businesses and is used to connect within and between them as well as send information in a more sophisticated manner (Flynn et al., 2016). The aforementioned criteria can thus be used to demonstrate the significance of IoT. It is essential for any firm seeking to perform better to adopt and use IoT properly. Supply chain integration can be enhanced with IoT capabilities (demand-side and supply-side integration) of any firm and this amalgamation enables an organization to improve its performance, sustainable CE and henceforth, increase profits. The use of IoT is increasing gradually in the whole world but in Jordan, its popularity is relatively low. The purpose of this study is to investigate the usage of IoT capabilities along with two mediators, namely Internet-enabled supply process integration and Internet-enabled demand process integration, whose outcome variable will be supply chain performance in Jordanian supply businesses.

Therefore, the primary viewpoint is observed via the framework of a circular economy. An important factor to take into account is the impact of IoT capabilities on improving supply chain performance. It involves understanding the impact of IoT capabilities on the integration of demand and supply processes facilitated by the Internet. This study fills a gap of a theoretical framework for CE by utilizing the Resource-Based View (RBV) perspective. More precisely, it examines how the unique resources and talents of a company affect the effectiveness of its supply chain. From an RBV perspective, CE would involve identifying internal resources within an organization that can facilitate the implementation of circular strategies throughout their supply chains. These resources can include input materials, parts, finished goods/services, machinery, facilities, and infrastructure, which are all considered RBV resources (Nandi et al., 2021; Saqib and Zhang, 2021). Organizational competencies encompass the understanding, technology resources, expertise, and effectiveness of business processes associated with the planning, leading, coordinating, and managing of CE practices. For instance, having a collection of technological resources such as the IoT can be integrated with supply chain to operate sustainable operations based on Industry 4.0 can be considered as strategic resource combinations to gain a competitive advantage (D'Adamo et., 2024; Nandi et al., 2021).

In addition, the study employed the dynamic capabilities theory, which provides insights into how companies may adapt to a changing environment and sustain their competitive edge (Floyd et., 2024; Jum'a et al., 2023). The implementation of CE presents various problems such as elevated levels of uncertainty, decreased production efficiency, surplus stocks, intricate material management, and sophisticated data handling (Chari et al., 2022). Within the framework of CE, the theory posits that companies must consistently engage in innovation and enhance their operational methods to enhance supply chain performance. This enables enterprises to effectively address uncertainties and embrace circular practices. This study examines the impact of dynamic capabilities of the IoT on firms' ability to efficiently manage and adapt their technology resources and integrate demand and supply processes in response to market changes. The findings provide valuable insights for firms seeking to enhance their supply chain performance and competitiveness (Chari et al., 2022; (Jum'a et al., 2023).

This paper consists of several sections. A literature review was conducted using the most relevant studies related to the study's purpose. In the following section, this study presents a conceptual model and the hypothesis. We then discuss the methodology in detail. Section 4 describes the findings and discussion of the study. We discuss the implications, conclusions, and limitations of the study in the last section.

2. Literature review

2.1 IoT & Supply chain

Supply chain management is now a complex issue, and several intrinsic and extrinsic factors are influential on this issue selecting all these dormant variables is also impossible. In the past few decades, companies have turned their capabilities into competitive advantages due to the development of information technology (IT) (Jum'a & Kilani, 2022; Tang et al., 2018). Industry 4.0 suggests that advanced technologies like the IoT will expand. The adoption of IoT in the CE is still at an early stage, despite its significant potential (Jauhar et al., 2023; Sun & Wang, 2022). IoT technology is changing corporate environmental practices and business models in response to increasing environmental concerns. Studies examined the role of IoT technology for sustainable CE practices and its effects on economic and environmental performance, which subsequently affect supply chain performance (Agrawal et al., 2022; Sun & Wang, 2022). The intense rivalry that exists now among businesses is a result of the demands of rapidly evolving technologies and global concerns (K. Lee et al., 2022). Manufacturing is portrayed as having to move resources, introduce more complicated payment systems, and reduce product life cycles to meet the pressure of technological advancements and international challenges (Caputo et al., 2016; Jum'a et al., 2022). Therefore, better technological integration is needed to satisfy more sophisticated client needs. To compete in the business world's competitiveness, organizations must develop innovative tactics. Information technology was viewed as providing a competitive edge, thus some businesses employ it to support their strategy (Jum'a et al., 2022).

As recognized as one of the most significant technologies on the "World Economic Forum agenda for 2016", the IoT is gaining in popularity (Ben-Daya et al., 2019). Over the Internet, the IoT connects gadgets and things (De Vass et al., 2018). It combines the physical and digital worlds by combining intelligent devices worldwide (De Vass et al., 2021b). To bridge the virtual and physical worlds, there are multiple IoT technologies that work together in an innovative alliance (Balaji & Roy, 2017). An integrated approach combining rough set theory and decision-making trial and evaluation laboratory (DEMATEL), rough strength relation analysis (RSRA), was used to identify and investigate drivers of IoT adoption in SCM (Ali et al., 2023). The broad literature study on IoT and SCM studies found 14 drivers, which were examined to find the most important drivers. The findings may assist supply chain practitioners deploy IoT to address post-pandemic disruptions, hazards, and vulnerabilities (Ali et al., 2023). Moreover, supply chain management experts suggest it could enable machine-based decision-making with minimal human involvement (Zhou et al., 2015). Global supply chain networks benefit from a new worldwide internet-based information service structure that facilitates the exchange of goods and services and foster IoT applications towards sustainable CE (Acerbi et al., 2021; Ding et al., 2023; I. Lee & Lee, 2015). The logistics sector has been greatly influenced by the IoT, leading to its transformation into an intelligent service provider. The study demonstrates a robust positive association between the efficiency of logistics and the size of the IoT market. Furthermore, there is a growing tendency for the development of the IoT industry and a decrease in carbon emissions. Environmental legislation indirectly fosters sustainability by stimulating technological innovation (Ding et al., 2023).

This study coincides with two major downstream and upstream factors namely internet-enabled supply and demand processes as mediation variables for assessing the supply chain performance. Moreover, another study conducted a science mapping review of IoT applications in industrial management, identifying research topics and gaps through scientometric analysis of articles (Mu & Antwi-Afari, 2024). While it offers a comprehensive overview, it lacks empirical testing of IoT's impact on supply chain performance as in this study. In contrast, this study focuses on empirically testing the impact of IoT on supply chain performance within Jordanian manufacturing firms. It provides insights into the mediating role of interconnected systems in supply and demand dynamics, offering practical implications.

A summary of prior studies on this topic is presented in Table 1, which summarizes studies on supply chain performance under internet-enabled supply and demand process integration.

Table 1. An overview of IoT and supply chain integration studies

Author(s)	Independent variable	Dependent variable	Mediator/ Moderator	Major Findings
(De Vass et al., 2018)	IoT capability, Internal integration, Supplier integration, Customer integration,	Supply chain performance, Organisational performance		Based on the empirical findings of this research, IoT-enabled integration is observed to enhance both supply chain performance and overall organizational performance.Integration-related aspects such as suppliers, internal processes, and customers are all significantly impacted by the adoption of the IoT.
(K. Lee et al., 2022)	Benefits of IoT adoption, Challenges of IoT adoption	Organizational performance	Supply chain performance	The study's findings supported six of seven hypotheses examined. It was concluded in the study that adoption of IoT in Malaysian manufacturing companies will improve their supply chain performance, which will further contribute to their success as an organization.
(Shafique et al., 2018)	IoT capability	Green supply chain performance, energy consumption behaviour, green training	Supplier integration, and customer integration	Based on the results of the study, the impact of IoT on the green supply chain performance of supply chains is significant, both in terms of supply chain integration and consumer integration. Furthermore, customers and supply chain integration played a significant role in mediating the relationship between IoT and green supply chain performance.
(Saengchai & Jermsittipa rsert, 2019)	IoT capability	Sustainability performance	Supplier integration, Internal integration, Customer integration	The study demonstrates that IoT capabilities can improve companies' sustainability performance. The three mediators—supplier integration, internal integration, and customer integration—were shown to play a major role in mediating IoT capabilities and sustainability performance.
(Abbass & Mehmood, 2020)	IoT capability	Cost leadership policy formation & Differential policy formation	Marketing intelligence capability	Both cost leadership policy formation and differentiation policy formation were positively influenced by IoT capability and marketing intelligence capability.
(W. W. H. Weng, 2020)	IoT capability	Cost leadership strategy formation & Differential strategy formation with control		IoT capability had a positive impact on both cost leadership strategy and differential strategy leadership but no control variable's impact was observed.

		variables- types of firms, firm size and IT size		
(W. Weng, 2020)	IoT capability	Marketing intelligence capability with control variables- types of firms, firm size and IT size		IoT capability had a positive impact on marketing intelligence capability but no control variable's impact was observed.
(W.-H. Weng, 2020)	IoT capability	Business strategy performance (cost performance and differentiation performance under uncertainty) with control variables- types of firms, firm size and IT size	Marketing intelligence capability	Marketing intelligence played a partial role in mediating cost performance and differentiation performance under uncertainty using IoT capability.
Liu et al., (2015)	IT operational and transformational capability, Internet-enabled supply and demand process integration	Firm performance		A positive impact of IT organizational and transformational capability was seen on both demand-side and supply-side integration of firms' supply and demand processes.

2.2 Development of hypothesis and conceptual framework

2.2.1 Influence of Internet of Things capabilities

An organization's IoT capability is the ability to merge IoT resources and skills with its strategic direction as a whole. (Bharadwaj, 2000; W. W. H. Weng, 2020). With the capabilities of IoT, a corporation can leverage the aforementioned aspects of IoT for business value. By utilizing IoT, businesses may spot possible risks and new business possibilities while remaining competitive, making IoT a source of competitive advantage (X. Yu et al., 2016).

A sustainable CE and the IoT capabilities work together to create a symbiotic partnership that promotes operational efficiency and environmental responsibility (Sun & Wang, 2022). Reduced waste and continuous resource usage are key components of a sustainable circular economy, which also aims to minimize environmental impact and promote lifespan (Vegter et al., 2023; Agyabeng-Mensah et al., 2023; Elia et al., 2019). Throughout the whole product lifecycle, IoT capabilities play a critical role by offering real-time monitoring, data analytics, and connectivity. IoT makes it possible to track and manage resources, which improves decision-making and streamlines procedures. IoT promotes sustainable behaviors, waste reduction, and resource efficiency through sensors, smart devices, and data analytics(Agrawal et al., 2022; Sassanelli et al., 2022). With IoT-enabled capabilities, companies can develop or use IoT-integrated products and environments for business advantages, and produce or use IoT-connected products for business benefits (Porter & Heppelmann, 2014; W.-H. Weng, 2020). IoT capacities are a crucial component of contemporary businesses and are used to connect within and between them as well as send information in a more sophisticated manner. The aforementioned criteria can thus be used to demonstrate the significance of IoT. IoT must be adopted and used efficiently if any firm is to increase performance (Saengchai & Jermsittiparsert, 2019). With IoT, the information gap in existing supply chains can be bridged to the extent that data can be captured, transferred, processed, and acted upon in real-time among supply chain organizations, processes, equipment, and people (Ben-Daya et al., 2019; Borgia, 2014; W. W. H. Weng, 2020). According to the literature, IoT can help with real-time data acquisition, increasing communication and integration between and inside firms (Yan et al., 2014). In light of this evidence this study postulated three hypotheses below:

Hypothesis H1. IoT capabilities positively influences internet-enabled supply process integration.

Hypothesis H2. IoT capabilities positively influences internet-enabled demand process integration.

Hypothesis H3. IoT capabilities positively influences supply chain performance.

2.2.2 Influence of internet-enabled supply and demand process integration.

Demand- and supply-side integration enabled by the Internet is the strategic engagement of a company with its channel partners on demand, respectively, and supply processes, respectively, via the Internet (Devaraj et al., 2007; Esper et al., 2010). It has been observed that both processes can increase organizational capability to a higher level (Devaraj et al., 2007; Flynn et al., 2010). A supply-side process is responsible for supporting and delivering products and services, including incoming and outgoing logistics, within and outside the company. (Esper et al., 2010; Flynn et al., 2010). Taking advantage of this integration will improve the likelihood that top partners will anticipate and materialize under the firm's wing (Flynn et al., 2010). Business performance can be improved by reducing out-of-stock products, reducing expedite costs, and increasing responsiveness (Liu et al., 2015). Supply process integration further reduces friction and disputes among firms (Jum’a et al., 2022; Osmonbekov et al., 2009). Therefore, it can facilitate supply chain coordination by integrating complementary resources from upstream and downstream companies. Hence, this study postulates the hypotheses below:

Hypothesis H4. Internet-enabled supply process integration positively influences supply chain performance.

During demand generation and sustainment processes, such as marketing, sales, and customer relationship management, companies generate and sustain demand both inside and outside the company (Liu et al., 2015). This integration can enlarge any organizational performance (Flynn et al., 2010; Osmonbekov et al., 2009; Rollins et al., 2012) through using the internet or IoT having real timing, amount, and content discussion with partners. The overall scenario of the demand process and the needs of customers will be visible through demand-side integration. Moreover, this doesn’t acknowledge with present conditions of the firm but also assists in better organizing and increases mutual dependency through better efficient and effective performance (Osmonbekov et al., 2009; Rollins et al., 2012). Including these statements, this study assumes this hypothesis as below:

Hypothesis H5. Internet-enabled demand process integration positively influences supply chain performance.

2.2.3 Mediating role of internet-enabled supply and demand process integration

As both demand and supply side processes are the differential part of integrating supply chain mechanisms and pointing out above the evidence, this study has attempted to use both as mediating roles between IoT capabilities and the supply chain performance of the firm. Additionally, to know about the dimensions of both processes simultaneously, it's also important to understand how a supply chain mechanism operates (Flynn et al., 2010; Jum'a & Kilani, 2022). This study aims to investigate how IT competence affects business performance by enabling the integration of supply and demand processes that are supported by the Internet. So, for this, two mediating roles are assumed as below:

Hypothesis H6a. Internet-enabled supply process integration mediates the relationship between IoT capabilities and supply chain performance.

Hypothesis H6b. Internet-enabled demand process integration mediates the relationship between IoT capabilities and supply chain performance.

This study's proposed research model is shown in figure 1:

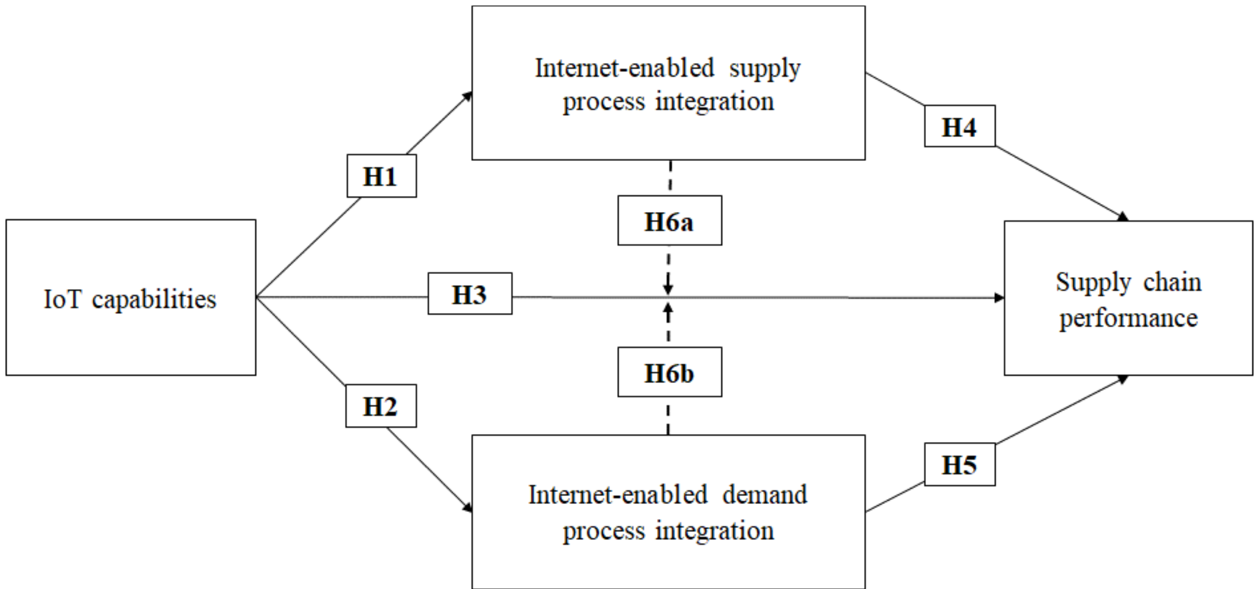

Figure 1. Conceptual framework

3. Methodology

3.1 Sampling procedure

The manufacturing industry in Jordan is relatively small in size but exhibits a wide range of industries. It contributes to almost 25% of the country's Gross Domestic Product (GDP) and plays a significant role in fostering economic growth and progress (Jum'a & Bushnaq, 2023). Jordan, as a developing country, holds considerable importance and relevance for a multitude of reasons. Jordan serves as a prominent business center in the Middle East, with a wide range of supply chain management (SCM) and sustainability professionals (Abushaikha et al., 2023). Moreover, examining local obstacles and prospects, such as legislative frameworks and industry dynamics, can offer useful understanding of the intricacies of the circular economy. For instance, the recently approved National Waste Management Strategy of Jordan is advocating for the implementation and improvement of circular economy principles in the solid waste industry. One of the main goals of the approach is to incrementally increase fees and improve the reutilization, recovery, and recycling of materials from the solid waste stream (Abu-Qdais et al., 2023). By

2034, the intention is to divert 50% of recyclable materials such as paper, metal, plastic, and glass, as well as 75% of bio-waste from landfills to recycling and composting facilities (Abu-Qdais et al., 2023). Although the study is examining Jordan as a developing nation provides a more comprehensive and detailed analysis, it may restrict the applicability of the results to other countries. By acknowledging these constraints, researchers can provide targeted suggestions that take into account the wider ramifications of IoT capabilities beyond the context of Jordan.

Therefore, participants in the study were managers working at various levels in Jordanian manufacturing firms. A majority of the companies were located in Amman, the capital and largest city of Jordan. The convenience sampling procedure makes data collection simple and cost-effective was adopted. In spite of the fact that convenience sampling may be classified as a non-probability sampling technique, it can also be used to estimate population parameters (Malhotra, 2010). Using partial least square structural equation modelling (PLS-SEM), Hair et al. (2019) recommended using at least 100 samples. A structured questionnaire was distributed to the participants online using email and social media. 550 questionnaires were distributed, with 268 of them being received and useable from the participants during July to September 2022, reflecting a 48.7 percent response rate. These data were employed for statistical data analysis to test the model proposed in the literature review.

3.2 Measurement items

A validated measurement item for the study variables was derived from previous studies.

The items of IoT capabilities in the study by De Vass et al. (2018) were constructed based on their functionality published in academic literature and consultancy documents from DHL firm. The items have been adapted with consideration for the core capabilities of the Internet of Things, including identification, monitoring, measurement, control, automation, analysis, sharing of information, and collaboration. Executive interviews from various manufacturing companies were used to validate the items developed for internet-enabled supply/demand process integration. The firm's integration of supply side processes such as exchanging information about inventory status and planned orders, collaborating on joint plans regarding inventory requirements, and coordinating online procurement with channel partners was specifically tested on four items related to internet-enabled supply process integration. The firm's integration of various demand side processes, including joint development of demand forecasts, joint plans for service support, joint plans for the introduction of new products/services and rollover via the internet with channel partners, was measured by four items about internet-enabled demand process integration.

Therefore, IoT capabilities related items were adopted by (De Vass et al., 2018). We adopted items of integration of internet-enabled supply chains and integration of internet-enabled demand chains from (Liu et al., 2015). In addition, we adopted items related to supply chain performance from (De Vass et al., 2018). Table 2 shows that the questionnaire was divided into two sections, one of which contained demographic information. Measuring items related to the study variables were contained in the second part. A 5-point Likert scale was used to measure the scale items. I strongly disagreed with (1), strongly agree with (5).

Table 2. Constructs and measurement items

Constructs	Measurement items
IoT capabilities	In our supply chain, IoT provides the following capabilities: • Facilitating the identification of individual items. • Providing identification at the unit level (e.g., containers, boxes, pallets). • Enabling tracking, monitoring, and tracing of entities and individuals in the supply chain through automated data capture. • Permitting the quantification of supply chain processes, activities, and environmental conditions. • Supporting a remote-control system for supply chain processes. • Allowing for autonomous decision-making within supply chains.

	• Optimizing supply chain activities through the provision of real-time information. • Assisting supply chain operations by delivering real-time intelligence. • Supplying a vast and varied quantity of data for tactical and strategic decision-making via data analytics. • Reinforcing the exchange of information within and between organizations. • Facilitating decision-making within and between entities in the supply chain. • Strengthening communication among operators. • Enhancing coordination between operators.
Internet-enabled supply process integration	• We disseminate inventory level data to our principal channel partner through online platforms. • We transmit our planned order information to our vital channel partner via web-based communication. • Together with our key partners, we form joint strategies concerning inventory requirements using online tools. • We coordinate procurement activities with our important partners through online platforms (for instance, placing and tracking orders with suppliers online and enabling suppliers to bid online).
Internet-enabled demand process integration	• We collaborate with our essential partners to formulate joint demand forecasts using digital means. • We and our significant partners craft joint strategies on introducing and rolling over new products/services through the Internet. • We collaborate with our central partners to devise joint service support strategies online. • We manage the introduction of new products/services with our key partners using digital communication platforms.
Supply chain performance	The supply chain processes we developed have allowed us to: • Enhance the quality of the product. • Improve the reliability of supply chain deliveries. • Improve the fill rate. • Ensure perfect order fulfilment. • Make sure deliveries are error-free. • Improving supply chain flexibility (reacting to changes in product volume, mix, and price). • Reducing the cycle time from cash to cash. • Cost reduction in the supply chain management process. • Lower the cost of goods sold. • Enhance employee productivity (value-added).

3.3 Profile of the respondents

Table 3 presents the respondents' profiles and showed that there were 92.2% male and 7.8% female participants. The highest participation was received from the age group between 31 and 40 years (46.3%). The majority of the participants had years of experience from 5 to 10 years (39.6%). 81.3% of the respondents had a bachelor's degree. 72.4% of responses were received from the first-line managers. Finally, the majority of the participants' firms were mid-sized with employees ranging from 20 to 99 (60.1%).

Table 3. The respondents' demographic profiles

Variables	**Categories**	**N**	**%**
Gender	Male	247	92.2
	Female	21	7.8
Age	20 – 30 years	70	26.1
	30 – 40 years	124	46.3
	40 – 50 years	45	16.8
	Above 50 year	29	10.8
Years of experience	Less than 5 Years	73	27.2
	5-10 Years	106	39.6
	More than 10 Years	89	33.2
Education level	Diploma degree	8	3.0
	Undergraduates	218	81.3
	Graduates & post-graduates	42	15.7
Managerial position	First line managers	194	72.4
	Middle managers	47	17.5
	Top managers	27	10.1
Employees	Less than 20	21	7.8
	20 - 99	161	60.1
	100 and more	86	32.1

4. Results

This section presents the analysis and findings of the data. A SPSS 25 version and a SmartPLS version were used to analyze the data. In this section, descriptive statistics are presented first, followed by multicollinearity. Thereafter, the results of SEM were presented in two parts: measurement model and structural model. We conclude this section with a description of the hypotheses testing results.

4.1 Descriptive analysis

The descriptive statistics are presented in Table 4 and include mean, standard deviation, skewness, kurtosis, and standard error. Results showed that IoT capabilities scored the highest (M = 3.93, SD = 0.992). While internet-enabled demand process integration had the lowest mean value (M =3.54, SD =1.024) among the other constructs.

Table 4. Descriptive statistics (N =268)

Latent variables	Mean	Std. Deviation	Skewness	Std. Error	Kurtosis	Std. Error
IoT capabilities	3.93	.992	-1.902	.149	2.376	.297
Internet-enabled supply process integration	3.74	.933	-1.553	.149	2.181	.297
Internet-enabled demand process integration	3.54	1.024	.294	.149	-1.133	.297
Supply chain performance	3.75	.969	-1.623	.149	2.021	.297

4.2 Test of multicollinearity

The multicollinearity problem may restrict the predictability of the results obtained from the multivariate analysis. Thereby, values of tolerance and variance inflation factor (VIF) were used to detect the presence of such problem. As shown in Table 5, the results showed that all the values of tolerance were above 0.10 and VIF were less than 3 which falls within the recommended threshold (Hair et al., 2019).

Table 5. Collinearity statistics

Independent variables	Collinearity Statistics	
	Tolerance	**VIF**
IoT capabilities	.789	1.268
Internet-enabled supply process integration	.752	1.330
Internet-enabled demand process integration	.933	1.072

4.3 Structural equation modelling

Many researchers and practitioners are better acquainted with CB-SEM than PLS-SEM, therefore they need to provide a rationale for selecting PLS-SEM over CB-SEM. According to (Hair et al., 2019), researchers need to select either CB-SEM or PLS-SEM based on their study goals. This study centers on the selection of PLS-SEM instead of CB-SEM for certain reasons. The existing data do not adhere to ideal normal distributions sou unlike CB-SEM, PLS-SEM operates under a distribution-free assumption (Hair et al., 2019). PLS-SEM outperforms CB-SEM when dealing with complicated models, and small sample sizes(Agyabeng-Mensah et al., 2023). PLS-SEM is the recommended method for predicting endogenous latent variables in line with the research objectives. This study use PLS-SEM for data analysis and hypothesis testing. The adoption of PLS-SEM in this study is mostly owing to the causal-predictive and reflective characteristics of the research model being investigated. PLS-SEM has garnered significant interest from supply chain scholars in recent years (Agyabeng-Mensah et al., 2023). According to this review, PLS-SEM seems to be the suitable method for this research. Therefore, a partial least squares approach was used for SEM. An analysis of measurement models and a structural model analysis were conducted in two phases of the SEM. We used the SmartPLS version 3 software program (Ringle et al., 2015) to estimate both models.

4.3.1 Measurement model analysis

Both discriminant validity and convergent validity were evaluated in the measurement model analysis. Convergent validity was assessed using average variance extracted (AVE) and factor loadings. As shown in Table 6, the results showed that all the values of factor loadings were above 0.70 and all AVE values were higher than 0.50 and thus acceptable standard of convergent validity (Hair et al., 2019). According to the benchmark, Cronbach's alpha and composite reliability should be above 0.70 to ensure that the constructs were highly reliable. Thereby, the results indicated that all the latent variables exposed sufficient reliability and validity. Overall, the model depicted as illustrated in Figure 2.

Table 6. Construct reliability and validity

Constructs	Items	Factor loadings	Cronbach's alpha	Composite reliability	AVE
IoT capabilities	IoT.cap1	0.913	0.982	0.983	0.821
	IoT.cap2	0.917			
	IoT.cap3	0.908			
	IoT.cap.4	0.935			
	IoT.cap5	0.912			
	IoT.cap6	0.907			
	IoT.cap7	0.910			
	IoT.cap8	0.887			
	IoT.cap9	0.888			
	IoT.cap10	0.923			
	IoT.cap11	0.901			
	IoT.cap12	0.906			
	IoT.cap13	0.868			
Internet-enabled supply process integration	SPI.1	0.950	0.945	0.961	0.860
	SPI.2	0.890			
	SPI.3	0.923			
	SPI.4	0.945			
Internet-enabled demand process integration	DPI.1	0.966	0.961	0.971	0.893
	DPI.2	0.966			
	DPI.3	0.926			
	DPI.4	0.922			
Supply chain performance	SCP.1	0.933	0.981	0.984	0.857
	SCP.2	0.926			
	SCP.3	0.927			
	SCP.4	0.954			
	SCP.5	0.938			
	SCP.6	0.909			
	SCP.7	0.936			
	SCP.8	0.918			
	SCP.9	0.907			
	SCP.10	0.907			

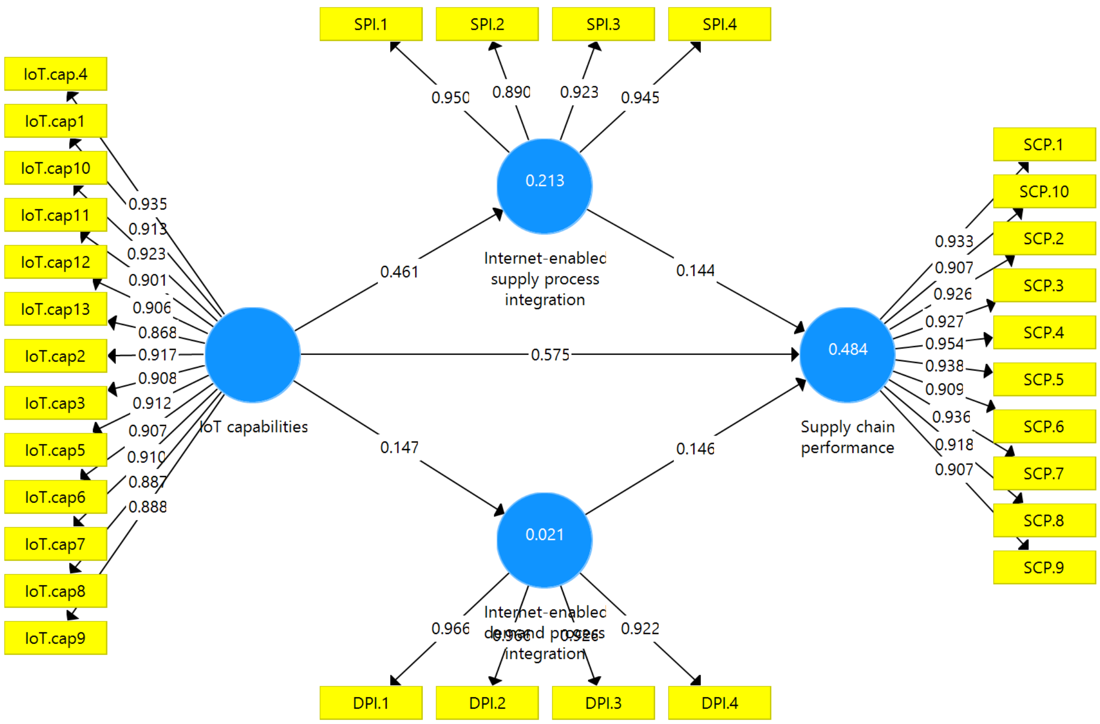

Figure 2. Measurement model diagram

Discriminant validity assessment was done by following the guidelines of (Fornell & Larcker, 1981). The criterion is that inter-construct correlations should be less than the square root of AVE of a particular construct. The diagonal elements shown in Table 7 represented the square root of AVE which were higher than the correlation coefficients represented by off-diagonal elements.

Table 7. Discriminant validity

Latent variables	1.	2.	3.	4.
1. Internet-enabled demand process integration	0.945			
2. Internet-enabled supply process integration	0.265	0.927		
3. IoT capabilities	0.147	0.461	0.906	
4. Supply chain performance	0.268	0.448	0.662	0.925

4.3.2 Structural model analysis

The structural model analysis started with a model estimation which was performed by a sub-sample of 1000. The key results from model estimation were shown in Table 8 including paths, beta, t statistics and p values. The r square values and model fit indices were also calculated for a better representation of the model scenario. Supply chain performance had the r square value of 0.484 indicating that a 48.4% variation in supply chain performance was explained by the model. Moreover, model fitness measures such as χ^2, GFI, CFI, and RMSEA are not applicable for PLS-SEM (Hair et al., 2019), rather values of SRMR and NFI which can be obtained from SmartPLS software were used. The results showed that the SRMR value was 0.05 which was less than 0.09 but the NFI value was 0.721 which was not equal to or more than 0.90 (Byrne, 2013).

Table 8. Results of the structural model

Paths	Beta	T Statistics	P Values	Results
H1. IoT capabilities → Internet-enabled supply process integration	0.461	6.124	0.000	Supported
H2. IoT capabilities → Internet-enabled demand process integration	0.147	2.537	0.011	Supported
H3. IoT capabilities → Supply chain performance	0.575	7.800	0.000	Supported
H4. Internet-enabled supply process integration → Supply chain performance	0.144	2.255	0.024	Supported
H5. Internet-enabled demand process integration → Supply chain performance	0.146	3.333	0.001	Supported
Effects of mediation				
H6a. IoT capabilities → Internet-enabled supply process integration → Supply chain performance	0.066	1.963	0.050	Supported
H6b. IoT capabilities → Internet-enabled demand process integration → Supply chain performance	0.021	2.195	0.028	Supported

The results of hypotheses testing showed that all the estimated paths were statistically significant and positive. Among the path coefficients, IoT capabilities had the largest value and thus, effects on supply chain performance (beta = 0.575, $p < 0.000$). The result indicated that if IoT capabilities are increased by 1 unit, supply chain performance will be increased by 0.575 units, considering other effects as constant. The relationship between IoT capabilities and supply chain performance was found to be notably influenced by the mediating effects of both internet-enabled supply process integration and demand process integration. Since the direct effect of IoT capabilities on supply chain performance was also observed to be significant, the mediators in this study were classified as partial mediators.

5. Discussion

Companies in the supply chain sector are readily integrating IoT into their processes. This incorporation represents a novel and seamless shift. Not only does it offer insights into raw materials and parts, but it also generates real-time maintenance data, manages inventory, facilitates information sharing, and enables joint ordering. Its increasing accessibility and acceptance across diverse scenarios (De Vass et al., 2018), further enhances operational efficiency and revenue maximization by monitoring quality, managing quality-controlled logistics, bolstering reverse logistics, and collecting product usage data. This study put forth five hypotheses, mediated by two factors, for examination within Jordanian manufacturing firms. The outcomes for all variables were positive, significant, and definitive.

The study presents novel findings regarding the seamless integration of IoT technologies into supply chain processes, particularly within Jordanian manufacturing firms. Contrary to previous work, which primarily focused on the potential benefits of IoT only, this paper introduces a framework that highlights the role of internet-enabled demand and supply processes along with IoT capabilities in enahncing supply chain performance. The findings reveal several significant contributions to the existing literature, including the positive impact of IoT capabilities on supply process integration, the enhancement of demand process integration, and the improvement of overall supply chain performance. Additionally, the study underscores the mediating role of internet-enabled processes in facilitating the relationship between IoT capabilities and supply chain performance. Moreover, it highlights how IoT technologies contribute to the adoption and enhancement of sustainable circular economy practices within supply chain operations.

In the circular economy context, the IoT affects supply chain performance. The IoT improves resource allocation, reduces inactivity, and simplifies transit routes by monitoring and tracking in real time (Khan et al., 2023). These optimizations reduce costs and boost operational efficiency, aligning with the circular economy's focus on resource value and waste reduction (Saqib et al., 2023; Tan & Sidhu, 2022). By improving visibility and transparency throughout the supply chain, IoT helps ensure sustainability compliance. Increased transparency helps track product paths, improving end-of-life management (Birkel & Hartmann, 2020). The IoT allows precise monitoring of materials and products, which is essential for circular economy methods like remanufacturing, refurbishment, and recycling. Whereas, circular manufacturing (CM) stands out as a key solution for sustainable manufacturing, embodying the principles of the circular economy (CE) within the manufacturing sector. CM focuses on extending the lifecycle of products, minimizing resource consumption, and establishing a closed-loop system for resources (Acerbi et al., 2024) .This encourages resource conservation and sustainability (Birkel & Hartmann, 2020). IoT's predictive maintenance improves the circular economy by proactively fixing equipment. Real-time sensor data predicts maintenance needs before failures, reducing inactivity, asset lifespan, and resource usage (Khan et al., 2023). This proactive strategy demonstrates the circular economy's goal of maximizing product usefulness and minimizing resource waste. This makes the supply chain more resilient and sustainable (Tan & Sidhu, 2022). The sustainability cycle relies on IoT's reverse logistics capabilities. The IoT provides real-time insights on returned products and resources, simplifying reverse logistics, lowering shipping costs, and improving recycling (Birkel & Hartmann, 2020). The closed-loop strategy promotes resource conservation and supply chain value in the circular economy (Tan & Sidhu, 2022).

Firstly, the impact of IoT capabilities on internet-enabled supply process integration and it comes positive and significant. Studies insight similar output resemblance of this (Li et al., 2009; Osmonbekov et al., 2009). IoT capabilities like as operational, organizational and transformational capabilities can enhance internet-enabled supply processes through several pathways such as revealing genuine data and information on supply chain-related issues, integrating separated data sources and updating with current infrastructural conditions (Devaraj et al., 2007; Li et al., 2009; Osmonbekov et al., 2009). Reliable and continuous IoT capabilities also assist businesses in overcoming technological hurdles associated with internet deployment, which ultimately makes it possible to integrate the internet into supply and demand operations.

Second, internet-enabled demand processes integrate well with IoT capabilities and produce positive outcomes. Similar results have been reported in several articles (De Vass et al., 2018; Liu et al., 2015). The IoT facilitates the flow of data that controls supply and demand processes at a business management level, including demand projections, manufacturing plans, delivery services, and inventory management (Li et al., 2009). Jabbour et al. (2020) argued that companies can overcome fragmentation in supply chains that prevent information flow and activity coordination by integrating supply and demand processes.

Thirdly, IoT capabilities on supply chain performance come statistically significant with a positive amount which is the same as concurrent studies (De Vass et al., 2018; Liu et al., 2015). Studies revealed that IoT makes the stronger overall performance of a firm in a supply chain web by integrating under the umbrella of the internet. (De Vass et al., 2018) claimed that Supply chain integration can be improved by synchronizing all information flow with physical flow through IoT to bridge the gap between physical and digital worlds. If the business is unable to invest in data storage, the supply chain will undoubtedly become chaotic (I. Lee & Lee, 2015). On the other hand, whether the business can profit from the use of IoT in the supply chain, IoT may enhance product monitoring and traceability, better inventory management, and control, and enhance operational efficiency (Alzoubi, 2021; Haddud et al., 2017).

Thus, IoT technologies, such as RFID tags and sensors, enable supply chain item identification, improving inventory visibility and reducing stockouts. They automate data capture for real-time tracking, monitoring, and tracing, enhancing inventory management, goods in transit visibility, and regulatory compliance. IoT sensors also allow firms to quantify and analyze supply chain processes, activities, and environmental conditions, enabling data-driven approaches to identify inefficiencies, optimize resource use, and mitigate risks. Real-time data from IoT systems provides insights for inventory, transportation, and production, enabling agile decision-making, proactive problem-solving, and dynamic resource allocation. IoT also enables remote supply chain management systems, allowing asset management, equipment maintenance, and transportation logistics to be monitored and controlled remotely. IoT-enabled systems can analyze massive amounts of data and execute predefined algorithms, improving agility, decision latency, and network performance. IoT also facilitates data-driven decision-making, risk mitigation, and performance improvement across the supply chain.

Fourth and fifth, the internet-driven demand and supply chain process has a statistically significant impact on supply chain performance. In several studies, internet-connected supply and demand processes were found to affect a firm's performance or performance of a supply chain

(Esper et al., 2010; Liu et al., 2015). Firms can better understand and anticipate their upstream partners' demands with Internet-enabled supply chain processes (Flynn et al., 2010). Supply processes, schedules, capacities, and activities can be communicated in real-time with upstream partners in most countries through the internet. This discussion improves comprehension of the ordering and shipping procedures, which can reduce the likelihood of logistical mistakes (Osmonbekov et al., 2009). Thus, businesses may efficiently lower the quantity of out-of-stock products, lower the cost of expediting and boost responsiveness, all of which would improve performance (K. Lee et al., 2022). Similarly, demand-process integration, it is facilitated by the internet may improve business performance by increasing the validity of demand information (Liu et al., 2015; Rollins et al., 2012). Using the internet to specify the time, volume, and content of downstream partners' operations can help businesses better understand demand processes and consumer demands (Osmonbekov et al., 2009). To strategically plan and coordinates company's actions with downstream partners, and monitoring collaborative efforts, businesses can use this demand-related information. (Rollins et al., 2012). Moreover, the current literature seldom explores the connection between IoT and CE. Ding et al. (2023) found that IoT capabilities such as monitoring, tracking, optimization, and design evolution enhance the performance of sustainable CE and supply chain operations.

Consequently, Internet-enabled supply process integration improves demand forecasting, reduces stockouts, and enhances order fulfillment by allowing real-time sharing of inventory data with channel partners online. This fosters trust and collaboration, enhancing supply chain operations and performance. Web-based communication channels facilitate efficient sharing of planned order information, aiding in shipment prediction, inventory planning, and order optimization. This enhances partner coordination, shortens lead times, and boosts supply chain performance. Online collaboration on inventory strategies increases resilience, responsiveness, and efficiency. Online platforms also simplify procurement processes, reducing communication costs and improving supplier relationships. Moreover, internet-enabled demand process integration enables businesses to collaborate digitally with key partners, improving demand forecasting accuracy and inventory optimization. This aligns demand and supply, reduces stockouts, and enhances supply chain performance. Digital platforms facilitate joint product launches, reducing risks and improving market responsiveness. Central partners can develop online service support strategies, enhancing service quality, customer loyalty, and competitiveness. Digital communication platforms facilitate efficient product introductions, reducing time-to-market risks and improving supply chain performance.

This study developed a framework in which mediating variables between IoT capabilities and supply chain performance were the internet-enabled demand process and the internet-enabled supply process. Both mediate positively and significantly under statistical evidence. As IoT capabilities are implemented to lower hurdles and rising overall performance and adoption of CE principles through the improvement and adoption IoT based technologies, the readiness of partners, the balance between suppliers and customers.

Finally, the paper emphasizes the importance of human resources in implementing and utilizing IoT technologies in supply chains. It highlights the need for skilled personnel to manage and interpret vast amounts of data generated by IoT sensors. Investing in human capital through training programs and talent acquisition is crucial for maximizing the benefits of IoT in supply chain management. Valuing human resources fosters innovation, adaptability, and continuous improvement, enhancing supply chain performance and competitiveness (Taddei et al., 2024). The paper also addresses sustainability challenges, including reducing dependence on imported raw materials. IoT technologies offer real-time monitoring, optimization, local sourcing, circular economy practices, and resource efficiency. However, the paper acknowledges complex challenges, such as supply chain disruptions, regulatory compliance, and stakeholder engagement (Taddei et al., 2024).

5.1 Managerial implications

This study offers an integrated model for manufacturing firms under Jordan on enabling factors of IoT capabilities towards supply chain performance through two drivers: internet-based demand process and supply process integration.

In the aftermath of the COVID-19 pandemic, there is a heightened focus on the strategic deployment of technology to enhance the management of global supply chains (Baldwin & Tomiura, 2020). Consequently, managers are confronted with the imperative to judiciously weigh the advantages of IoT-enabled digitalization against its inherent challenges. The findings provide managers with information on IoT capabilities as an extension of the well-established capability for supply chain integration through digital means. For instance, the use of palm-sized smart electronic devices helps with the automatic capture of more important logistics-related data, enabling managers to study the analytics of these data. Businesses increasingly see the importance of making decisions based on excellent data as data analytics gain popularity. Retail organizations will undoubtedly profit from the adoption and deployment of IoT in their day-to-day logistical operations.

The hindsight of this study is that managers need to expand IoT capabilities in addition to current ICT capabilities to gain a lasting competitive advantage. The findings imply that before pursuing demand or supply-oriented integration with their consumers or suppliers, retail managers must first build internal integration inside the internal operations. Supply chain performance is impacted more by IoT-enabled supply and demand integration than by IoT-enabled internal integration, contrary to popular belief (Ataseven & Nair, 2017; W. Yu, 2015). Due to the pervasiveness and omnipresence of IoT, it may be claimed that external integration provided by IoT is more significant for supply chain performance increases outside of company borders. Retail managers should extend their vision beyond just their running industry to embrace the entire supply chain, including suppliers and consumers. Additionally, they should think about connecting current IoT devices with vendors (like GPS) and consumers (like smartphones), combining all digital data into a single internet-based platform to share, talk, and analyze information from one another. This approach to a single supply chain system might result in larger gains for all partners, achieving the IoT platform's fundamental goal of creating a dynamic global network (Borgia, 2014). The IoT and the CE are two prominent topics that will greatly influence both business and society (Sun & Wang, 2022). This study was among the first to explore the potential of IoT capabilities in enhancing the IoT supply chain integration and ultimately supply chain performance and CE. Industrial case studies have reported the advantages of IoT for their supply chains and the sustainable CE (Sun & Wang, 2022). IoT can provide businesses with a transparent, decentralized, and secure transaction process, along with the possibility of improved efficiency and responsiveness. Ultimately, these characteristics will bring about beneficial effects on the economy, society, and the environment. In conclusion, managers should consider participants' point that reducing e-waste and minimizing the number of devices is important to reduce e-waste and enhance sustainability.

Thus, this paper underscores the significant contribution of IoT technologies in enhancing supply chain management. It emphasizes how IoT facilitates real-time tracking, monitoring, and tracing of products, leading to improved inventory visibility, reduced stockouts, and optimized resource utilization. Moreover, IoT enables remote supply chain management, autonomous decision-making, and seamless communication among supply chain partners. By leveraging IoT data and digital platforms, organizations can enhance collaboration, align strategies, and improve performance across various supply chain processes, from procurement to demand forecasting and customer service. Additionally, the integration of IoT with online platforms fosters trust, transparency, and efficiency, ultimately driving innovation, market responsiveness, and customer satisfaction while reducing costs and lead times.

5.2 Theoretical Implications

This study offers significant theoretical insights into the realm of Jordan's manufacturing sector, a Middle Eastern entity embracing IoT technologies within supply chain operations. Firstly, the research enhances the existing literature on IoT adoption, underlining the role of IoT capabilities in supply chain management. Secondly, it elucidates the influence of IoT capabilities on a firm's supply chain performance, incorporating two mediating variables - the internet-enabled demand and supply processes. This innovative and unique approach provides new insight into the relationships between these factors. Thirdly, the research investigates the impact of internet-facilitated integration of supply and demand processes on supply chain performance. It posits that the integration of internet-enabled demand and supply processes can directly influence business outcomes, thus enriching the operations management literature on the nexus between supply chain integration and corporate performance. Moreover, this research enriches the literature on IT business value and supply chain management from an industry perspective. Lastly, the study introduces an innovative aspect by linking IoT adoption and supply chain performance in the context of market-based analytics. Specifically, it underscores the adoption of integrated demand

and supply approaches, positing that such integration can enhance organizational productivity in a smooth, continuous, and accelerated manner.

Despite the potential of IoT to fortify both internal and external integrations of a supply chain (De Vass et al., 2018), previous work did not thoroughly examine its additional capabilities such as visibility, automatic data capture, business intelligence, and enhanced communication. Moreover, this study provides a deeper understanding of how firms employ IoT to capture and scrutinize data pertaining to the movement of goods.

6. Conclusion

The purpose of this study was to integrate IoT capabilities through two discussed topics: internet-enabled supply chain processes and their impact on supply chain performance in manufacturing firms. In addition to strengthening the overall connection between supplier and customer, IoT capabilities can also be used to reduce the obstacles associated with extra transportation costs, communication costs, or conventional strategies to analyze production and supply chains with real-time-based technology. IoT capability can be used to develop the supply chain amalgamation of any firm and this incorporation helps firms to improve their performances and increase revenues. While certain academics have interpreted the integration of IoT within supply chain operations as somewhat hyperbolic, this study proposes that the strategic adoption of IoT can bolster supply chain process integration, subsequently improving overall supply chain performance. Both demand and supply mechanisms, conducted via internet-enabled platforms, can now assess the advantages and disadvantages of comprehensive marketing conditions. This enhanced visibility can assist decision-making teams in responding to the prevailing situations.

This research holds uniqueness in its inclusion of thirteen distinct IoT capabilities that Jordanian manufacturing firms could leverage to enhance their IoT performance. IoT capabilities, through automated data capture and the ability to quantify supply chain processes, activities, and environmental conditions, enable identification at both individual item and unit levels. These capabilities also enhance the tracking, monitoring, and tracing of entities and individuals within the supply chain. Moreover, IoT capabilities foster the implementation of a remote-control system for supply chain operations, autonomous decision-making capacity within the supply chain, and the optimization of supply chain activities through real-time information provision. Furthermore, IoT capabilities support supply chain operations by delivering real-time insights, providing copious data for tactical and strategic decision-making via data analytics, and bolstering information exchange within and across firms. IoT capabilities also enhance communication among operators and improve coordination, thereby facilitating decision-making within and between firms in the supply chain. Therefore, the study's findings suggest that IoT capabilities significantly and positively impact both the integration of supply and demand processes over the internet and overall supply chain performance.

Furthermore, the findings suggest that the integration of internet-enabled demand and supply processes substantially enhances supply chain performance. For manufacturing firms in Jordan, the integration of supply processes via the internet proves advantageous. It facilitates online communication with key channel partners regarding aspects such as inventory levels, planned orders, and collaborative inventory strategies. Additionally, it allows them to coordinate supplier procurement procedures online. By integrating demand processes online, manufacturing firms can create joint demand forecasts, plans for introducing and rolling out new products/services, plans for providing service support, and plans for coordinating new product/service introductions online that will add value to their operations. The digitalization of the supply chain has garnered significant interest from both practitioners and researchers in recent years. Integrating circularity into business operations is crucial for attaining sustainability and meeting the Sustainable Development Goals (SDGs) set by the United Nations. This study investigates the correlation between the adoption of IoT capabilities, their application in integrating internet-enabled supply and demand processes, and the performance of supply chain firms within a CE context.

This study emphasizes the importance of manufacturing firms integrating demand and supply processes via the internet. In this study, the findings indicate that Internet-enabled demand process integration and Internet-enabled supply process integration are mediating the relationship between IoT capabilities and supply chain performance. These two distinct forms of integration will aid businesses in improving their supply chain operations and performance by increasing product quality, increasing delivery reliability and fill rate, assuring flawless order fulfillment, assuring error-free deliveries, reducing costs in the supply chain management process in terms of product prices and employee productivity, and improving supply chain flexibility as a whole. Albeit some drawbacks are there. As this study only attempted to target Jordanian manufacturing firm, others' presence and the role of managerial personnel was not observed. Secondly, only IoT capability is addressed as a single factor while organizational, operational, or else capabilities are not addressed there. Thirdly, a small sample was used so, variation or opinion of vast managerial function was not in the discussion as well as on the study population. Yet this study focused on and suggested to managerial as well as policymakers to address IoT with caution. The findings of this research directly support the SDGs by demonstrating how IoT-enabled supply chain enhancements lead to more efficient resource utilization and waste management, thereby contributing to sustainable industrialization and fostering innovation in line with SDG 9 (Industry, Innovation, and Infrastructure).

Competing Interests: The authors declare that they have no conflict of interest.

Reference

Abbass, A., & Mehmood, K. (2020). Impact of Internet of Things on business policy: the mediating role of marketing intelligence capability. *International Journal of Business Information Systems*.

Abedin, S. F., Alam, M. G. R., Haw, R., & Hong, C. S. (2015). A system model for energy efficient green-IoT network. *2015 International Conference on Information Networking (ICOIN)*, 177–182.

Abu-Qdais, H. A., Shatnawi, N., & Al-Shahrabi, R. (2023). Modeling the Impact of Fees and Circular Economy Options on the Financial Sustainability of the Solid Waste Management System in Jordan. *Resources*, 12(3), 32. https://doi.org/10.3390/resources12030032

Abushaikha, I., Alnsour, J., Jum', L., a, N. A., & Abubaker, A. (2023). Understanding urban logistics clusters: a qualitative study. *International Journal of Logistics Economics and Globalisation*, *10*(3), 289–305. https://doi.org/10.1504/ijleg.2023.13546

Acerbi, F., Sassanelli, C., Terzi, S., & Taisch, M. (2021). A systematic literature review on data and information required for circular manufacturing strategies adoption. *Sustainability* (Switzerland), 13(4), 1–27. https://doi.org/10.3390/su13042047

Acerbi, F., Sassanelli, C., & Taisch, M. (2024). A maturity model enhancing data-driven circular manufacturing. *Production Planning & Control*, 1-19.

Agrawal, R., Wankhede, V. A., Kumar, A., Upadhyay, A., & Garza-Reyes, J. A. (2022). Nexus of circular economy and sustainable business performance in the era of digitalization. *International Journal of Productivity and Performance Management*, *71*(3), 748–774.

Agyabeng-Mensah, Y., Baah, C., Afum, E., & Kumi, C. A. (2023). Circular supply chain practices and corporate sustainability performance: do ethical supply chain leadership and environmental orientation make a difference? *Journal of Manufacturing Technology Management*, *34*(2), 213–233.

Ali, S. M., Ashraf, M. A., Taqi, H. M. M., Ahmed, S., Rob, S. M. A., Kabir, G., & Paul, S. K. (2023). Drivers for Internet of Things (IoT) adoption in supply chains: Implications for sustainability in the post-pandemic era. *Computers and Industrial Engineering*, 183, 109515. https://doi.org/10.1016/j.cie.2023.109515

Alzoubi, H. M. (2021). An Investigation Of The Role Of Supply Chain Visibility Into The Scottish Blood Supply Chain. *Journal of Legal, Ethical and Regulatory Issues*, *24*(1).

Ataseven, C., & Nair, A. (2017). Assessment of supply chain integration and performance relationships: A meta-analytic investigation of the literature. *International Journal of Production Economics*, *185*, 252–265.

Attaran, M. (2020). Digital technology enablers and their implications for supply chain management. *Supply Chain Forum: An International Journal*, *21*(3), 158–172.

Atzori, L., Iera, A., & Morabito, G. (2010). The internet of things: A survey. *Computer Networks*, *54*(15), 2787–2805.

Balaji, M. S., & Roy, S. K. (2017). Value co-creation with Internet of things technology in the retail industry. *Journal of Marketing Management*, *33*(1–2), 7–31.

Baldwin, R., & Tomiura, E. (2020). Thinking ahead about the trade impact of COVID-19. *Economics in the Time of COVID-19*, *59*, 59–71.

Ben-Daya, M., Hassini, E., & Bahroun, Z. (2019). Internet of things and supply chain management: a literature review. *International Journal of Production Research*, *57*(15–16), 4719–4742.

Bharadwaj, A. S. (2000). A resource-based perspective on information technology capability and firm performance: an empirical investigation. *MIS Quarterly*, 169–196.

Birkel, H. S., & Hartmann, E. (2019). Impact of IoT challenges and risks for SCM. *Supply Chain Management: An International Journal*.

Birkel, H. S., & Hartmann, E. (2020). Internet of Things – the future of managing supply chain risks. Supply Chain Management, 25(5), 535–548. https://doi.org/10.1108/SCM-09-2019-0356

Borgia, E. (2014). The Internet of Things vision: Key features, applications and open issues. *Computer Communications*, *54*, 1–31.

Bressanelli, G., Adrodegari, F., Perona, M., & Saccani, N. (2018). Exploring how usage-focused business models enable circular economy through digital technologies. *Sustainability*, *10*(3), 639.

Caputo, A., Marzi, G., & Pellegrini, M. M. (2016). The internet of things in manufacturing innovation processes: development and application of a conceptual framework. *Business Process Management Journal*.

Chari, A., Niedenzu, D., Despeisse, M., Machado, C. G., Azevedo, J. D., Boavida-Dias, R., & Johansson, B. (2022). Dynamic capabilities for circular manufacturing supply chains—Exploring the role of Industry 4.0 and resilience. *Business Strategy and the Environment*, 31(5), 2500–2517. https://doi.org/10.1002/bse.3040

Constantinides, E., Kahlert, M., & de Vries, S. A. (2017). The relevance of technological autonomy in the acceptance of IoT services in retail. *2nd International Conference on Internet of Things, Data and Cloud Computing, ICC 2017*.

D'Adamo, I., Favari, D., Gastaldi, M., & Kirchherr, J. (2024). Towards circular economy indicators: Evidence from the European Union. *Waste Management & Research*, 0734242X241237171.

Ding, S., Ward, H., & Tukker, A. (2023). How Internet of Things can influence the sustainability performance of logistics industries – A Chinese case study. *Cleaner Logistics and Supply Chain*, 6, 100094. https://doi.org/10.1016/j.clscn.2023.100094

De Lima, F. A., & Seuring, S. (2023). A Delphi study examining risk and uncertainty management in circular supply chains. *International Journal of Production Economics*, *258*, 108810. https://doi.org/10.1016/j.ijpe.2023.108810

De Vass, T., Shee, H., & Miah, S. J. (2018). The effect of "Internet of Things" on supply chain integration and performance: An organisational capability perspective. *Australasian Journal of Information Systems*, *22*.

De Vass, T., Shee, H., & Miah, S. J. (2021a). Iot in supply chain management: a narrative on retail sector sustainability. *International Journal of Logistics Research and Applications*, *24*(6), 605–624.

De Vass, T., Shee, H., & Miah, S. J. (2021b). IoT in supply chain management: Opportunities and challenges for businesses in early industry 4.0 context. *Operations and Supply Chain Management: An International Journal*, *14*(2), 148–161.

Devaraj, S., Krajewski, L., & Wei, J. C. (2007). Impact of eBusiness technologies on operational performance: the role of production information integration in the supply chain. *Journal of Operations Management*, *25*(6), 1199–1216.

Ding, S., Tukker, A., & Ward, H. (2023). Opportunities and risks of internet of things (IoT) technologies for circular business models: A literature review. *Journal of Environmental Management*, *336*, 117662.

Elia, V., Gnoni, M. G., & Tornese, F. (2019). Designing a sustainable dynamic collection service for WEEE: an economic and environmental analysis through simulation. *Waste Management & Research*, *37*(4), 402-411.

Esper, T. L., Ellinger, A. E., Stank, T. P., Flint, D. J., & Moon, M. (2010). Demand and supply integration: a conceptual framework of value creation through knowledge management. *Journal of the Academy of Marketing Science*, *38*(1), 5–18.

Farooq, M. U., Waseem, M., Mazhar, S., Khairi, A., & Kamal, T. (2015). A review on internet of things (IoT). *International Journal of Computer Applications*, *113*(1), 1–7.

Flynn, B. B., Huo, B., & Zhao, X. (2010). The impact of supply chain integration on performance: A contingency and configuration approach. *Journal of Operations Management*, *28*(1), 58–71.

Floyd, J. A., D'Adamo, I., Wamba, S. F., & Gastaldi, M. (2024). Competitiveness and sustainability in the paper industry: The valorisation of human resources as an enabling factor. *Computers & Industrial Engineering*, 110035.

Flynn, B. B., Koufteros, X., & Lu, G. (2016). On theory in supply chain uncertainty and its implications for supply chain integration. *Journal of Supply Chain Management*, *52*(3), 3–27.

Fornell, C., & Larcker, D. F. (1981). *Structural equation models with unobservable variables and measurement error: Algebra and statistics*. Sage Publications Sage CA: Los Angeles, CA.

Ghazal, T. M., Hasan, M. K., Alshurideh, M. T., Alzoubi, H. M., Ahmad, M., Akbar, S. S., Al Kurdi, B., & Akour, I. A. (2021). IoT for smart cities: Machine learning approaches in smart healthcare—A review. *Future Internet*, *13*(8), 218.

Haddud, A., DeSouza, A., Khare, A., & Lee, H. (2017). Examining potential benefits and challenges associated with the Internet of Things integration in supply chains. *Journal of Manufacturing Technology Management*.

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2019). Multivariate Data Analysis (Eight). *Hampshire, UK: Cengage Learning*.

Hecklau, F., Galeitzke, M., Flachs, S., & Kohl, H. (2016). Holistic approach for human resource management in Industry 4.0. *Procedia Cirp*, *54*, 1–6.

Jauhar, S., Pratap, S., Lakshay, Paul, S., & Gunasekaran, A. (2023). Internet of things based innovative solutions and emerging research clusters in circular economy. *Operations Management Research*, *16*(4), 1968–1988.

Jum'a, L., Ikram, M., Alkalha, Z., & Alaraj, M. (2022). Do Companies Adopt Big Data as Determinants of Sustainability: Evidence from Manufacturing Companies in Jordan. *Global Journal of Flexible Systems Management*, 1–16.

Jum'a, L., & Kilani, S. (2022). Adoption enablers of big data analytics in supply chain management practices: the moderating role of innovation culture. *Uncertain Supply Chain Management*, *10*(3), 711–720.

Jum'a, L., & Bushnaq, M. (2023). Investigating the role of flexibility as a moderator between supply chain integration and firm performance: the case of manufacturing sector. *Journal of Advances in Management Research*. https://doi.org/10.1108/JAMR-07-2023-0188

Jum'a, L., Zimon, D., & Madzik, P. (2023). Impact of big data technological and personal capabilities on sustainable performance on Jordanian manufacturing companies: the mediating role of innovation. Journal of Enterprise Information Management. https://doi.org/10.1108/JEIM-09-2022-0323

Khan, R., Khan, S. U., Zaheer, R., & Khan, S. (2012). Future internet: the internet of things architecture, possible applications and key challenges. *2012 10th International Conference on Frontiers of Information Technology*, 257–260.

Khan, Y., Su'ud, M. B. M., Alam, M. M., Ahmad, S. F., Ahmad, A. Y. A. B., & Khan, N. (2023). Application of Internet of Things (IoT) in Sustainable Supply Chain Management. *Sustainability* (Switzerland), 15(1), 694. https://doi.org/10.3390/su15010694

Lee, I., & Lee, K. (2015). The Internet of Things (IoT): Applications, investments, and challenges for enterprises. *Business Horizons*, *58*(4), 431–440.

Lee, K., Romzi, P., Hanaysha, J., Alzoubi, H., & Alshurideh, M. (2022). Investigating the impact of benefits and challenges of IOT adoption on supply chain performance and organizational performance: An empirical study in Malaysia. *Uncertain Supply Chain Management*, *10*(2), 537–550.

Li, G., Yang, H., Sun, L., & Sohal, A. S. (2009). The impact of IT implementation on supply chain integration and performance. *International Journal of Production Economics*, *120*(1), 125–138.

Liu, H., Huang, Q., Wei, S., & Huang, L. (2015). The impacts of IT capability on internet-enabled supply and demand process integration, and firm performance in manufacturing and services. *The International Journal of Logistics Management*.

Liu, H., Ke, W., Wei, K. K., & Hua, Z. (2013). Effects of supply chain integration and market orientation on firm performance: Evidence from China. *International Journal of Operations & Production Management*.

Madakam, S., Lake, V., Lake, V., & Lake, V. (2015). Internet of Things (IoT): A literature review. *Journal of Computer and Communications*, *3*(05), 164.

Mattern, F., & Floerkemeier, C. (2010). From the Internet of Computers to the Internet of Things. In *From active data management to event-based systems and more* (pp. 242–259). Springer.

Mishra, D., Gunasekaran, A., Childe, S. J., Papadopoulos, T., Dubey, R., & Wamba, S. (2016). Vision, applications and future challenges of Internet of Things: A bibliometric study of the recent literature. *Industrial Management & Data Systems*.

Mu, X., & Antwi-Afari, M. F. (2024). The applications of Internet of Things (IoT) in industrial management: a science mapping review. *International Journal of Production Research*, 62(5), 1928–1952. https://doi.org/10.1080/00207543.2023.2290229

Nandi, S., Sarkis, J., Hervani, A., & Helms, M. (2021). Do blockchain and circular economy practices improve post COVID-19 supply chains? A resource-based and resource dependence perspective. *Industrial Management and Data Systems*, 121(2), 333–363. https://doi.org/10.1108/IMDS-09-2020-0560

Porter, M. E., & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. *Harvard Business Review*, *92*(11), 64–88.

Qin, J., Liu, Y., & Grosvenor, R. (2016). A categorical framework of manufacturing for industry 4.0 and beyond. *Procedia Cirp*, *52*, 173–178.

Queiroz, M. M., Pereira, S. C. F., Telles, R., & Machado, M. C. (2019). Industry 4.0 and digital supply chain capabilities: A framework for understanding digitalisation challenges and opportunities. *Benchmarking: An International Journal*.

Rollins, M., Bellenger, D. N., & Johnston, W. J. (2012). Does customer information usage improve a firm's performance in business-to-business markets? *Industrial Marketing Management*, *41*(6), 984–994.

Sassanelli, C., Garza-Reyes, J. A., Liu, Y., de Jesus Pacheco, D. A., & Luthra, S. (2023). The disruptive action of Industry 4.0 technologies cross-fertilizing Circular Economy throughout society. *Computers & Industrial Engineering*, 109548.

Saengchai, S., & Jermsittiparsert, K. (2019). Improving sustainability performance through internet of things capability in thailand: mediating role of IOT enabled supply chain integration. *International Journal of Supply Chain Management*, *8*(5), 572–584.

Saqib, Z. A., Qin, L., Menhas, R., & Lei, G. (2023). Strategic Sustainability and Operational Initiatives in Small-and Medium-Sized Manufacturers: An Empirical Analysis. *Sustainability*, *15*(7), 6330.

Saqib, Z. A., & Zhang, Q. (2021). Impact of sustainable practices on sustainable performance: the moderating role of supply chain visibility. *Journal of Manufacturing Technology Management*, *32*(7), 1421-1443.

Sassanelli, C., & Terzi, S. (2022). The D-BEST reference model: a flexible and sustainable support for the digital transformation of small and medium enterprises. *Global Journal of Flexible Systems Management*, *23*(3), 345-370.

Shafique, M. N., Rashid, A., Bajwa, I. S., Kazmi, R., Khurshid, M. M., & Tahir, W. A. (2018). Effect of IoT capabilities and energy consumption behavior on green supply chain integration. *Applied Sciences*, *8*(12), 2481.

Shamout, M., Ben-Abdallah, R., Alshurideh, M., Alzoubi, H., Kurdi, B., & Hamadneh, S. (2022). A conceptual model for the adoption of autonomous robots in supply chain and logistics industry. *Uncertain Supply Chain Management*, *10*(2), 577–592.

Sun, X., & Wang, X. (2022). Modeling and analyzing the impact of the internet of things-based Industry 4.0 on circular economy practices for sustainable development: Evidence from the food processing industry of China. *Frontiers in Psychology*, *13*, 866361.

Tan, W. C., & Sidhu, M. S. (2022). Review of RFID and IoT integration in supply chain management. *Operations Research Perspectives*, *9*, 100229. https://doi.org/10.1016/j.orp.2022.100229

Tang, C.-P., Huang, T. C.-K., & Wang, S.-T. (2018). The impact of Internet of things implementation on firm performance. *Telematics and Informatics*, *35*(7), 2038–2053.

Taddei, E., Sassanelli, C., Rosa, P., & Terzi, S. (2024). Circular supply chains theoretical gaps and practical barriers: A model to support approaching firms in the era of industry 4.0. *Computers and Industrial Engineering*, 190, 110049. https://doi.org/10.1016/j.cie.2024.110049

Vegter, D., van Hillegersberg, J., & Olthaar, M. (2023). Performance measurement system for circular supply chain management. Sustainable Production and Consumption, 36, 171–183. https://doi.org/10.1016/j.spc.2023.01.003

Weng, W. (2020). *Toward the Enhancement of Marketing Intelligence Capability: The Role of Internet of Things*. EasyChair.

Weng, W. W. H. (2020). *Effect of Internet of Things on Business Strategy: An Organizational Capability Perspective*. EasyChair.

Weng, W.-H. (2020). Internet of things utilization in marketing for competitive advantage: An organizational capability perspective. *Proc. Int. Conf. Electron. Bus*, *2020*, 200–209.

Whitmore, A., Agarwal, A., & Da Xu, L. (2015). The Internet of Things—A survey of topics and trends. *Information Systems Frontiers*, *17*(2), 261–274.

Yan, J., Xin, S., Liu, Q., Xu, W., Yang, L., Fan, L., Chen, B., & Wang, Q. (2014). Intelligent supply chain integration and management based on cloud of things. *International Journal of Distributed Sensor Networks*, *10*(3), 624839.

Yu, W. (2015). The effect of IT-enabled supply chain integration on performance. *Production Planning & Control*, *26*(12), 945–957.

Yu, X., Nguyen, B., & Chen, Y. (2016). Internet of things capability and alliance: Entrepreneurial orientation, market orientation and product and process innovation. *Internet Research*.

Zhou, L., Chong, A. Y. L., & Ngai, E. W. T. (2015). Supply chain management in the era of the internet of things. *International Journal of Production Economics*, *159*, 1–3.