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The Role of Logistics 4.0 and Industry 4.0 in Promoting Sustainable Operations and Performance

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Abstract

Digitalization advancements have moved manufacturing towards Industry 4.0 (I4.0), which allows smart logistical transformations that have a significant impact on the society and environment. Logistics (L4.0) incorporates modern technology and the internet into business systems and promotes sustainable operations in the business environment. This study identified and examined the main components and technology developments of I4.0 and L4.0 that facilitate green practices in the manufacturing and service sectors. A literature review was conducted to investigate the present research development, role, and future research studies of I4.0 and L4.0 technologies to achieve sustainability in organizations. This paper also examined a detailed discussion of the relationship and impact of I4.0 and L4.0 technologies in manufacturing organizations. This study considered 205 research papers that were published between 2000 and 2024. The findings from the literature review highlighted that I4.0 and L4.0 have a considerable impact and play a significant role in sustainable operations and performance. Furthermore, this study provides research scopes, insights, and future research directions of I4.0 and L4.0 in different industrial sectors, which will be useful for industry and academia in achieving manufacturing sustainability. This study helps supply chain partners focus on these high-level dimensions in order to successfully implement I4.0 and L4.0.

Keywords: L4.0; I4.0; Sustainable Operations; Green Logistics; Sustainable Performance.

1. Introduction

Industry 4.0 (I4.0) paradigm has become popular in manufacturing in recent years, which impacts both production and logistical systems [1]. I4.0 is a phenomenon that is transforming business models and decision-making due to the integration of digital technology and increasing participation in products, services and processes. Disruptive technologies including block chain, artificial intelligence (AI), 3D printing, the Internet of Things (IoT), robotics, cyber-physical systems (CPS), augmented reality (AR), digital twins, etc. have contributed to the evolution of I4.0 [2]. The main pillar of Industry 4.0 is the integration of manufacturing operations and information flows throughout the entire production chain and digital systems [3]. Industry 4.0 streamlines logistics by enhancing visibility in real-time, improving supply chain processes, and increasing efficiency and flexibility [4]. Logistics is an important tool of SCM and it plays an important role in an organization's economic growth as it effectively manages the flow of resources and information [5]. Logistics include a broad range of operations, including transportation, inventory control, warehousing, and procurement [6]. For both supply chain management and logistics, the I4.0 revolution has enabled the digitalization of industrial activities by proposing the concept of L4.0[7]. Logistics is shifting to Logistics 4.0 in order to address global supply chain issues and satisfy customer needs for more customized and quicker delivery by combining traditional logistics with technologies associated with Industry 4.0 [8], [9].

Logistics 4.0 is a logistical system that enables the long-term sustainable, affordable, satisfaction of consumer needs, personalized, and more flexible supply chains and logistics based on rising digital technology [10], [11].Many technologies, including AI, BD, IoT, Robotics, Big Data, CC and RFID, are being used in logistics operations [12], [13]. The adoption of advanced technologies in L4.0 improves system efficiency and operational effectiveness in logistics and transport [14].Thus, L4.0 operations provide increased flexibility and adaptability to market demands [15]. It will also optimize manufacturing networks, resulting in decreased production and storage costs and improved customer service [16]. L4.0 offers several advantages, such as prompt delivery and supply, increased corporate agility, flexibility, responsiveness, and predictive analytics [17].

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Figure 1 shows the key components and technologies of L4.0. Implementing these advanced elements and technology can help businesses become more efficient, flexible, and transparent, which will make their supply chains more competitive and sustainable.

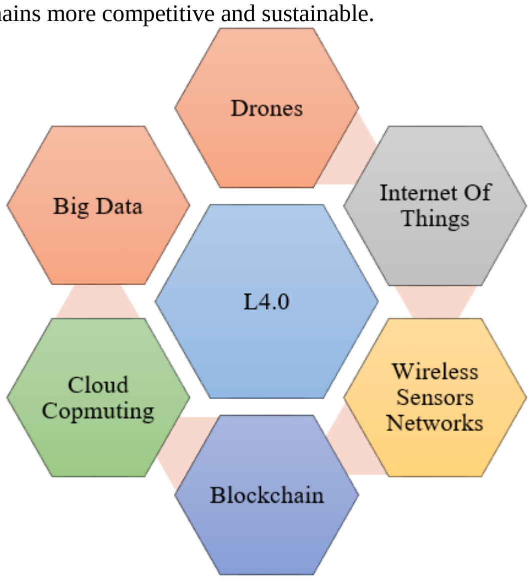

Figure 1. The technologies and components of L4.0 (Adopted from [1])

Logistics 4.0 plays an important role in supporting sustainable operations by using advanced technologies that improve productivity, minimize waste, and optimize resource utilization[8]. Logistics 4.0 facilitates sustainable operations by providing greater visibility of sustainability efforts throughout the supply chain and focusing on optimizing routes, reducing fuel usage, minimizing environmental impact, and reducing waste through real-time data and automation [18].The integration of I4.0 and L4.0 technologies provides an efficient approach for obtaining sustainable operations and enhancing performance [19]. These developments are crucial for companies striving to boost productivity, reduce their impact on the environment, and stay competitive in a market [20].

The purpose of this study is to examine the impact and relationship between I4.0 and L4.0 models in the implementation of green practices for obtaining sustainable operations. This review paper addresses the main technologies, challenges, barriers and implementation of L4.0 and I4.0 faced by organizations when incorporating green practices in their operations. This study also demonstrates the adoption and utilization of I4.0 and L4.0 for sustainable operations throughout companies, sectors, and geographic locations.

2. RESEARCH GAP

Organizations are adopting green practices due to growing regulatory demands and ecological concerns [21]. The integration of IoT, Big Data (BD), AI, and blockchain processes within L4.0 causes notable challenges with the utilization of advanced digital technology. There are several studies focusing on the roles of I4.0 and L4.0 in the past literature [22], [23]. While these technologies have been examined for their impact on organizational performance the combined impact on sustainable operations and performance remains underexplored.There is a lack of comprehensive studies that investigate how these various technologies work to promote environmental sustainability, resource optimization, and sustainable performance, this creates a gap that needs to be fulfilled in order to fully understand their role and impact in sustainable operations and accomplishing overall sustainability goals of organizations. Table 1 shows the research gap in the integration between L4.0 and Industry I4.0, as well as their impact on sustainable operations and performance in past studies.

Table 1. The contribution table from the literature review

AUTHOR	LOGISTICS 4.0	INDUSTRY 4.0	SUSTAINABLE OPERATIONS	SUSTAINABLE PERFORMANCE
[24]		√	√	
[25]		√	√	
[26]		√		√
[16]	√	√		
[27]		√	√	
[28]	√	√		
[29]	√	√		
[30]		√	√	
[31]	√			√
[32]	√		√	
[33]	√	√		
[34]	√	√		
[35]	√			√
[36]		√	√	
[3]	√		√	
[6]	√	√		
[37]	√			√
[38]		√	√	
[39]	√	√		
[40]	√	√		
[41]	√	√		
[42]	√		√	
[43]	√	√		
[44]	√	√		
[45]	√	√		
[8]	√	√		
[46]	√			√
[47]		√	√	
[48]		√	√	

The table illustrates the research gap, as previous research has not considered Industry 4.0, Logistics 4.0, sustainable operations, and sustainable performance in a single study. It is therefore highly required to conduct research considering the mentioned factors in a single study and it is also required to find the collective impact of I4.0 and L4.0 on sustainable performance and sustainable operations in the industrial setting. Addressing this gap could develop a thorough understanding of their combined impact and provide helpful insights for industries pursuing sustainable change. In addition, the findings of this research can also help in highlighting the need for framework development in which these technologies (I4.0 and L4.0) can be integrated to adopt sustainable practices and operations in the industrial sector.

3. Need For this Study

As per the highlighted gap (see Table 1), a literature review on the impact of L4.0 and I4.0 on sustainable operations and sustainable performance was required to be conducted. In this regard, the present literature review was conducted. Previous studies examined the individual impacts of I4.0 and L4.0, sustainable operations and sustainable performance and their collective effects on promoting sustainable practices in organizations. Addressing this gap is essential as industries face greater pressure to adopt green practices, optimize resources, and enhance overall performance. By exploring how I4.0 and L4.0 technologies can be integrated to adopt sustainable operations to increase sustainable performance.

4. RESEARCH QUESTIONS

This research was based on three research questions stated below;

1. What are the key technologies of I4.0 and L4.0 that are adopted to improve sustainable performance?
2. What is the relationship between I4.0 and L4.0?
3. What is the impact of I4.0 and L4.0 technologies on sustainable operations and sustainable performance?

5. RESEARCH METHODOLOGY

This study carried out a narrative literature review. A narrative literature review is a qualitative and descriptive method for reviewing existing studies, aiming for an in-depth understanding of a particular topic. For example, A narrative analysis explores the digital technologies that have been used in manufacturing industries across time, highlighting trends, benefits, and challenges while revealing gaps in understanding their long-term impact on industries.

In the present research, thematic analysis was carried out to gain insights associated with the impact of I4.0 and L4.0 technologies on sustainable operations and sustainable performance. The findings from the downloaded papers related to I4.0 and L4.0 were discussed in the table and the details included author, methodology, and findings. In addition, the business models from the literature concerning I4.0 and L4.0 were also discussed. An analysis was conducted to recognize the common elements and unique features of different I4.0 and L4.0 technologies.

5.1. Selection of Papers

The literature review as conducted in this article was initiated with the downloading and selecting of the research papers as presented in Figure 2. This process started with the keyword search on “I4.0”, “L4.0”, “I.40 and sustainable performance”, and “I4.0 and sustainable operations”, was performed on literature published between 2010 and 2024. The platforms from which the papers were accessed/downloaded from Web of Science, PubMed, IEEE Xplore, JSTOR, Google Scholar, Scopus, and Springer Link. Five hundred 500 papers were accessed and downloaded among them 250 papers were related to the topic and included in this study. As per the paper selection criteria for the present research, included papers should be of the last 10 years, and must be available in English language. Furthermore, only peer-reviewed journal articles, and conference proceedings were considered for this study. Studies that did not address I4.0 or L4.0 technologies and their impact on sustainable performance or sustainable operations were excluded.

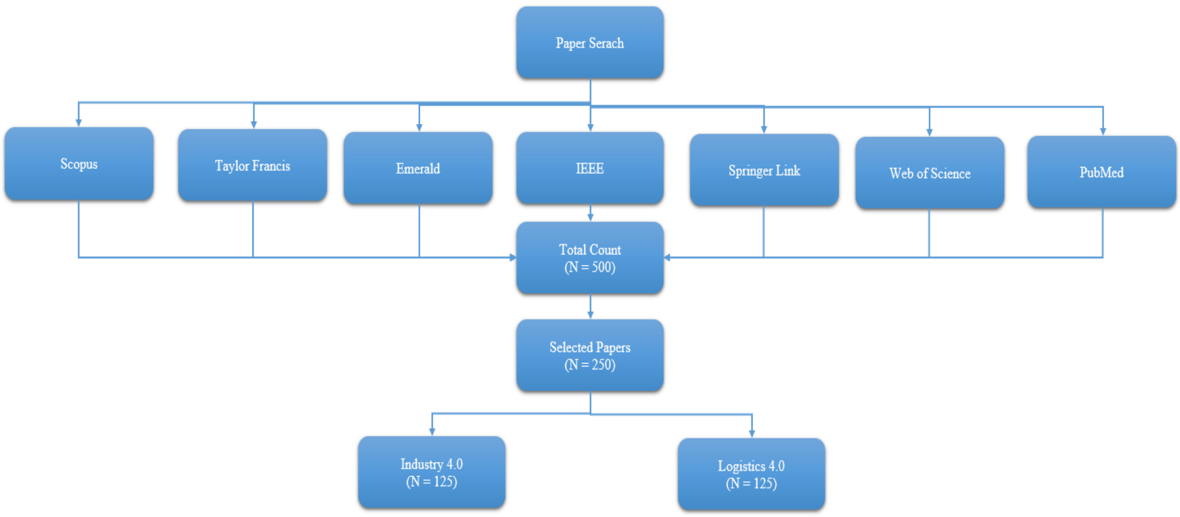

Figure 2. The diagram representing the selection process of the research papers included in this research paper

6. LITERATURE REVIEW

6.1. Logistics

In the modern manufacturing and commercial industries, logistics play a substantial part in terms of economy and effectiveness [49], [50].Logistics is a component of supply chain management (SCM), which enables you to efficiently plan, carry out, regulate, and transfer information between businesses, partners, and customers to satisfy client needs [20], [51], [52]. The management system, material flows, and information flows are the logistical components of I4.0's potential in this industry [20]. Supply chain management depends extensively on logistics to organize and schedule the timely, safe, and efficient transportation of goods[53].There are several characteristics and issues (efficiency, flexibility, sustainability) associated with supply, production, distribution, and reverse logistics chains [54]. The performance of logistics is impacted by both managerial (**Leadership and Decision-Making**) and structural factors (technology infrastructure, network design, warehouse and distribution) [55]. Planning, conducting and supervising the transportation of commodities and materials from the point of origin to the goal of satisfying consumer demands is a function of logistics [12].Logistics management controls the process of transferring goods, people, and data in a rapid, economical, secure, and sustainable manner [56], [57].

6.2. Evolution of Logistics to L4.0

Employing I4.0 in the field of transportation is known as "L4.0." [58].

Logistics 1.0: Logistics 1.0 is the traditional logistics system that appeared in the initial stages of logistics management. Logistics 1.0 includes the basic transportation, and distribution processes that exclude recent advanced technologies. The primary goal of L1.0 was to transport items from one point to another in a timely and cost-effective manner [59].

Logistics 2.0: The evolution of L2.0 was to enhance process integration and resource utilization in comparison to L1.0's manual systems. L2.0 refers to the next stage of logistics evolution, in which organizations begin adopting technology to improve efficiency and visibility [58].

Logistics 3.0: During L3.0, technology-assisted production technologies start to emerge, as begins the use of software to support technological activities in logistics process management. Warehouse Management Systems and Transport Management Systems are two examples of software-based logistics management systems that have been implemented physically [60].

Logistics 4.0: L4.0 is known as the digital era with the integration of modernization, applications and software in the logistics industry. The idea behind L4.0 is smart products and services. "Smart logistics" can help organizations become more adaptable and flexible while offering benefits that encourage effort for the additional benefit [59].

Figure 4 shows the evolution of L4.0. L4.0 also referred to as the 4th industrial revolution, is the combination of the logistics industry with an array of technologies, including sensors, AI, BD, IoT and developments in automation, which are primarily focused on automating the packing and shipping procedures.

- Logistics 4.0

In 2011, the phrase L4.0 originated as a response to and promotion of I4.0 [41]. L4.0 emerged as a result of I4.0, the integration of technological advances, and increased usage of the Internet in business systems [61]. Logistics 4.0 refers to smart logistics, which enables smart management of processes [62]. L4.0 is a strategic technological strategy that integrates various technologies to improve supply chain effectiveness and efficiency. It aims to shift the focus of organizations to value chains, maximizing value delivered to consumers and customers while increasing competitiveness[63], [64]. Key technologies of L4.0 are IoT, BD, CC, AI, ML, block chain, robotics, 3D Printing, and AR [65], [66], [67] are shown in figure 5.

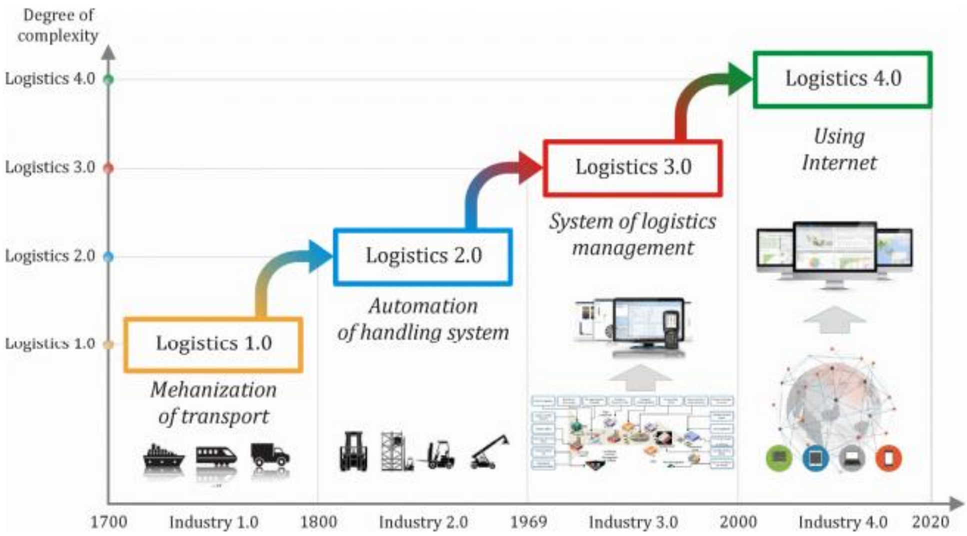

Figure 3. Evolution of Logistics (Source: [41])

Figure 4. Logistics 4.0 Technologies (Source: adapted from [41])

Khan et al. (2022) identified the critical success elements for L4.0 and the most influential critical success elements were highlighted including top management commitment, top management support, and technology infrastructure[5]. Another study examined the drivers of L4.0 and found that information technology infrastructure, top management support, and financial investment were the most important factors in L4.0 adoption. This research provided a more in-depth understanding of the factors that drive L4.0 adoption in developing nations[68]. According to (Markov &Vitliemov, 2020), block chain technology (BCT and production transparency have the greatest impact on the logistics and supply chain in the automotive industry. However, the major challenges they face are cybersecurity and false information[69]. Albrecht et al., (2024) investigated the understanding of the role of digital technologies in the idea of Logistics 4.0, the results showed the 10 digital technology affordances in intralogistics; condition for monitoring of goods and assets, assistance with manual tasks, monitoring of manual tasks, automation of manual tasks, strategic decision-making, tracking of goods and assets, automation of operational decisions, ubiquitous data availability, interruptions in management, and support for operational scheduling [70]. Another study investigated L4.0 challenges, current trends, and elements of business operations. Logistics 4.0's elements include automated solutions, instant information interchange and real-time big data analysis, which offer business opportunities [38]. Glistau and Machado (2018) reviewed the concepts and ideas of L4.0, solutions of L4.0, and requirements [40]. A systematic literature review was conducted by (Vasiulis Ferreira Rodrigues et al.,2022), in order to understand L4.0 and they found that L4.0 improves organizational capacities, optimizes value chain, and resources, and promotes the development of long-term supply chain operations[71].

6.2.1. Transformation Brought by L4.0

The integration of advanced technologies AI, IoT, C, Blockchain, CS, BD, RFID and AM is transforming logistics operations in various ways. These operations are material handling, transportation management, technology infrastructure, warehouse, safety, security, service quality, packaging, and distribution. The transformation of logistics operations and L4.0 technologies are shown in table 4.

Table 2. Tasks and technologies of L4.0 discussed in past studies

Authors	Logistics' Tasks	Use of Logistics 4.0 Technologies
[72]	Safety/Security	IoTs, CT, 3D AM, TT, and CC
[73], [46], [6], [74], [31], [44], [7], [75], [14], [76]	General Contributions	AM, BD, AI, CC, Blockchain, IoT, BD, CC, RFID, GPS, CPS, Robotics, VR, AR, CPS, 3D printing, AGVS, ICT, BDA, and Simulation
[48]	Service Quality	AI, AM, Advanced Robotics, and Block Chain
[77]	Digital/Automotive Transformation	IoTs, AI, CPS and Autonomous robots
[47]	Technology Infrastructure	CS, Robust and ICT
[78]	Communication Networks	Simulation, IoT, SS, CS, AR, BD and AI
[79]	Information Management	CS, CC, BD, RFID, Sensors, and Robots
[79], [59], [31], [80], [79], [81], [82], [83]	Transportation	CS, CC, BD, RFID, CPS, AM, Sensors, Robots, CL, CD, IoTs, 3D Printing, VR, ERP, AVs, Sensors, BD, AR, TMS, GPS and Automation
[84], [83]	Packaging	CPS, RFID, BD, IoT, Sensors, AGVs and BCT
[83]	Distribution	Sensors, IoT, AGVs, CPS, and BT
[81], [84], [83]	Warehousing	AR, CPS, RFID, Big Data, Sensors, IoT, AGVs, and BCT
[85], [13], [86], [35]	Material Handling	CPS, RFID, IoTs, CC, ERP, Drones, Mobile applications, AI, Bar Codes, Block Chain, and WMS
[58]	Planning & Control	Cloud software, AI, BDA, Blockchain, and Networking
[87]	Production	IoTs, CPS

Table 4 shows the L4.0 technologies in various logistics tasks in organizations. AGVs and intelligent robots will be essential for warehouse operations including storing, picking, loading, and unloading, while autonomous vehicles will move things from one place to another place without the need for any drivers[14]. AI and GPS technologies, which enable intelligent robots and autonomous vehicles, will improve the automation of logistics operations[72].Processes such as tracking the location of products, sorting, and data entry for common smart products with RFID tags and QR codes can be managed with the use of scanners, readers, or mobile applications that can identify these codes [14]. Smart devices will be made possible by many sensor types, which will improve the automation of logistics operations. CPS is regarded as the main component of automation because it describes systems that combine all information and physical systems in the internet that provide global access[44]. Real-time tracking and monitoring of products, inventory, and machinery throughout the supply chain is made possible by IoT in L4.0, which enhances operational effectiveness and visibility. Data collected through IoT supports proactive decision-making and enhancesthe efficiency of logistics operations[60]. Big Data is essential to Logistics 4.0 because it enables to gathering, storing, and analysis of massive quantities of data generated throughout the supply chain. Big Data analytics helps with proactive problem-solving and well-informed decision-making by detecting trends, and patterns. By utilizing Big Data, businesses can reduce operational costs, reduce waste increase sustainability by maximizing resource utilization, and increase consumer retention through customized products[7]. L4.0 is revolutionized by AM by enabling on-demand production, reducing dependency on conventional supply networks. AM enables confined production, reducing lead times and transportation expenses by offering highly customized goods. Through the integration of AM with IoT and AI, L4.0 expands production and distribution and enhances efficiency [88]. In L4.0, simulation is performed by constructing digital twins, or virtual versions of logistics systems, to simulate actual operations. These simulations combine sensors, BD, and data from IoT devices to analyze aspects like transportation routes, factory layouts, and demand variations. This data is processed using advanced algorithms and computational techniques to find mistakes, forecast results, and validate possible solutions without interfering with the actual business operations. Through real-time insights into transportation networks, warehouse management, and resource allocation, simulation improves decision-making [72]. In L4.0, robotics plays a revolutionary role by increasing efficiency throughout logistical operations, minimising repetitive tasks, and enhancing reliability. In order to increase speed and reduce human error, robots are used in warehouses to select, pick, pack, and organise goods[89]. Real-time data and decision-making are made possible by these robotic systems when combined with IoT and AI, they improve supply chain agility and fast responses to shifting logistics demands [63].Blockchain enables supply chain operations to be transparent, secure, and efficient. By effectively transferring information such as shipment details, credentials, and compliance records, blockchain improves trust among stakeholders. Logistics procedures like payments, customs clearances, and order fulfillment are handled automatically by smart contracts, which lowers expenses and delays [90]. AR reduces errors and increases efficiency in warehousing by guiding employees through operations including selecting and packaging by incorporating digital instructions on real things. AR improves safety and speeds up delivery times in the transportation industry by allowing drivers to observe traffic conditions and get navigational assistance. By incorporating technical data, AR additionally simplifies remote maintenance and troubleshooting, allowing employees to resolve problems more rapidly and precisely [81].

6.2.2. L4.0 in Different Sectors and Countries

The overview, adoption, past studies, and implementation of L4.0 technologies across the various sectors and countries are shown in table Table 5.

Table 3. L4.0 Technologies in Various Sectors and Countries in Literature

Author	Year	Sector	Country	Result
[69]	2020	Automotive	Bulgaria	The article investigated the applications of Logistics 4.0 and Supply Chain 4.0 in the Bulgarian automotive sector. The findings indicate that production transparency and blockchain technologies provide great advantages. However, cybersecurity and incorrect data are significant challenges.
[72]	2024	Logistics	Global	This study investigated tracking and tracing applications in logistics focusing on visibility, transparency, operational efficiency and security. The findings identified three significant application areas including container asset management, intermodal cargo tracking and process certification. The study emphasizes the importance of Logistics 4.0 technology for improving logistics operations.
[59]	2021	Logistics	Turkey	This study investigated the impact of Industry 4.0 on the logistics sector and demonstrates its expanding influence on Turkish transportation networks. It discovers no significant relationship between trade infrastructure improvements and the adoption of Industry 4.0, digitalization, or internet access.
[91]	2021	Manufacturing	Central Europe	The study investigates the relationship between the logistical performance of the manufacturing industry and logistical 4.0 technologies. Findings showed that smart and lean approaches significantly improve performance while that while ICT and autonomous systems are still underutilized,
[65]	2019	Manufacturing	Poland and Norway	A Grey Decision Model (GDM) was proposed to evaluate L4.0 maturity and identify key variables influencing its implementation. Findings revealed that none of the businesses reached the greatest stages of maturity, and the majority

				are at lower levels, emphasizing the necessity of personalized growth efforts. While AI and Logistics 4.0 have a lot of potential in the implementation of L4.0 in businesses.
[7]	2020	Logistics	Global	This study provided a risk framework for L4.0 that addressed technological, economic, and social issues. Findings emphasized risks such as employment losses, ambiguous data ownership regulations, big investments, and data security concerns.
[38]	2017	Logistics	Poland	The purpose of this study is to investigate how Logistics 4.0 enables new business models by facilitating real-time information interchange, automation, and big data analysis. The findings revealed the significance of information and sustainability needs for manufacturing industries.
[48]	**2022**	**Logistics and Suppl Chain**	Global	This study evaluated criteria for assessing Logistics 4.0 service quality (L4.0SQ) and investigated emerging technologies that promote sustainability and value creation. It discovered that AI, AM, advanced robotics and blockchain are critical technologies for increasing service quality. These enablers improve logistics flexibility and responsiveness while solving difficulties in traditional supply chains.
[52]	2023	Automotive	Turkey	This study investigates the influence of Logistics 4.0 on intralogistics, in terms of cost savings and process efficiency. The case study demonstrated a 13.37% cost decrease, mainly due to the deployment of RFID technology. The findings show that further optimization with unmanned technology could improve efficiency.
[92]	2021	Automotive	Global	This study investigated the role of Big Data technologies in promoting L4.0. Findings revealed that implementing a Big Data warehouse in the logistics department improves analytical capacities and also highlights issues such as management, infrastructure limits and data quality.
[54]	2019	Logistics	Germany	This study investigated how I4.0 affects logistics and supply chain management and provides assistance using the Arrowhead Framework. The results show that I4.0 brings about major technological changes, and the suggested Arrowhead Framework can improve efficiency and adaptability.
[51]	2020	Logistics	Poland	The study evaluates two Polish manufacturing organizations' competence adoption using an L4.0 maturity model. The results showed that the model demonstrated flexibility and offered useful information for businesses to assess their progress in digital transformation.
[93]	2022	Logistics	Oman	With an emphasis on the impact of technologies like AI, IoTs, and robotics, this study evaluated the skills required for implementing L4.0 in Oman's logistics sector. Findings revealed that the country's workforce for coming challenges in the logistics sector, policy initiatives and emphasize the significance of aligning education with business needs for implementation of L4.0.
[83]	2017	Logistics	Global	To improve operations including distribution, shipping, and warehousing, this study investigated how Third-party Logistics (3PL) companies are utilizing I4.0 technologies. The findings revealed that technologies including AV, blockchain, 3D printing and electronic marketplace platforms play important roles in logistic sectors and this represented a significant advancement in L4.0.
[39]	2024	Manufacturing	Global	The study aims to investigate how I4.0 technologies influence L4.0 and sustainability in manufacturing supply chains. The findings provide insights for improving logistics performance and encouraging the implementation of I4.0 technologies in small and medium-sized manufacturing firms.
[32]	2021	Logistics	Colombia	The use of artificial AI in international logistics and its effects on education was examined in this research. Findings showed that AI is playing a bigger role in logistics since it can automate processes and make decisions based on data. Fewer businesses implement AI in their business operations.
[66]	2022	Logistics	Singapore, The United States, South Korea	This study investigates the use of autonomous trucks in logistics, emphasizing the advantages, and effectiveness of this technology. According to the study, autonomous vehicles increase environmental sustainability, safety, and transportation efficiency.
[94]	2018	Logistics	South Koria	This study was carried out to activate the Busan New Port and the Pusan New Port, building a smart refrigeration logistics center in Busan, Korea. The findings suggest helping revitalize Busan's port logistics sector by offering a strategic direction for the functioning of this smart logistics center.
[68]	2022	Logistics and Supply Chain	India	This study investigated the factors influencing logistics 4.0 adoption in India. The findings revealed that IT infrastructure, financial investment and top management support are critical factors for effective logistics 4.0 adoption in emerging economies.
[19]	2021	Logistics	Czech Republic	This study developed a method for assessing internal logistics capability for Industry 4.0. findings focused on IoT connectivity and integration across logistics areas.
[64]	2019	Logistics	Germany	The study creates the Smart Logistics Zone (SLZ) to improve intralogistics by integrating intelligent technology and improving process stability. The results revealed that SLZ promotes connectivity in logistics, removes disintegrated solutions, and reveals efficiency through technology.
[95]	2021	Manufacturing and Logistics	Italy	This study investigates technologies that assist internal logistics activities and enable an L4.0 model. It offers a technology taxonomy for several logistical

				sectors, with a focus on human-technology interaction.
[96]	2024	Logistics	Portugal	The purpose of the study is to investigate the role of Business intelligence in I4.0 and L4.0 technologies to obtain a competitive edge. According to the findings, BI played an essential part in decision-making optimization, and in order to maximize its effectiveness, top management and staff engagement were key factors.
[97]	2024	Logistics	India	This study was conducted to find the Critical Success Factors for the implementation of L4.0. The findings revealed the significance of, integration, smart technology and coordination for effective adoption, highlighting management devotion as the most important CSF. In order to enhance L4.0 implementation, the study also recommends that organizations focus on important big data analytics and IoT.
[90]	2020	Logistics	Brazil	This research investigates Brazilian logistics companies' interest in Big Data Analytics and IoT. Findings revealed the practical applications and implementation issues for these technologies within the framework of L4.0. The study also confirms the increased interest in BDA and IoT.
[76]	2020	Automotive	South Africa	The research investigates the organizational, technological, and environmental abilities and their impact on Logistics 4.0 capabilities and business performance. Findings discovered that technological and environmental capabilities have a greater influence on L4.0 capabilities.
[10]	2022	Manufacturing	North eastern United States of America, Central Europe, north Thailand,	A measuring model for L4.0 in manufacturing firms was developed and validated by this study, which addresses the lack of understanding regarding its elements. The study analyzed data from 239 experts to identify three factors: material flow transparency, automation, and organizational abilities. Practitioners may assess practices, plan implementations, and evaluate maturity with the help of this model.
[98]	2019	Service Sector	Poland	The study findings were presented with consideration to the size of the organization, taking into account its industry (construction, transportation, storage, hotel, catering, IT, finance, insurance, and education) as well as its size (micro, small, and medium-sized, and big companies).
[99]	2021	Food	UK	The study was conducted in the food sector in order to find the key technologies in the logistics sector. The study concluded that technologies like 3D printing, AR, AI, IoT, CS, BD, blockchains, automation, simulation, robotics, and CC were essential technologies for the sustainable growth of food logistics.

6.3. Industry 4.0

The German government was the first to use the phrase Industry 4.0, which refers to the arrangement of industrial processes using digital technologies and tools that can communicate with one another on their own throughout the value chain[100], [101], [60]. According to Szabo et al., (2020), the fourth industrial revolution, or Industry 4.0, is marked by the integration of advanced technologies into industrial processes, including automated machinery, real-time data, and AI. CPS, BD, and IoTs[44]. In order to improve business operations, I4.0 technologies promote digitalization through the implementation of automated systems and developing technologies [102]. Over the past four years, industry 4.0's effects have transformed the manufacturing sector to create value-creating economies for industries [24]. Today's manufacturing companies are under a lot of pressure due to competitive markets and higher manufacturing costs [103], [25], [104], [27]. According to Tsaramiris et al., (2022), IoTs, AI, BD, CC, ML, 5G, 3D Printing, robots, 6G networks, VR, and drones were the key technologies of I4.0 that have a transformative impact in different industries [105]. Qureshi et al., (2024) revealed the importance of I4.0 in enhancing sustainability in the supply chain of companies. I4.0 technologies, including CC, BD, IoTs and robotics, significantly improve the sustainability and efficiency of logistics operations. The results of this study also supported I4.0 technologies in L4.0 which improved sustainability in manufacturing logistics [39]. I4.0 is a collective phrase for various technologies including BD, IoTs, CC, AM, ML, BDA, CS, CC, DTT, AR, robotics, simulation, blockchain and IoE [104], [106], [107] are among the modern technological innovations that form the foundation of I4.0. Some of the key technologies of I4.0 are presented in Figure 5.

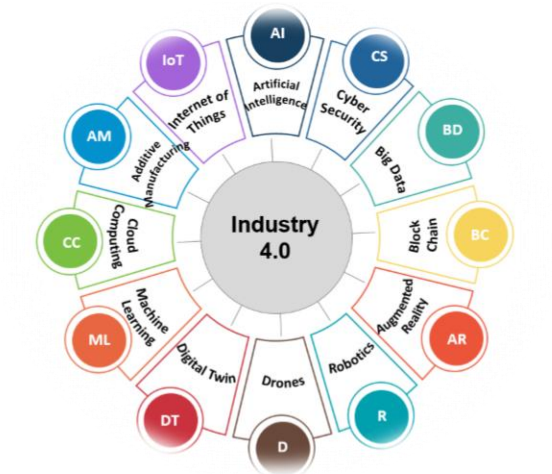

Figure 6. I4.0 Technologies (Source: adapted from [104])

6.3.1. Industrial Revolutions

The first industrial revolution began in the last decade of the 18th century [17]. It is parallel to the shift from manual to mechanized production by steam and water [34]. The mass manufacturing and electrification of production processes marked the 2nd industrial Revolution at the end of the 19th century [52]. A 3rd industrial revolution, known as the digital revolution, shifted from mechanical to analog systems by using computers and digital technologies. The 20th century industrial automation was enabled by electronics and information technologies [34]. The 4th industrial revolution comes with several titles including I4.0, Industry of the Future, Smart Factory, and Digital Factory [108]. The 4th IR was marked by the integration of smart technologies such as IoT, CC, ML, AM, and automation into manufacturing industries. Figure 6 illustrates all four industrial revolutions.

6.4. I4.0 Technologies

I4.0 technologies are a transformative paradigm of technological advancement that integrates digital technology into operations in industries. These technologies including IoTs, CC, AI, ML, AR, BDA, CPS, block chain and robots, which allows smooth optimization, automation, and communication across industrial processes [63]. I4.0 also referred to as smart manufacturing, is defined by the use of contemporary technologies for automation, digital transformation, and networking. As a result, manufacturing and production processes become more productive and efficient. Some of the major technologies reported in the previously conducted research as presented in Table 2.

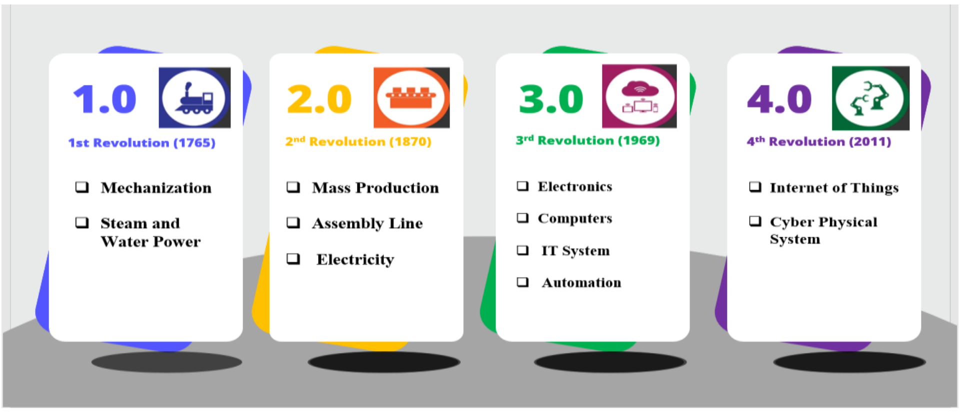

Figure 7. Industrial Evolution (Source: [34])

Table 4. I4.0 enabled smart manufacturing [77]

I4.0 Technologies	Definition	Sources
Cyber-Physical Systems	A cyber-physical system is a framework that incorporates virtual analytics, networks, computers and the real world to constantly track and control physical systems.	[109], [110], [111], [77], [25], [22], [6] ,[87], [112], [44], [59], [79], [113], [34], [16], [28], [7], [114], [115], [116], [117]
Artificial Intelligence	AI is an emerging technology of I4.0 that uses machines to attempt to simulate human intelligence.	[73], [118],[77], [48], [119], [37], [99], [112], [59], [7], [108], [120], [121], [16], [62], [122], [123], [116], [41], [124]
Internet of Things	The Internet of things is a network of connected tools that communicate and share information with other digital tools and the cloud.	[110], [73], [102], [77], [25], [6], [119], [14], [87], [112], [44], [59], [108], [113], [125], [22], [120], [121], [34], [28], [114], [62], [7], [116], [99], [41]
Automation and Robotics	It is an automated technology that can create, build, and function without the need for human involvement.	[112], [110], [75], [73], [102], [25], [6], [14], [44], [59], [108], [113], [16], [48], [99], [41], [126]
Additive Manufacturing	Additive manufacturing also called 3D printing, is an advanced manufacturing process that allows materials to be joined, typically layer by layer, to generate items from 3D model data.	[110], [75], [77], [25], [6], [48], [44], [59], [108], [16], [127], [62], [112], [123], [7], [116], [99], [41], [128], [129]
Cloud Computing	Cloud computing is the internet-based supply of computer facilities including databases, storage devices, software, analytics and computer facilities. Its goals include enabling quicker innovation, adaptable resource allocation, and scalability benefits.	[110], [75], [73], [102], [77],[25], [130], [37], [131], [14], [112], [44], [59], [79], [108], [113], [120], [16], [123], [116], [99], [41].
Big Data Analytics	Big data defines the software, tools and methods used to collect and analyze a wide range of data sets to create the facts.	[110], [132], [102], [130], [25], [119], [37], [131], [14], [112], [44], [113], [125], [22], [120], [121], [16], [114], [123], [99], [41]
Blockchain	Blockchain is a decentralized digital technology that guarantees security, traceability, and transparency.	[110], [8], [73], [42], [25], [6], [131], [14], [104], [108], [113], [16], [123], [7], [116], [99], [41]
Machine Learning	Machine learning is a technique that enables computers to learn from information and perform enhanced performance by using algorithms.	[133], [134], [135], [105], [136], [65], [119], [43], [17], [137], [138], [29], [139], [70], [140], [141], [10], [17], [142]
Miniaturization of Electronics	The process of producing ever-smaller mechanical, optical, and electrical components is known as "miniaturization of electronics.	[110], [112], [143], [144], [145], [146], [147], [148], [149],[150]
Autonomous Vehicles	Autonomous vehicles are those that can navigate on their own without the need for human guidance.	[73], [77], [25], [44], [59], [108], [113], [41]
Simulation	simulation is the virtualization of activities, simulations enable the measurement of process efficiency before its implementation.	[73], [151], [102], [6], [37], [14], [112], [108], [113], [121], [16], [99], [41], [152]
Cyber security	Cybersecurity is the technology of protecting programs, networks, and systems from online threats.	[102], [47], [37], [112], [44], [113], [16], [99], [41]
Virtual Technology	Virtual technology enables the creation of a virtualized representation of	[77], [6], [14], [112], [108], [113], [121],

	tangible computers, networks, servers and storage.	[114], [99], [41]
Robust ICT	It is a computer program that functions in multiple ways and has a very low failure rate is referred to as robust.	[153], [47], [113], [123], [154], [3], [155], [156], [157], [158], [159]
Autonomous Robots	A robot that functions without the assistance of a human.	[121], [160], [41], [77], [83], [58], [161], [58], [162], [115], [163], [120], [164], [161], [58], [165], [105], [166]
Smart Factory	The term smart factory refers to the use of many modern technology combinations to produce a highly adaptable and self-adjusting production capability.	[79], [22], [120], [34], [28], [114], [115], [116], [41]
Drones	Drones are also referred to as unmanned aerial vehicles (UAVs). Drones are aircraft that are not piloted by a human attendant, crew, or passenger.	[108], [113], [41], [83], [63], [167], [168], [169], [135], [170], [105], [171]
Automatic Guided Vehicles	Self-guided vehicles, mobile robots, or autonomous guided vehicles are the names of AGVs, which are used to move materials in a controlled environment without the assistance of a driver or operator.	[114], [41], [172], [99], [17], [61], [173], [174], [175], [103], [100], [176], [177]
Smart Sensors	Smart sensors serve as production tools, gathering copious volumes of data on goods and surroundings.	[121], [81], [178], [141], [179], [180], [138], [137], [181], [38]

6.5. I4.0 Technologies and their Applications

All IoT-related advanced manufacturing technologies, including computer vision, robots, predictive maintenance, and smart wearables, are included in I4.0. The different technologies of I4.0, purpose, methodologies used and outcomes of the past studies are shown in Table 3.

6.6. Green Logistics

The term ‘eco-logistics’ is sometimes known as green logistics (GL) and is a collection of sustainable standards and procedures designed to minimize environmental damage [17]. The practice of minimizing the effects of shipping and logistics procedures on the environment is known as GL [48].

According to Kumar (2015), green logistics refers to supply chain management methods and approaches that reduce the energy and environmental impact of transportation distribution. These techniques and strategies concentrate on material handling, waste management, packaging, and transportation. In order to meet the needs of customers, green logistics encompasses all operations associated with the environment and flows of goods and information between the point of production and the point of consumption. Green logistics is the process of planning a company's logistics while considering its environmental impact. Its goal is to reduce the environmental impact of the company while maintaining its economic activity.

According to Khoa et al. (2020), GL is one of the current practices that organizations are using to improve economic efficiency. This study highlighted that green logistics practices improve global competitiveness, and obtain a competitive advantage in the market [187]. Mohammad Nehme (2022) demonstrated the significance of GL, social accountability, and life cycle management in accomplishing sustainability. He offers ideas for improving green logistics processes and proposes a sustainable value chain model [188]. Nesan, (2023) conducted a study on customer satisfaction with green logistics services in Malaysia and examined issues including waste management, and high carbon emissions. He emphasized the significance of service features i.e. responsiveness, empathy for customer satisfaction and dependability in businesses [189]. The barriers and key drivers to implementing GL in logistics organizations were examined by Chen Chiaw Fen (2020). The findings demonstrate that the main driver was the need for a green environment and the primary barrier was the lack of government regulations and laws [190]. A study investigated the growth of the circular economy focusing on sustainability and GL. An organizational strategy for GL was offered to improve environmental security and productivity in logistics systems. Regulatory and financial issues were recognized as the main barriers to the implementation of GL [191]. Isoraite (2023) addressed the concept of GL, highlighting its importance in reducing the ecological impact while reducing costs. He emphasized the importance of GL and investigated how GL promotes sustainable behaviors that contribute to financial sustainability [192]. The need for GL transformation in logistics systems was addressed by Dzwigol et al. (2021). This study focused on barriers of GL that lead to impact on the CE. The study proposed an organizational and economic framework for implementing GL, focusing on factors including cost reduction, waste reuse, and resource optimization are the main tools to improve sustainability in businesses [63]. Another study found the impact of GL Management Practices on sustainability performance in Indonesia and Ghana. The study found significant relationships between GLMP dimensions, namely environmental, economic, and social performance in both countries. The findings revealed GLMP's importance in promoting sustainability and offer comparative evidence for its effectiveness in various industrial environments [193].

Figure 7. Green Logistics(Source: [194])

Table 5. Applications of I4.0 technologies, Methodologies and results of existing Literature.

Reference	Sector	Country	Findings
[23]	Manufacturing	Bangladesh	This study investigated the combined impact of I4.0 technology and sustainable practices, specifically circular economy and green supply chain management practices in Bangladesh's garment sectors. The findings demonstrated that I4.0 technologies significantly improve sustainability performance, but circular economy and green supply chain management practices have less impact leading to enhanced sustainable supply chain outcomes.
[120]	Logistics	Bahrain, Kuwait, Saudi Arabia, Oman, United Arab Emirates	This study was carried out to investigate the adoption of I4.0 technologies in the logistics industry across the Gulf countries. The findings indicated that the key technologies in GCC are BD, CC, AI, IoT, CPS, block chain and smart factories were identified as a component of the adoption process in developing countries.
[182]	Manufacturing	Pakistan	A study was conducted to investigate the influence of I.40 on environmental and economic performance in Pakistan. The findings revealed that I4.0 has a significant impact and positive relationship with environmental and economical performance.
[156]	Automotive	Brazil	A maturity model for Industry 4.0 was developed in this study to help organizations evaluate the degree of readiness for implementing main technologies and key concepts. The findings revealed that smart factories, structure, and culture, smart processes, workforce, organizational strategy, and smart goods and services allowing technologies like IoTs, BDA, and CPS in the automotive industries were the five main elements of the proposed maturity model.
[183]	Manufacturing	Malaysia	This study investigated the impact of I4.0 technology on green innovation performance. The findings of this research indicated that I4.0 technologies have a positive impact on business innovation performance which promotes green innovation behaviour.
[118]	Manufacturing	India	This study highlighted the significance of the implementation and impact of I4.0 in the Indian market. The findings revealed the new trends and achievements in I4.0 in India and found that I.40 technologies such as SMS, IoT, and cloud-based manufacturing play a significant role in enhancing productivity and quality through these technologies in the Indian manufacturing sector.
[108]	Logistics, Healthcare, Energy, Agriculture, and education	Global	This study identified I4.0 neologisms and investigated their disruptive impact across industrial sectors. The findings identified 99 terms and addressed the influence of I4.0 on healthcare, logistics, education, agriculture, and the energy sector. The study highlighted the integration of disruptive technologies including AI, 3D printing, and block chain have great impact across these major industries.
[184]	Manufacturing	Malaysia	This study investigated the role of I4.0 in achieving sustainability in industrial organizations by employing a framework. The findings indicated that It infrastructure and top management have a positive impact on I4.0 implementation, but supply chain integration has no impact on organizations.
[173]	Food	Italy	The purpose of this study was to implement AGVs in the food industry when compared to traditional forklifts.The study discovered that replacing forklifts with AGVs in the Italian food industry resulted in reduced operational costs, increased safety, and lower environmental effects in the manufacturing sector.
[137]	Manufacturing	India	A study was conducted in India and findings revealed that IoT and sensors played a transformative role in manufacturing organizations.
[185]	Logistics	Global	The study examined the crucial economic and social factors promoting the adoption of I4.0 technologies in City Logistics. The study highlighted key variables influencing the adoption of I4.0 technologies in City Logistics, including foreign direct investment, employment rate, GDP, R&D spending, and population size and showed that these factors have a significant impact on CL4.0.
[45]	Logistics	Germany	A study investigated the relationship between I4.0 and L4.0 using the concept of maturity models. Automation, CPS, IoT and data sharing from I4.0 are being applied to promote L4.0.
[186]	Logistics	Turkey	This study investigated the implementation of I4.0 principles in the logistics sector focusing on its key service areas including warehousing, information services, loading, transportation, and unloading. The company's R&D activities include CT, CC, simulation, digitalization, internet, robotic systems and mobile apps are the key technologies and organizations that must be included in their logistics sector.
[114]	Logistics and Manufacturing	Norway	The article explores the implementation of I4.0 technology in manufacturing logistics across a variety of production scenarios. It discovered that enterprises with high material flow complexity, ETO and low production repetitiveness are difficult to move to I4.0 in terms of manufacturing logistics.

Figure 6 shows the visual representation of the green logistics concept. When organizing a company's logistics, green logistics takes its environmental impact into account. Its goal is to decrease the company's environmental impact without compromising its economic activities [195].

6.7. Relationship Betweeen I4.0 and L4.0

Over time, logistics has become the more significant sector in manufacturing companies[196]. The logistics industry is being forced to grow with I4.0, which ultimately gave rise to the awareness of L4.0 [99], [197]. The topics of I4.0 and L4.0 are currently very popular and trending among businesses [44]. The use of I4.0 technology in logistics ultimately leads to L4.0 [178]. According to Torbacki and Kijewska., (2019), I4.0 and L4.0 are interconnected and complementary concepts. Both have a mutual focus on sustainability and operational excellence. Logistics 4.0 supports Industry 4.0 by maintaining a continuous and sustainable relationship among production and distribution systems, making logistics an essential facilitator of Industry 4.0's goals [87]. Tubis and Grzybowska, (2022) also supported the relationship among I4.0 and L4.0. This study provided the framework for digital transformation in manufacturing, while L4.0 uses the principles to optimize logistics and supply chains. Both principles are interconnected and essential for improving operational efficiency, sustainability, and competition. Overall, the combination of I4.0 and L4.0 is essential for ensuring long-term growth and financial stability [43]. According to Szabo et al, (2020), I4.0 and L4.0 are critical for businesses to be competitive in today's digitalized economy. Larger enterprises and smaller businesses with significant resources are leading the way in integrating these technologies into their operations. Thus, a balanced strategy for integrating I4.0 and L4.0 technologies in organizations improves performance while reducing unnecessary costs [44]. Another Study has revealed that I4.0 significantly affects supply chain management and logistics procedures [54]. I4.0 and L4.0 both are linked by the mutual necessity of employees to evolve to digital change and automation. Both demand a comprehensive knowledge of data analysis and IT. The competencies identified for I4.0, including multidisciplinary skills and communication are also required for L4.0. Both sectors use advanced technology for I4.0 competencies which encourages the growth and adoption of L4.0 is demonstrated by Sapper et al., (2021)[198]. Richnak, (2022) found a strong link between I4.0 technologies and various logistical processes. This study examined how I4.0 and L4.0 are strongly connected by the implementation of advanced technologies in logistics processes. The effective implementation of these technologies in logistics increases adaptability, flexibility, and productivity [121]. Qureshi et al., (2024) examined the relationship between I4.0 technologies and L4.0. This study emphasizes their importance in enhancing sustainability in the supply chain of companies. I4.0 technologies, including CC, BD, IoTs and robotics, significantly improve the sustainability and efficiency of logistics operations. The results of this study also supported I4.0 technologies in L4.0 which improved sustainability in manufacturing logistics [39]. According to ElkeGlistau., (2018), I4.0 and L4.0 are interconnected, their primary focus is on digitalization, and the incorporation of advanced technology into manufacturing and logistics. This relationship enables supply chains to be more automated, sustainable and efficient. The use of I4.0 technology in L4.0 improves business models in their operations across manufacturing and logistics sectors [199]. A study investigated the relationship between I4.0 and L4.0 using the concept of maturity models. Automation, CPS, IoT and data sharing from I4.0 are being applied to promote L4.0 [45]. The study was conducted by Douaioui et al., (2018), who emphasized that the successful adoption of I4.0 relies on L4.0. I4.0 technologies such as IoTs, CPS, DS and automation are critical for enhancing logistics by enabling continuous monitoring and management of risks. Logistics needs to be as flexible and agile as manufacturing processes to accomplish the objectives of I4.0. In short, L4.0 is important for promoting I4.0 through facilitating just-in-time, personalized, and cost-effective delivery networks [34].Michowics, (2022) investigated the role of logistics in the context of I4.0 and the digital factory. The findings highlighted the significance of successful logistics techniques in achieving productivity through L4.0 and I4.0in modern production systems[61].

6.8. Sustainable Operations and Performance

Over the last 20 years, there has been a growing focus on organizations to pay more focus towards the environment[200]. In recent years, organizations that prioritize sustainability in their operations have received a lot of recognition. Over the past 6 to 8 years, sustainability has received a lot of attention from researchers and organizations[201]. Many sustainability outcomes are strongly affected by operations management decisions [202]. Sustainability management practices and strategies are growing rapidly as sustainability becomes a more serious issue for many organizations [203]. Sustainable Operations started to get attention over the past few years. Operations that are carried through by integrating sustainable development principles are known as sustainable operations. The capability of an organization to function in a way that maximizes long-lasting success while minimizing adverse effects on the environment, society, and economy is referred to as sustainable performance [204]. Moreover, the primary goal of organizations pursuing sustainable performance is to reduce the negative effects that transportation, services, and manufacturing have on the environment [205], [206].

By highlighting the integration of environmental and social goals into operations management, Bettley and Burnley (2008) investigated a connection between sustainable operations and sustainable performance. The findings demonstrated that stakeholder-driven strategies and closed-loop supply chains are the main sustainable performance indicators. Furthermore, sustainable operations improve value generation and sustainable organizational performance [203]. According to Warhurst, (2022), the development and implementation of sustainability performance indicators evaluate and represent contributions to the sustainable creation goals. This study highlighted the significance of sustainable performance indicators in linking with sustainable operations and found that sustainability performance control, evaluate, and assesses the operations management systems [207]. Another study offered a technique for identifying and analyzing key business-related and environmental performance indicators in order to improve sustainable performance in the supply chain. This study highlighted that information loss, effective measurement and reducing complexity are the key performance indicators that promote sustainable operations and help supply chain management achieve better sustainable performance outcomes [208]. Another study was carried out in the manufacturing sectors of Malaysia to examine the link between sustainable operations and sustainability performance, considering social, economic, and environmental factors. To help industries evaluate sustainability and identify strategies to improve performance, a framework was developed that showed a significant influence on sustainability performance [209]. D' Agostini et., (2017) also conducted a study in which they examined the relationship between sustainable operations and sustainable performance. This study revealed a positive relationship and impact between sustainable operations and sustainable performance [210].The impact of lean operations on sustainable performance outcomes was investigated by Piercy & Rich. Additionally, it highlighted that lean approaches and sustainable operations enhance overall sustainability performance [211]. Adum et al., (2020), examined the relationship between sustainable operations, sustainable performance, and green manufacturing practices. It found that green practices have a positive effect and overall sustainable performance can be improved by incorporating green practices into sustainable operations [212].A fundamental competitive capability of every organization is sustainable performance, which depends on economic, social, and environmental factors [213]. The economic dimension assists businesses in measuring the economic aspects of their sustainable performance, including, good quality, profitability, investment, costs, and profit [214], while the social dimension measures the satisfaction of employees, customers, and the community [163]. The environmental dimension encompasses the energy, water, and resources used throughout processes [106], [215].

7. THEMATIC ANALYSIS

Thematic analysis is a qualitative analysis that is used to analyze the themes, classifications, topics and ideas which are related to the data [216]. Thematic analysis has gained wide attention because it is a useful, unique, flexible, approachable, adaptable, and more established qualitative approach [217], [218]. Thematic analysis was conducted under these headings in which the results of the various studies are discussed reflecting the adoption of I4.0, the impact of I4.0 on sustainable operations and sustainable performance, and the impact of L4.0 on the sustainable operations and sustainable performance in the different industrial sectors in different countries. In addition, the thematic analysis also helped the authors to analyze and link the findings of the considered studies related to the themes as presented in the below-given headings.

7.1. I4.0 and the Adoption of Sustainable Operations

I4.0 integrates digital technologies including, IoT, AI, CC, ML, CPS, AM, blockchain, robots, sensors and automation in manufacturing operations to improve productivity, efficiency, flexibility, and sustainability [106]. The integration of modern technologies to promote environmental and social sustainability was achieved by the implementation of sustainable operations in the framework of I4.0 [25]. According to Machado et al., (2020), resources like energy, raw materials and capital can be utilized more efficiently by integration of I4.0 technologies. For instance, sensors and IoTscan measure the consumption of energy and detect inadequacies instantly in business operations [219]. Dubey et al., (2017), stated that organizations can develop excellent sustainable manufacturing systems by effectively integrating Industry 4.0 with environmentally friendly practices [220]. According to Wang et al. (2016), many I4.0-based technologies have the potential to make operations more sustainable [221]. ML, IoTblockchain, and machine learning are examples of I4.0-based technologies that many Indian businesses are starting to implement to develop sustainable operations in their business as these technologies are found to increase process efficiency [217]. A survey of the literature showed that countries including the United States, Hungary, Germany, China, Austria, Italy, and India, have adopted the I4.0 concept to develop sustainable operations in their businesses which assist companies in achieving sustainability [222]. Hozdie, (2015), found out that I4.0 technologies including AM, CPS, IoT, and CM are the key technologies that play an important role in achieving the sustainable operations [222]. To determine the main barriers hindering SC from sustainable operations in the context of I4.0, another study was conducted by Tsaramirsis et al., (2022). The findings demonstrated a positive relationship with digitalized manufacturing processes that are more effective and affordable [184]. In order to achieve sustainable operations, the IoT, CPS, AM and CM were the four main I4.0 technologies claimed by Jabbour et al., (2018) [223]. Lardo& Russo, (2020) claimed that the use of I4.0 technologies offers an effective path towards sustainable operations and corporate social responsibility [224]. Bag et al., (2021) stated that I4.0 Technologies will support efficient product life cycle management and create sustainable operations. Furthermore, this study revealed that companies must integrate advanced technologies, such as IoT, 3D printing, and CPS to create a new inventive environment in industry operations [225]. According to Pacaux-Lemoine and Trentesaux (2019), I4.0 is a speculative idea that promotes the growth of autonomous production systems through the use of IoT, CPS, and AI [226]. Man and Strandhagen (2017) claim that integrating I4.0 technologies in value chains leads to proposed sustainable operations management decisions. Results showed that sustainable operations management helps in implementing the relationship between I4.0 methodologies and circular economy principles [227]. The successful adoption of I4.0 technologies provides the foundation for the proposed CE framework and its implementation was demonstrated by (Gunasekaran et al., 2014). This study highlighted that sustainable operations management can be divided into sustainable logistics choices, procedures, and products [228]. Khan et al., (2021) analyzed sustainable and industrial operations in the context of I4.0 the results indicated that CE, security, smart communication, safety, CPS, BD, BI, AI, VR and sustainability are the main technologies of I4.0 that help the organizations to achieve the sustainable operations [229].

7.2. Impact of I4.0 on Sustainable Performance

In recent years, I4.0 technologies and sustainable performance have gained popularity among both academics and practitioners. I4.0 refers to solutions that use digitalization and smart devices to boost productivity, reduce costs and i mprove business performance [106]. A study was carried out to investigate the impact of circular economy capabilities and corporate sustainability performance by I4.0 capabilities. The results showed that GSCI, SSCF, and I4.0 technologies greatly enhance the circular economy, promoting business sustainability. In order to achieve sustainable development goals, Industry 4.0 needs to be in line with circular economy actions [230]. Technologies such as additive manufacturing, IoT, AI and big data analytics are revolutionizing manufacturing and manufacturing techniques from the perspective of I4.0, which is defined by the integration of digital, physical, and biological systems [231]. These technologies greatly improve sustainable performance in addition to increasing operational efficiency and productivity [17]. Real-time data from machinery is gathered by IoT devices and sensors, allowing for effective resource management and predictive maintenance, which lowers waste and carbon emissions. AI and machine learning algorithms improve decision-making, forecast equipment breakdowns, and optimize logistics, all of which lead to lower emissions and more efficiency. BDA provides insights into optimizing supply chains and enhancing resource utilization [90]. While AM (3D printing) enables customized production with little waste, reducing supply chains and permitting the use of sustainable materials, advanced robots increase precision and safety, minimize workplace injuries, and reduce material waste [2]. Digital twins simulate and analyze performance to find inefficiencies and optimize operations, while CPS improves real-time monitoring and control of activities, boosting energy efficiency and waste minimization. Blockchain technology supports ethical sourcing and circular economy principles by ensuring transparency and security in tracking transactions and supply chain activity [230]. Large datasets can be stored and analyzed more easily with cloud computing, which also allows for remote monitoring and less physical infrastructure, which reduces resources [232]. Moreover, I4.0 technologies reduce dependency on fossil fuels by enabling the integration of renewable energy sources into industrial processes through smart grids and energy management systems [219], [233]. In conclusion, I4.0 technologies are essential for promoting sustainable performance because they minimize environmental effects, reduce waste, and improve efficiency. This helps businesses maintain a balance between social responsibility, environmental stewardship, and economic growth [74]. To summarise, I4.0 technologies play an essential role in encouraging sustainable performance by optimizing productivity, cutting down on waste, and mitigating environmental effects [230]. By implementing these technologies, businesses can strike a balance between social responsibility, environmental protection, and economic growth. Organizations may increase their competitiveness and further the larger objective of sustainable development by utilizing I4.0 [29]. SMEs must use cutting-edge technology in the current competitive atmosphere to understand I4.0 dynamics and sustainable operations for operational excellence [36]. I4.0 is essentially the expression of technologies that, as a result of digitalization and smart devices, improve corporate performance, lower costs, and boost efficiency [106], [205].

7.3. L4.0 and the Adoption of Sustainable Operations

According to the literature, L4.0 promotes high transparency, enhanced traceability and visibility across manufacturing sustainable operations and supply chains. L4.0 improved flexibility, control capability, decision-making capability, reduced cost, and enhanced sustainability in operations in manufacturing organizations [234], [100], [17].Kumaran et al., (2024) revealed that L4.0 plays an important role in driving sustainable operations by smart technologies to optimize distribution, manufacturing, delivery and procurement processes. L4.0 enhanced sustainability and productivity by promoting sustainable operations by minimizing the environmental effects. By focusing on digitalization with triple bottom line, L4.0 enhanced social, economic and environmental practices [235]. L4.0 including Data analysis and automation (IoT, CC, BD and Robotics) has a significant impact on sustainable operations management and production management and plays a main role in manufacturing processes and supply chains to achieve sustainability goals was studied by Qureshi et al., (2024) [39]. HadiBaloueiJamkaneh, (2022) examined the impact of emerging technologies as enablers of sustainable operations and identified L4.0 and Service Quality criteria. The criteria were categorized as social value and technologies including AI, AM, advanced robotics and blockchain were found to be essential for sustainable operations. These results help firms boost operational flexibility, enhance service quality, and integrate logistical procedures with sustainable objectives [236].

7.4. Impact of L4.0 on the Sustainable Performance

Sustainable performance in manufacturing is enhanced through the role of L4.0 [237], [238]. According to BalouelJamkhaneh, et al., (2022), to achieve sustainable performance, every business has to move towards sustainability. In order to incorporate sustainability (social, economic, and environmental) into their operations, logistics companies need to concentrate on the three mentioned aspects. A study was carried out that revealed L4.0 promotes supply chain traceability and transparency, all of which are necessary for long-term success [13]. L4.0 technology such as blockchain technology can offer an unchangeable record of each movement and transaction inside the supply chain to improve sustainable performance [66]. Additionally, L4.0 promotes sustainable performance and circular economy by making it easier to manage returns, recycling, and remanufacturing procedures effectively [239]. Research was carried out to examine the production process in light of sustainability and L4.0. The findings showed that the major performance indicators that offered insights into linking L4.0 practices with sustainable performance goals were waste management, lead time, energy efficiency, flexibility, and automation [87]. Qureshi et al., (2024) conducted a study to promote sustainability in manufacturing supply chains with the help of I4.0 and L4.0 technologies including CC, IoT and robotics. According to the findings of this study, L4.0 technologies support SMEs and logistics companies in achieving sustainable performance of logistics and help in the accomplishment of sustainability objectives [39]. Doha et al., (2016) stated that L4.0 encourages organizations to achieve sustainable performance with a concentration on ICT, sensors, human-machine interaction and lean management [240]. Employing L4.0 technologies like IoT, AI, and blockchain improved sustainable performance by reducing emissions, and optimizing resource utilization. To ensure alignment with sustainable goals managerial commitment, and technology infrastructure were the key drivers which helped businesses attain sustainable supply chain performance over the long run [47]. Catarina et al., (2023) integrated lean manufacturing and I4.0, this study highlighted how lean L4.0 promotes continuous logistics improvement while accomplishing sustainability objectives. Setup reduction, waste reduction, and cost control were the key performance indicators[241]. Lean L4.0 helps companies to decrease costs, improve supply chain, increase efficiency and reduce environmental impact by optimizing resources to enhance sustainable performance in logistics operations [242], [243]. It helps organizations to achieve operations management drivers including lean manufacturing, supply chain, and total quality management in order to enhance the productivity and optimization of manufacturing process [244], [245], [246], [247].

8. FINDINGS FROM THE LITERATURE

Several important conclusions have been identified from the case studies and literature study. Using I4.0 and L4.0 technologies increases the operating efficiency significantly in businesses. Manufacturing processes become more efficient and flexible and waste is decreased through automation, IoT integration, and real-time data analytics. These technologies minimize environmental impact and maximize resource utilization to enable sustainable operations. Businesses using these technologies report improved overall results. Metrics that track progress include customer satisfaction, quality control, and manufacturing speed [248]. Notwithstanding its advantages, L4.0 and I4.0 are not yet widely adopted because of barriers (policy, rules, and laws) and challenges in many countries [157]. These include the requirement for qualified workers, cybersecurity issues, and hefty initial investment prices. Many industries, including manufacturing, logistics, and the automotive sector, have successfully implemented these technologies and shown notable gains in performance and sustainability [249]. Businesses may swiftly make well-informed decisions, optimize inventory levels, and save lead times by utilizing big data and advanced analytics [119]. Robotic process automation (RPA) and automated guided vehicles (AGVs) are examples of automated systems that boost throughput, decrease human error, and streamline activities. By maximizing the use of energy, materials, and other resources, smart systems minimize waste and its negative effects on the environment. Energy management systems and smart grids are two examples of technologies that monitor and control energy consumption, resulting in significant energy savings. Through improved load planning and routing, enhanced logistics planning and execution lower emissions. High standards of quality are ensured by sophisticated sensors and AI-driven inspection systems, which lower defects and recall rates. Even with the obvious advantages, many obstacles are preventing these technologies from being widely used. Implementation of I4.0 and L4.0 calls for large capital investments in new infrastructure, technology, and training. Businesses need to implement strong security measures because of the increased connection and reliance on digital technologies, which exposes them to cybersecurity threats. The demand for workers knowledgeable in cutting-edge technologies is rising, making education and training expenditures necessary. Efficiency is determined by L4.0. It realizes tiny batch sizes and scalable infrastructure while reducing transaction costs and enabling flexibility inside networks [250]. It has been noted that L4.0 capabilities are significantly impacted by organizational, technological, and environmental capabilities. Nonetheless, it has been discovered that the results of environmental and technological capabilities on L4.0 capabilities have a major impact on business success [76]. To encounter the demands of I4.0, the concept of L4.0, encompasses the most recent information and communication technology (ICT), software programs, and innovative business models and ideas that work together to fully digitalize and automate logistics operations [41]. Key elements for the adoption of L4.0 are financial investment, IT infrastructure, and top management support examined by [68].

9. CONCLUSION

The main objective of the paper is to determine the relationship and impact of I4.0 and L4.0 on the manufacturing and logistics industries. Logistics is an essential part of the supply chain, and companies pay serious attention to them. Customers benefit from the implementation of L4.0 due to increased traceability, short lead times and transparency. This study covered a wide range of I4.0 technologies that fall under the L4.0. It is concluded that key technologies like blockchain, AI, BD, simulation, IoT, CC, CS, AR, AM, sensors and robotics are essential to the long-term growth of logistics in companies of various sectors. These technologies increase the efficiency, productivity, and profitability of companies. It is obvious that without I4.0, L4.0 is impractical and to help the industries, establish their future development strategy and have a clear understanding of what L4.0 entails, this study includes key technological components being used for logistics in the various sectors and their impact on the adoption of sustainable operations and performance of the company.The findings showed that implementing I4.0 and L4.0 technologies can improve sustainability in manufacturing. The research in I4.0 and L4.0 in manufacturing industries has various new scopes that help in sustainable operations and achieve sustainable performance. The findings of this study show that I4.0 and L4.0 have a considerable impact and connection with each other. Furthermore, it was concluded that I.40 and L4.0 have a favorable connection and influence on sustainable operations and performance. The study's findings will provide valuable insights to both business and academic executives. This paper discusses the relationship between Industry 4.0 and Logistics 4.0, in addition to the role of technologies and their contributions in their implementation in the logistics process. Logistics 4.0 offers several advantages, including improved data visibility and connectivity, a physical network with fast and dependable delivery options, logistics productivity efficiency, and a reduced negative impact on the environment.

10. LIMITATIONS AND FUTURE SUGGESTIONS

This study focused on the manufacturing and logistics sector other studies will be carried out in various sectors such as healthcare, education, and agriculture. This study is based on the literature review additional studies will be carried real-world case studies to support these technologies. This study mainly focuses on sustainable performance further study will be conducted by focusing on operational, and financial performance. Further studies should focus on framework development using I4.0 and L4.0 technologies in large and small organizations to achieve effective outcomes.

11. CONFLICT OF INTEREST

There was no conflict of interest among the authors of the present research.

REFERENCES

[1] R. Nour, “Enhancing the Logistics 4.0 Firms through Information Technology,” *Sustain.*, vol. 14, no. 23, 2022, doi: 10.3390/su142315860.

[2] C. Danjou *et al.*, “Industry 4.0 in Construction Site Logistics: A Comparative Analysis of Research and Practice,” *J. Mod. Proj. Manag.*, vol. 7, no. 4, pp. 296–310, 2020, doi: 10.19255/JMPM02214.

[3] J. H. C. Nobrega *et al.*, “Logistics 4.0 in brazil: Critical analysis and relationships with sdg 9 targets,” *Sustain.*, vol. 13, no. 23, 2021, doi: 10.3390/su132313012.

[4] N. T. Ching, M. Ghobakhloo, M. Iranmanesh, P. Maroufkhani, and S. Asadi, “Industry 4.0 applications for sustainable manufacturing: A systematic literature review and a roadmap to sustainable development,” *J. Clean. Prod.*, vol. 334, no. December 2020, p. 130133, 2022, doi: 10.1016/j.jclepro.2021.130133.

[5] S. Khan, R. Singh, A. Haleem, J. Dsilva, and S. S. Ali, “Exploration of Critical Success Factors of Logistics 4.0: A DEMATEL Approach,” *Logistics*, vol. 6, no. 1, pp. 1–14, 2022, doi: 10.3390/logistics6010013.

[6] O. K. Efthymiou and S. T. Ponis, “Industry 4.0 technologies and their impact in contemporary logistics: A systematic literature review,” *Sustain.*, vol. 13, no. 21, 2021, doi: 10.3390/su132111643.

[7] O. Kodym, L. Kubáč, and L. Kavka, “Risks associated with Logistics 4.0 and their minimization using Blockchain,” *Open Eng.*, vol. 10, no. 1, pp. 74–85, 2020, doi: 10.1515/eng-2020-0017.

[8] B. J. Soledispa-Cañarte *et al.*, “Advancing Agribusiness Sustainability and Competitiveness Through Logistics 4.0: a Bibliometric and Systematic Literature Review,” *Logforum*, vol. 19, no. 1, pp. 155–168, 2023, doi: 10.17270/J.LOG.2023.807.

[9] E. Competitiveness, C. Abul, A. Rashed, M. N. Bagum, and M. H. Kibria, “Integrating Supply Chain Partners through Implementing Industry,” *Jordan Journal of Mechanical and Industrial Engineering*, vol. 1, no. 2, pp. 351–363, 2024.

[10] P. Dallasega, M. Woschank, J. Sarkis, and K. Y. Tippayawong, “Logistics 4.0 measurement model: empirical validation based on an international survey,” *Ind. Manag. Data Syst.*, vol. 122, no. 5, pp. 1384–1409, 2022, doi: 10.1108/IMDS-11-2021-0694.

[11] G. Samawi, “A Structural Quality Model for New Product Development to Enhance Resilience in Closed-Loop Formulated Food Supply Chains,” *Jordan Journal of Mechanical and Industrial Engineering*, vol. 1, no. 4, pp. 671–689, 2024.

[12] Daniel Gracia-Rodriguez, “Environmental Practices in Logistics and Their Effectiveness in Organizations,” *Russ. Law J.*, vol. 11, no. 8s, pp. 842–853, 2023, doi: 10.52783/rlj.v11i8s.1426.

[13] C. Cimini, A. Lagorio, F. Pirola, and R. Pinto, “Exploring human factors in Logistics 4.0: Empirical evidence from a case study,” *IFAC-PapersOnLine*, vol. 52, no. 13, pp. 2183–2188, 2019, doi: 10.1016/j.ifacol.2019.11.529.

[14] A. Edirisuriya, S. Weerabahu, and R. Wickramarachchi, “Applicability of Lean and Green Concepts in Logistics 4.0: A Systematic Review of Literature,” in *International Conference on Production and Operations Management Society, POMS 2018*, IEEE, 2018, pp. 1–8. doi: 10.1109/POMS.2018.8629443.

[15] S. Kumar, A. Goyal, and A. Singhal, “Manufacturing Flexibility and its Effect on System Performance,” *Jordan Journal of Mechanical and Industrial Engineering*, vol. 11, no. 2, pp. 105–112, 2017.

[16] G. Dubey, R. K. Gupta, S. Kumar, and M. Kumar, “Study of industry 4.0 pillars and their uses in increasing productivity and reducing logistics defects,” in *Materials Today: Proceedings*, Elsevier Ltd, 2022, pp. 85–91. doi: 10.1016/j.matpr.2022.02.335.

[17] L. Barreto, A. Amaral, and T. Pereira, “Industry 4.0 implications in logistics: an overview,” *Procedia Manuf.*, vol. 13, pp. 1245–1252, 2017, doi: 10.1016/j.promfg.2017.09.045.

[18] N. Schmidtke, F. Behrendt, L. Thater, and S. Meixner, “Technical potentials and challenges within internal logistics 4.0,” in *Proceedings of 4th IEEE International Conference on Logistics Operations Management*, IEEE, 2018, pp. 1–10. doi: 10.1109/GOL.2018.8378072.

[19] M. Zoubek and M. Simon, “A framework for a logistics 4.0 maturity model with a specification for internal logistics,” *MM Sci. J.*, pp. 4264–4274, 2021, doi: 10.17973/MMSJ.2021_03_2020073.

[20] O. Maiboroda *et al.*, “Assessment of Perspective Development of Transport and Logistics Systems at Macro and Micro Level under the Conditions of Industry 4.0 Integration,” *IJCSNS Int. J. Comput. Sci. Netw. Secur.*, vol. 21, no. 3, p. 235, 2021, doi: 10.22937/IJCSNS.2021.21.3.32.

[21] D. Al, A. Abu, and H. Taleb, “Assessing the Thermal Effectiveness of Implementing Green Roofs in the Urban Neighborhood,” *Jordan Journal of Mechanical and Industrial Engineering*, vol. 13, no. 3, pp. 161–174, 2019.

[22] M. Imran, W. ul Hameed, and A. ul Haque, "Influence of Industry 4.0 on the production and service sectors in Pakistan: Evidence from textile and logistics industries," *Soc. Sci.*, vol. 7, no. 12, 2018, doi: 10.3390/socsci7120246.

[23] C. L. Karmaker, R. Al Aziz, T. Ahmed, S. M. Misbauddin, and M. A. Moktadir, "Impact of industry 4.0 technologies on sustainable supply chain performance: The mediating role of green supply chain management practices and circular economy," *J. Clean. Prod.*, vol. 419, no. December 2022, p. 138249, 2023, doi: 10.1016/j.jclepro.2023.138249.

[24] K. Aravindaraj and P. Rajan Chinna, "A systematic literature review of integration of industry 4.0 and warehouse management to achieve Sustainable Development Goals (SDGs)," *Clean. Logist. Supply Chain*, vol. 5, no. July, 2022, doi: 10.1016/j.clscn.2022.100072.

[25] A. Behl, R. Singh, V. Pereira, and B. Laker, "Analysis of Industry 4.0 and circular economy enablers: A step towards resilient sustainable operations management," *Technol. Forecast. Soc. Change*, vol. 189, no. December 2022, p. 122363, 2023, doi: 10.1016/j.techfore.2023.122363.

[26] M. Beltrami, G. Orzes, J. Sarkis, and M. Sartor, "Industry 4.0 and sustainability: Towards conceptualization and theory," *J. Clean. Prod.*, vol. 312, p. 127733, 2021, doi: 10.1016/j.jclepro.2021.127733.

[27] T. Stock and G. Seliger, "Opportunities of Sustainable Manufacturing in Industry 4.0," *Procedia CIRP*, vol. 40, no. Icc, pp. 536–541, 2016, doi: 10.1016/j.procir.2016.01.129.

[28] E. Hofmann and M. Rüsch, "Industry 4.0 and the current status as well as future prospects on logistics," *Elsevier*, vol. 89, pp. 23–34, 2017, doi: 10.1016/j.compind.2017.04.002.

[29] S. Bag, G. Yadav, L. C. Wood, P. Dhamija, and S. Joshi, "Industry 4.0 and the circular economy: Resource melioration in logistics," *Resour. Policy*, vol. 68, no. May, p. 101776, 2020, doi: 10.1016/j.resourpol.2020.101776.

[30] M. Pourmehdi, M. M. Paydar, P. Ghadimi, and A. H. Azadnia, "Analysis and evaluation of challenges in the integration of Industry 4.0 and sustainable steel reverse logistics network," *Comput. Ind. Eng.*, vol. 163, no. October 2021, p. 107808, 2022, doi: 10.1016/j.cie.2021.107808.

[31] N. K. Dev, R. Shankar, and F. H. Qaiser, "Industry 4.0 and circular economy: Operational excellence for sustainable reverse supply chain performance," *Resour. Conserv. Recycl.*, vol. 153, no. November 2019, p. 104583, 2020, doi: 10.1016/j.resconrec.2019.104583.

[32] P. Kumar, R. K. Singh, and V. Kumar, "Managing supply chains for sustainable operations in the era of industry 4.0 and circular economy: Analysis of barriers," *Resour. Conserv. Recycl.*, vol. 164, no. March 2020, p. 105215, 2021, doi: 10.1016/j.resconrec.2020.105215.

[33] S. Kayapinar, "THE PAST, PRESENT AND FUTURE OF INDUSTRY 4.0: LOGISTICS SECTOR," *Uluslararası Bölgesel Kalkınma Konf.*, no. September 2017, pp. 21–23, 2017, [Online]. Available: www.lojiport.com,

[34] K. Douaioui, M. Fri, C. Mabroukki, and E. A. Semma, "The interaction between industry 4.0 and smart logistics: Concepts and perspectives," *Int. Colloq. Logist. Supply Chain Manag. LOGISTIQUA 2018*, pp. 128–132, 2018, doi: 10.1109/LOGISTIQUA.2018.8428300.

[35] S. Ferraro, A. Cantini, L. Leoni, and F. De Carlo, "Sustainable Logistics 4.0: A Study on Selecting the Best Technology for Internal Material Handling," *Sustain.*, vol. 15, no. 9, 2023, doi: 10.3390/su15097067.

[36] S. Gupta, B. Prathipati, G. S. Dangayach, P. N. Rao, and S. Jagtap, "Development of a Structural Model for the Adoption of Industry 4.0 Enabled Sustainable Operations for Operational Excellence," *Sustain.*, vol. 14, no. 17, 2022, doi: 10.3390/su141711103.

[37] J. Vrchota, M. Pech, L. Rolínek, and J. Bednář, "Sustainability outcomes of green processes in relation to industry 4.0 in manufacturing: Systematic review," *Sustain.*, vol. 12, no. 15, 2020, doi: 10.3390/su12155968.

[38] J. O. Strandhagen, L. R. Vallandingham, G. Fragapane, J. W. Strandhagen, A. B. H. Stangeland, and N. Sharma, "Logistics 4.0 and emerging sustainable business models," *Adv. Manuf.*, vol. 5, no. 4, pp. 359–369, 2017, doi: 10.1007/s40436-017-0198-1.

[39] K. M. Qureshi, B. G. Mewada, S. Kaur, A. Khan, M. M. Al-Qahtani, and M. R. N. M. Qureshi, "Investigating industry 4.0 technologies in logistics 4.0 usage towards sustainable manufacturing supply chain," *Heliyon*, vol. 10, no. 10, p. e30661, 2024, doi: 10.1016/j.heliyon.2024.e30661.

[40] E. Glistau and N. I. C. Machado, "Logistics 4.0 and the revalidation of logistics concepts and strategies," in *ResearchGate*, 2018. doi: 10.26649/musci.2018.023.

[41] G. Radivojević and L. Milosavljević, "The Concept of Logistics 4.0," in *4th Logistics International Conference*, Serbia, 2019, pp. 283–292.

[42] M. Alazab and S. Alhyari, "Industry 4.0 Innovation: A Systematic Literature Review on the Role of Blockchain Technology in Creating Smart and Sustainable Manufacturing Facilities," *Inf.*, vol. 15, no. 2, 2024, doi: 10.3390/info15020078.

[43] A. A. Tubis and K. Grzybowska, "In Search of Industry 4.0 and Logistics 4.0 in Small-Medium Enterprises—A State of the Art Review," *Energies*, vol. 15, 2022.

[44] A. A. Szabó, Á. B. Tóth, and B. Illés, "Industry 4.0 and logistics 4.0 – intelligent designs in FMCG logistics," *Adv. Logist. Syst. - Theory Pract.*, vol. 14, no. 1, pp. 14–24, 2020, [Online]. Available: https://als.uni-miskolc.hu/index.php/als/article/view/110

[45] M. Sternad, T. Lerher, and B. Gajsek, "Maturity levels for logistics 4.0 based on NRW's industry 4.0 maturity model," *18th Int. Sci. Conf. Bus. Logist. Mod. Manag.*, pp. 695–708, 2018.

[46] S. Bag and J. H. C. Pretorius, "Relationships between industry 4.0, sustainable manufacturing and circular economy: proposal of a research framework," *Int. J. Organ. Anal.*, vol. 30, no. 4, pp. 864–898, 2022, doi: 10.1108/IJOA-04-2020-2120.

[47] S. Parhi, K. Joshi, A. Gunasekaran, and K. Sethuraman, "Reflecting on an empirical study of the digitalization initiatives for sustainability on logistics: The concept of sustainable logistics 4.0," *Clean. Logist. Supply Chain*, vol. 4, no. May, p. 100058, 2022, doi: 10.1016/j.clscn.2022.100058.

[48] H. Balouei Jamkhaneh, R. Shahin, and G. L. Tortorella, "Analysis of Logistics 4.0 service quality and its sustainability enabler scenarios in emerging economy," *Clean. Logist. Supply Chain*, vol. 4, no. April, p. 100053, 2022, doi: 10.1016/j.clscn.2022.100053.

[49] I. Antoniuk, R. Svitek, M. Krajcovic, and B. Furmannová, "Methodology of design and optimization of internal logistics in the concept of Industry 4.0," *Transp. Res. Procedia*, vol. 55, pp. 503–509, 2021, doi: 10.1016/j.trpro.2021.07.093.

[50] J. A. Farooquie and A. B. Mohapatra, "Japanese Manufacturing Techniques and Practices: An Indian Perspective," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 3, no. 3, pp. 174–181, 2009.

[51] F. Facchini, J. Oleśków-Szłapka, L. Ranieri, and A. Urbinati, "A maturity model for logistics 4.0: An empirical analysis and a roadmap for future research," *Sustain.*, vol. 12, no. 1, pp. 1–18, 2020, doi: 10.3390/SU12010086.

[52] Ü. Taş, "Case Study of Intralogistics in the Framework of Logistics 4.0," *Int. J. Automot. Sci. Technol.*, vol. 7, no. 1, pp. 18–24, 2023, doi: 10.30939/ijastech..1215381.

[53] B. Bigliardi, G. Casella, and E. Bottani, "Industry 4.0 in the logistics field: A bibliometric analysis," *IET Collab. Intell.*

Manuf., vol. 3, no. 1, pp. 4–12, 2021, doi: 10.1049/cim2.12015.

[54] D. Kozma, P. Varga, and C. Hegedus, "Supply Chain Management and Logistics 4.0-A Study on Arrowhead Framework Integration," in *Proceedings of 8th International Conference on Industrial Technology and Management, ICITM*, 2019, pp. 12–16. doi: 10.1109/ICITM.2019.8710670.

[55] D. Čámská and J. Klečka, "Cost development in logistics due to industry 4.0," *Logforum*, vol. 16, no. 2, pp. 219–227, 2020, doi: 10.17270/J.LOG.2020.415.

[56] M. Jreissat and L. Jraisat, "Sustainable Dyads in Supply Chain Management : A Qualitative," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 13, no. 4, pp. 277–290, 2019.

[57] P. Swarm and G. Algorithms, "Optimization of a Closed Loop Green Supply Chain using," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 12, no. 2, pp. 77–91, 2018.

[58] E. Glistau and N. I. Coello-Machado, "Solutions and Trends in Logistics 4.0," *Acta Polytech. Scand. Electr. Eng.*, no. December, pp. 129–132, 2019.

[59] M. Erdoğdu, "Development of Logistics Management and Relationship with Industry," *Int. J. Eng. Sci. Technol.*, vol. 3, no. 2, pp. 91–112, 2021, doi: 10.46328/ijonest.51.

[60] L. D. Galindo, "The Challenges of Logistics 4.0 for the Supply Chain Management and the Information Technology," Norwegian University of science and technology, 2016.

[61] E. Michlowics, "Logistics engineering and industry 4.0 and digital factory," *Arch. Transp.*, vol. 57, no. 1, pp. 59–72, 2021, doi: 10.5604/01.3001.0014.7484.

[62] M. Amr and A. Elkader, "Logistics 4 . 0 Technologies in Agriculture Systems : Potential," *Int. Assoc. Manag. Technol.*, vol. 1, pp. 1–14, 2020.

[63] N. Trushkina, H. Dzwigol, O. Serhieieva, and Y. Shkrygun, "Development of the Logistics 4.0 Concept in the Digital Economy," *Econ. Her. Donbas*, vol. 4, no. 62, pp. 85–96, 2020, doi: 10.12958/1817-3772-2020-4(62)-85-96.

[64] N. Schmidtke, E. Glistau, and F. Behrendt, "Magdeburg Logistics Model – the Smart Logistics Zone As a Concept for Enabling Logistics 4.0 Technologies," *Adv. Logist. Syst. - Theory Pract.*, vol. 13, no. 1, pp. 7–16, 2019, doi: 10.32971/als.2019.007.

[65] J. Olesskόw-Szłapka, H. Wojciechowski, R. Domański, and G. Pawłowski, "Logistics 4.0 maturity levels assessed based on GDM (grey decision model) and artificial intelligence in logistics 4.0 -trends and future perspective," *Procedia Manuf.*, vol. 39, no. 2019, pp. 1734–1742, 2019, doi: 10.1016/j.promfg.2020.01.266.

[66] E. Kim, Y. Kim, and J. Park, "The Necessity of Introducing Autonomous Trucks in Logistics 4.0," *Sustain.*, vol. 14, no. 7, pp. 1–10, 2022, doi: 10.3390/su14073978.

[67] S. W. & E. H. Grosse, "Logistics 4.0: A systematic review towards a new logistics system," *Int. J. Prod. Res.*, vol. 58, no. 1, p. 18–43., 2020.

[68] S. Khan, R. Singh, J. C. Sá, G. Santos, and L. P. Ferreira, "Modelling of Determinants of Logistics 4.0 Adoption: Insights from Developing Countries," *Machines*, vol. 10, no. 12, 2022, doi: 10.3390/machines10121242.

[69] K. Markov and P. Vitliemov, "Logistics 4.0 and supply chain 4.0 in the automotive industry," in *IOP Conference Series: Materials Science and Engineering*, 2020, pp. 0–6. doi: 10.1088/1757-899X/878/1/012047.

[70] T. Albrecht *et al.*, "Leveraging Digital Technologies in Logistics 4.0: Insights on Affordances from Intralogistics Processes," *Inf. Syst. Front.*, vol. 26, no. 2, pp. 755–774, 2024, doi: 10.1007/s10796-023-10394-6.

[71] N. Vasiulis Ferreira Rodrigues, P. De Camargo Fiorini, and É. Luiz Piato, "Logistics 4.0 and corporate sustainability: an organizational theory perspective," *Rev. Gestão da Produção Operações e Sist.*, vol. 17, no. 4, pp. 108–132, 2022, doi: 10.15675/gepros.v17i5.2950.

[72] P. Helo and V. V Thai, "International Journal of Production Economics Logistics 4 . 0 – digital transformation with smart connected tracking and tracing devices," *Int. J. Prod. Econ.*, vol. 275, no. July, p. 109336, 2024, doi: 10.1016/j.ijpe.2024.109336.

[73] P. Morella, M. P. Lambán, J. Royo, J. C. Sánchez, and J. Latapia, "Technologies Associated with Industry 4.0 in Green Supply Chains: A Systematic Literature Review," *Sustain.*, vol. 15, no. 12, 2023, doi: 10.3390/su15129784.

[74] B. Ślusarczyk, R. J. Nathan, and P. Pypłacz, "Employee preparedness for industry 4.0 in logistic sector: A cross-national study between poland and malaysia," *Soc. Sci.*, vol. 10, no. 7, 2021, doi: 10.3390/socsci10070258.

[75] A. L. Junge, "Digital Transformation Technologies As an Enabler for Sustainable Logistics and Supply Chain Processes – an Exploratory Framework," *Brazilian J. Oper. Prod. Manag.*, vol. 16, no. 3, pp. 462–472, 2019, doi: 10.14488/BJOPM.2019.v16.n3.a9.

[76] S. Bag, S. Gupta, and Z. Luo, "Examining the role of logistics 4.0 enabled dynamic capabilities on firm performance," *Int. J. Logist. Manag.*, vol. 31, no. 3, pp. 607–628, 2020, doi: 10.1108/IJLM-11-2019-0311.

[77] X. Sun, H. Yu, and W. D. Solvang, "Towards the smart and sustainable transformation of Reverse Logistics 4.0: a conceptualization and research agenda," *Environ. Sci. Pollut. Res.*, vol. 29, no. 46, pp. 69275–69293, 2022, doi: 10.1007/s11356-022-22473-3.

[78] A. Lagorio, C. Cimini, R. Pinto, and S. Cavalieri, "5G in Logistics 4.0: potential applications and challenges," *Procedia Comput. Sci.*, vol. 217, no. 2022, pp. 650–659, 2022, doi: 10.1016/j.procs.2022.12.261.

[79] G. Nagy, B. Illés, and Bányai, "Impact of Industry 4.0 on production logistics," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 448, no. 1, pp. 0–9, 2018, doi: 10.1088/1757-899X/448/1/012013.

[80] V. Gružauskas, E. Gimžauskienė, and V. Navickas, "Forecasting accuracy influence on logistics clusters activities: The case of the food industry," *J. Clean. Prod.*, vol. 240, 2019, doi: 10.1016/j.jclepro.2019.118225.

[81] A. Lagorio, V. Di Pasquale, C. Cimini, S. Miranda, and R. Pinto, "Augmented Reality in Logistics 4.0: implications for the human work," *IFAC-PapersOnLine*, vol. 55, no. 10, pp. 329–334, 2022, doi: 10.1016/j.ifacol.2022.09.408.

[82] H. Hilpert, J. Kranz, and M. Schumann, "Leveraging green is in logistics: Developing an artifact for greenhouse gas emission tracking," *Bus. Inf. Syst. Eng.*, vol. 5, no. 5, pp. 315–325, 2013, doi: 10.1007/s12599-013-0285-1.

[83] D. Horenberg, "Applications within Logistics 4.0 : A research conducted on the visions of 3PL service providers," University of Twente, 2017. [Online]. Available: http://purl.utwente.nl/essays/72668

[84] S. Perotti, R. F. Bastidas Santacruz, P. Bremer, and J. E. Beer, "Logistics 4.0 in warehousing: a conceptual framework of influencing factors, benefits and barriers," *Int. J. Logist. Manag.*, vol. 33, no. 5, pp. 193–220, 2022, doi: 10.1108/IJLM-02-2022-0068.

[85] N. K. Dev, R. Shankar, and F. H. Qaiser, "Industry 4.0 and circular economy: Operational excellence for sustainable reverse supply chain performance," *Resour. Conserv. Recycl.*, vol. 153, no. January 2019, p. 104583, 2020, doi: 10.1016/j.resconrec.2019.104583.

[86] E. B. and R. H. L. Sourour Trab, "A communicating object's approach for smart logistics and safety issues in warehouses," *Concurr. Eng.*, 2016.

[87] W. Torbacki and K. Kijewska, "Identifying key performance indicators to be used in logistics 4.0 and industry 4.0 for the

needs of sustainable municipal logistics by means of the DEMATEL method," *Transp. Res. Procedia*, vol. 39, no. 2018, pp. 534–543, 2019, doi: 10.1016/j.trpro.2019.06.055.

[88] J. V. L. Silva and R. A. Rezende, *Additive manufacturing and its future impact in logistics*, vol. 6, no. PART 1. IFAC, 2013. doi: 10.3182/20130911-3-BR-3021.00126.

[89] J. Guo, Y. Lv, and H. Zhang, "Coordinated Gait Control of Snake Like Robot Based on Electromechanical Tracking," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 16, no. 1, pp. 87–95, 2022.

[90] J. S. Correa, M. Sampaio, R. de Casto Barros, and W. de Castro Hilsdorf, "IoT and BDA in the Brazilian future logistics 4.0 scenario," *Production*, vol. 30, pp. 1–14, 2020, doi: 10.1590/0103-6513.20190102.

[91] M. Woschank and P. Dallasega, "The impact of logistics 4.0 on performance in manufacturing companies: A pilot study," *Procedia Manuf.*, vol. 55, pp. 487–491, 2021, doi: 10.1016/j.promfg.2021.10.066.

[92] M. S. C. and J. N. C. G. Nuno Silva, Júlio Barros, Maribel Y. Santos, Carlos Costa, Paulo Cortez, "Advancing Logistics 4.0 with the Implementation of a Big Data Warehouse: A Demonstration Case for the Automotive Industry," *Electronics*, vol. 10, no. 18, 2021, [Online]. Available: https://www.scopus.com/record/display.uri?eid=2-s2.0-85114626210&origin=resultslist&sort=plf-f&src=s&sid=99a564d5e3d58daabdcf074593958e21&sot=b&sdt=b&s=TITLE-ABS-KEY%28logistics+4.0%29&sl=52&sessionSearchId=99a564d5e3d58daabdcf074593958e21

[93] A. Benayoune, A. A. Hamid, N. Shaiful, F. Abdul, and K. Al, "Logistics 4.0 Skills Requirements: Evidence from a Developing Country," *Can. J. Bus. Inf. Stud.*, no. March, pp. 24–36, 2022, doi: 10.34104/cjbis.022.024036.

[94] G. S. Cho, "A Study on Establishment of Smart Logistics Center based on Logistics 4.0," *J. Multimed. Inf. Syst.*, vol. 5, no. 4, p. 265–272., 2018.

[95] A. Lagorio and F. P. and R. P. , Chiara Cimini, "A taxonomy of technologies for human-centred logistics 4.0," *Appl. Sci.*, vol. 11, no. 20, 2021, doi: 10.3390/app11209661.

[96] J. J. Vicente, L. Neves, and I. Bernardo, "The potential of Logistics 4.0 technologies: a case study through business intelligence framing by applying the Delphi method," *Front. Artif. Intell.*, vol. 7, no. October, 2024, doi: 10.3389/frai.2024.1469958.

[97] B. Nila and J. Roy, "Analysis of Critical Success Factors of Logistics 4.0 using D-number based Pythagorean Fuzzy DEMATEL method," *Decis. Mak. Adv.*, vol. 2, no. 1, pp. 92–104, 2024, doi: 10.31181/dma21202430.

[98] M. Kostrzewski, M. Kosacka-Olejnik, and K. Werner-Lewandowska, "Assessment of innovativeness level for chosen solutions related to Logistics 4.0," in *29th International Conference on Flexible Automation and Intelligent Manufacturing*, Elsevier B.V., 2019, pp. 621–628. doi: 10.1016/j.promfg.2020.01.080.

[99] S. Jagtap, F. Bader, G. Garcia-Garcia, H. Trollman, T. Fadiji, and K. Salonitis, "Food Logistics 4.0: Opportunities and Challenges," *Logistics*, vol. 5, no. 1, pp. 1–19, 2021, doi: 10.3390/logistics5010002.

[100] M. Maslarić, S. Nikoličić, and D. Mirčetić, "Logistics Response to the Industry 4.0: The Physical Internet," *Open Eng.*, vol. 6, no. 1, pp. 511–517, 2016, doi: 10.1515/eng-2016-0073.

[101] G. K. Hande Begüm Bumin Doyduk, Bihter Karagöz-İ, "Industry 4.0 from Logistics Firms Perspective," *Ekon. Maliye İşletme Derg.*, vol. 1, no. 1, pp. 47–53, 2018.

[102] S. S. Kamble, A. Gunasekaran, and S. A. Gawankar, "Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives," *Process Saf. Environ. Prot.*, vol. 117, pp. 408–425, 2018, doi: 10.1016/j.psep.2018.05.009.

[103] H. Hu, X. Jia, Q. He, S. Fu, and K. Liu, "Deep reinforcement learning based AGVs real-time scheduling with mixed rule for flexible shop floor in industry 4.0," *Comput. Ind. Eng.*, vol. 149, no. May, p. 106749, 2020, doi: 10.1016/j.cie.2020.106749.

[104] S. Shah, G. Dikgang, and S. Menon, "The Global Perception of Industry 4.0 For Reverse Logistics," *Internaional J. Econ. Manag. Syst.*, vol. 4, pp. 103–107, 2019, [Online]. Available: http://www.iaras.org/iaras/journals/ijems

[105] G. Tsaramirsis *et al.*, "A Modern Approach towards an Industry 4.0 Model: From Driving Technologies to Management," *J. Sensors*, vol. 2022, 2022, doi: 10.1155/2022/5023011.

[106] O. Yavuz, M. M. Uner, F. Okumus, and O. M. Karatepe, "Industry 4.0 technologies, sustainable operations practices and their impacts on sustainable performance," *J. Clean. Prod.*, vol. 387, no. December 2022, p. 135951, 2023, doi: 10.1016/j.jclepro.2023.135951.

[107] M. Zoubek and M. Simon, "Evaluation of the level and readiness of internal logistics for industry 4.0 in industrial companies," *Appl. Sci.*, vol. 11, no. 13, p. 6130, 2021, doi: 10.3390/app11136130.

[108] O. Bongomin *et al.*, "Industry 4.0 Disruption and Its Neologisms in Major Industrial Sectors: A State of the Art," *J. Eng. (United Kingdom)*, vol. 1, p. 8090521, 2020, doi: 10.1155/2020/8090521.

[109] A. Akanmu and C. J. Anumba, "Cyber-physical systems integration of building information models and the physical construction," *Eng. Constr. Archit. Manag.*, vol. 22, no. 5, pp. 516–535, 2015, doi: 10.1108/ECAM-07-2014-0097.

[110] A. Ghadge, D. G. Mogale, M. Bourlakis, L. M. Maiyar, and H. Moradlou, "Link between Industry 4.0 and green supply chain management: Evidence from the automotive industry," *Comput. Ind. Eng.*, vol. 169, no. June, p. 108303, 2022, doi: 10.1016/j.cie.2022.108303.

[111] N. Krishnamoorthy and S. Umarani, "Implementation and management of cloud security for industry 4.O - data using hybrid elliptical curve cryptography," *J. High Technol. Manag. Res.*, vol. 34, no. 2, p. 100474, 2023, doi: 10.1016/j.hitech.2023.100474.

[112] B. Tjahjono, C. Esplugues, E. Ares, and G. Pelaez, "What does Industry 4.0 mean to Supply Chain?," *Procedia Manuf.*, vol. 13, pp. 1175–1182, 2017, doi: 10.1016/j.promfg.2017.09.191.

[113] M. Zoubek and M. Simon, "Methodology for evaluating the readiness of internal logistics processes for Industry 4.0," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 947, no. 1, pp. 0–9, 2020, doi: 10.1088/1757-899X/947/1/012005.

[114] L. R. V. J. W. S. E. A. Jan Ola Strandhagen, "The fit of Industry 4.0 applications in manufacturing logistics: a multiple case study," *Adv. Manuf.*, vol. 5, no. 4, pp. 344–358, 2017, doi: 10.1007/s40436-017-0200-y.

[115] G. Atzeni, G. Vignali, L. Tebaldi, and E. Bottani, "A bibliometric analysis on collaborative robots in Logistics 4.0 environments," *Procedia Comput. Sci.*, vol. 180, no. 2019, pp. 686–695, 2021, doi: 10.1016/j.procs.2021.01.291.

[116] S. El Hamdi and A. Abouabdellah, "Logistics: Impact of Industry 4.0," *Appl. Siences*, vol. 12, no. 09, pp. 1–17, 2022.

[117] M. Chacko, Atul, and S. B. Boddapati, "A Conceptual Framework for Cyber-Physical Quality Monitoring System using Machine Learning," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 16, no. 5, pp. 821–833, 2022.

[118] G. Singh, G. Bhardwaj, S. Vikram Singh, P. Chaturvedi, V. Kumar, and S. Gupta, "Industry 4.0: The

Industrial Revolution and Future Landscape in Indian Market," *Proc. Int. Conf. Technol. Adv. Innov. ICTAI 2021*, pp. 500–505, 2021, doi: 10.1109/ICTAI53825.2021.9673154.

[119] A. Jamwal, R. Agrawal, M. Sharma, and A. Giallanza, "Industry 4.0 technologies for manufacturing sustainability: A systematic review and future research directions," *Appl. Sci.*, vol. 11, no. 12, 2021, doi: 10.3390/app11125725.

[120] N. Shaiful Fitri Abdul Rahman, A. Adam Hamid, T. C. Lirn, K. Al Kalbani, and B. Sahin, "The adoption of industry 4.0 practices by the logistics industry: A systematic review of the gulf region," *Clean. Logist. Supply Chain*, vol. 5, p. 100085, 2022, doi: 10.1016/j.clscn.2022.100085.

[121] P. Richnák, "Current Trend of Industry 4.0 in Logistics and Transformation of Logistics Processes Using Digital Technologies: An Empirical Study in the Slovak Republic," *Logistics*, vol. 6, no. 4, p. 79, 2022.

[122] V. G. Surange, J. Suthar, S. N. Teli, and A. Sutrisno, "Key Enablers for Transitioning to Circular Supply Chains in Electronics : An ISM MICMAC Analysis," vol. 1, no. 4, pp. 823–834, 2024.

[123] E. Glistau, N. I. Coello Machado, and S. Trojahn, "Logistics 4.0: Goals, trends and solutions," *Adv. Logist. Syst. - Theory Pract.*, vol. 16, no. 1, pp. 5–18, 2022, doi: 10.32971/als.2022.001.

[124] W. M. a M. Samhouri , A. Al-Ghandoor , S. Alhaj Ali , I. Hinti, "An Intelligent Machine Condition Monitoring System Using Time-Based Analysis: Neuro-Fuzzy Versus Neural Network," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 3, no. 4, pp. 294–305, 2009.

[125] K. Witkowski, "Internet of Things, Big Data, Industry 4.0 - Innovative Solutions in Logistics and Supply Chains Management," *Procedia Eng.*, vol. 182, pp. 763–769, 2017, doi: 10.1016/j.proeng.2017.03.197.

[126] S. Ghosh, B. Sarkar, S. Sanyal, and J. Saha, "Automated Maintenance Approach for Industrial Machineries by Soft Computing Techniques at Offline Monitoring Process," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 3, no. 1, pp. 59–68, 2009.

[127] A. Dasgupta and P. Dutta, "A Comprehensive Review on 3D Printing Technology: Current Applications and Challenges," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 16, no. 4, pp. 529–542, 2022.

[128] H. Alzyod and P. Ficzere, "The Influence of the Layer Orientation on Ultimate Tensile Strength of 3D Printed Poly-lactic Acid," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 16, no. 3, pp. 361–367, 2022.

[129] S. H. Huang, P. Liu, and A. Mokasdar, "Additive manufacturing and its societal impact : a literature review," *Int. J ournal Addit. Manuf. Technol.*, vol. 67, pp. 1191–1203, 2013, doi: 10.1007/s00170-012-4558-5.

[130] M. G. F. G. C. de Oliveira Neto, A. da Conceição Silva, *How can Industry 4.0 technologies and circular economy help companies and researchers collaborate and accelerate the transition to strong sustainability? A bibliometric review and a systematic literature review*, vol. 20, no. 3. Springer Berlin Heidelberg, 2023. doi: 10.1007/s13762-022-04234-4.

[131] X. Sun, H. Yu, W. D. Solvang, Y. Wang, and K. Wang, "The application of Industry 4.0 technologies in sustainable logistics: a systematic literature review (2012–2020) to explore future research opportunities," *Environ. Sci. Pollut. Res.*, vol. 29, no. 7, pp. 9560–9591, 2022, doi: 10.1007/s11356-021-17693-y.

[132] R. Chalmeta and N. J. Santos-deLeón, "Sustainable supply chain in the era of industry 4.0 and big data: A systematic analysis of literature and research," *Sustain.*, vol. 12, no. 10, 2020, doi: 10.3390/su12104108.

[133] R. Al-Jarrah, A. Al–Migdady, and HithamTlilan, "Utilizing Hybrid Machine Learning Framework for Half-Vehicle Suspension Control to Minimize Road-Induced Vibrations," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 18, no. 3, pp. 587–599, 2024, doi: 10.59038/jjmie/180312.

[134] L. Meng *et al.*, "Machine Learning in Additive Manufacturing: A Review," *Jom*, vol. 72, no. 6, pp. 2363–2377, 2020, doi: 10.1007/s11837-020-04155-y.

[135] A. Arishi, K. Krishnan, and M. Arishi, "Machine learning approach for truck-drones based last-mile delivery in the era of industry 4.0," *Eng. Appl. Artif. Intell.*, vol. 116, no. April, p. 105439, 2022, doi: 10.1016/j.engappai.2022.105439.

[136] M. von Stietencron *et al.*, "Towards logistics 4.0: an edge-cloud software framework for big data analytics in logistics processes," *Int. J. Prod. Res.*, vol. 60, no. 19, pp. 5994–6012, 2022, doi: 10.1080/00207543.2021.1977408.

[137] A. Varshney *et al.*, "Challenges in Sensors Technology for Industry 4.0 for Futuristic Metrological Applications," *Mapan - J. Metrol. Soc. India*, vol. 36, no. 2, pp. 215–226, 2021, doi: 10.1007/s12647-021-00453-1.

[138] K. P. Iyengar, A. D. Kariya, R. Botchu, V. K. Jain, and R. Vaishya, "Significant capabilities of SMART sensor technology and their applications for Industry 4.0 in trauma and orthopaedics," *Sensors Int.*, vol. 3, no. November 2021, p. 100163, 2022, doi: 10.1016/j.sintl.2022.100163.

[139] C. A. A. Rashed, M. N. Bagum, M. M. H. Kibria, R. A. Chowdhury, and M. A. Islam, "Integrating Supply Chain Partners through Implementing Industry 4.0 Technologies to Enhance Competitiveness," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 18, no. 2, pp. 351–363, 2024, doi: 10.59038/jjmie/180208.

[140] D. Kansy, "Technological conditions for Logistics 4.0 development," *Sci. Pap. Silesian Univ. Technol. Organ. Manag. Ser.*, vol. 2023, no. 170, pp. 215–232, 2023, doi: 10.29119/1641-3466.2023.170.13.

[141] T. Kalsoom, N. Ramzan, S. Ahmed, and M. Ur-Rehman, "Advances in sensor technologies in the era of smart factory and industry 4.0," *Sensors (Switzerland)*, vol. 20, no. 23, pp. 1–22, 2020, doi: 10.3390/s20236783.

[142] M. Wasif, M. Rababah, A. Fatima, S. Ur, and R. Baig, "Prediction of Springback using the Machine Learning Technique in high-tensile strength sheet metal during the V-Bending Process," vol. 17, no. 4, pp. 481–488, 2023.

[143] T. Masuzawa, "State of the art of micromachining," *CIRP Ann. - Manuf. Technol.*, vol. 49, no. 2, pp. 473–488, 2000, doi: 10.1016/S0007-8506(07)63451-9.

[144] H. Dinis and P. M. Mendes, "A comprehensive review of powering methods used in state-of-the-art miniaturized implantable electronic devices," *Biosens. Bioelectron.*, vol. 172, p. 112781, 2021, doi: 10.1016/j.bios.2020.112781.

[145] J. D. Boles, "Power Electronics Meet Piezoelectrics: Converters, Components, and Miniaturization," Massachusetts Institute of Technology, 2017.

[146] A. B. Lostetter, "Miniaturization, Packaging, and Thermal Analysis of Power Electronics Modules," Virginia Polytechnic Institute and State University in, 1998.

[147] P. Palm, J. Moisala, A. Kivikero, R. Tuominen, and A. Iihola, "Embedding active components inside Printed Circuit Board (PCB) - A solution for miniaturization of electronics," in *Proceedings of the International Symposium and Exhibition on Advanced Packaging Materials Processes, Properties and Interfaces*, IEEE, 2005, pp. 1–4. doi: 10.1109/ISAPM.2005.1432034.

[148] T. M. I. Băjenescu, "Miniaturisation of electronic components and the problem of devices overheating," *EEA - Electroteh. Electron. Autom.*, vol. 69, no. 2, pp. 53–58, 2021, doi: 10.46904/EEA.21.69.2.1108006.

[149] T. Goodwin, "Miniaturized telemetry antennas with integrated electronics," in *2008 IEEE International*

Conference on Microwaves, Communications, Antennas and Electronic Systems, COMCAS 2008, IEEE, 2008, pp. 1–6. doi: 10.1109/COMCAS.2008.4562829.

[150] J. Zikulnig *et al.*, "Printed Electronics Technologies for Additive Manufacturing of Hybrid Electronic Sensor Systems," *Adv. Sens. Res.*, vol. 2, no. 7, pp. 1–39, 2023, doi: 10.1002/adsr.202200073.

[151] A. A.-S. Omar Bataineh, Raid Al-Aomar, "Simulation-Based Optimization for Performance Enhancement of Public Departments," *Dep. P. (2010). Simulation-Based Optim. Perform. Enhanc. Public Dep. 4(3), 346–351.*, vol. 4, no. 3, pp. 346–351, 2010.

[152] N. A.-K. M. Tarawneh, F. Al-Ghathian, M. A. Nawafleh, "Numerical Simulation and Performance Evaluation of Stirling Engine Cycle," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 4, no. 5, 2010.

[153] C. N. Wang, Thi-Be-Oanh-Cao, T. T. Dang, and N. A. T. Nguyen, "Third-Party Logistics Provider Selection in the Industry 4.0 Era by Using a Fuzzy AHP and Fuzzy MARCOS Methodology," *IEEE Access*, vol. 12, no. March, pp. 67291–67313, 2024, doi: 10.1109/ACCESS.2024.3392892.

[154] M. Andronie, G. Lăzăroiu, R. Ștefănescu, C. Uță, and I. Dijmărescu, "Sustainable, smart, and sensing technologies for cyber-physical manufacturing systems: A systematic literature review," *Sustain.*, vol. 13, no. 10, 2021, doi: 10.3390/su13105495.

[155] G. Lampropoulos, K. Siakas, and T. Anastasiadis, "Internet of Things in the Context of Industry 4.0: An Overview," *Int. J. Entrep. Knowl.*, vol. 7, no. 1, pp. 4–19, 2019, doi: 10.2478/ijek-2019-0001.

[156] R. C. Santos and J. L. Martinho, "An Industry 4.0 maturity model proposal," *J. Manuf. Technol. Manag.*, vol. 31, no. 5, pp. 1023–1043, 2020, doi: 10.1108/JMTM-09-2018-0284.

[157] S. Tripathi and M. Gupta, "A holistic model for Global Industry 4.0 readiness assessment," *Benchmarking*, vol. 28, no. 10, pp. 3006–3039, 2021, doi: 10.1108/BIJ-07-2020-0354.

[158] G. Ismoilova, N. Feruza, N. Khadjieva, and M. Shaislamova, "Creating a Robust ICT Base for the Digital Economy," in *International Conference on Information Science and Communications Technologies: Applications, Trends and Opportunities, ICISCT 2019*, IEEE, 2019, pp. 1–4. doi: 10.1109/ICISCT47635.2019.9011898.

[159] I. Bertschek, M. Polder, and P. Schulte, "ICT and resilience in times of crisis: evidence from cross-country micro moments data," *Econ. Innov. New Technol.*, vol. 28, no. 8, pp. 759–774, 2019, doi: 10.1080/10438599.2018.1557417.

[160] Q. Zhang, "Design of Multi Joint Integrated Control System for Non Driven Robot," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 16, no. 1, pp. 105–111, 2022.

[161] P. E. Dossou, P. Torregrossa, and T. Martinez, "Industry 4.0 concepts and lean manufacturing implementation for optimizing a company logistics flows," *Procedia Comput. Sci.*, vol. 200, no. 2019, pp. 358–367, 2022, doi: 10.1016/j.procs.2022.01.234.

[162] H. Zhong, D. Wang, J. Gong, C. Ban, W. Wei, and Y. Long, "Design and Force Performance Analysis of a Climbing Robot Based on Halbach Magnetic Array," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 1, no. 4, pp. 811–822, 2024.

[163] S. K. Sahoo and B. B. Choudhury, "An Integrated MCDM Framework for Optimizing Rotary Actuator Selection in Smart Robotic Power Wheelchair Prototypes," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 18, no. 3, pp. 569–585, 2024, doi: 10.59038/jjmie/180311.

[164] Z. Meng, "Trajectory Tracking Control Algorithm of Six Degrees of Freedom Industrial Robot," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 16, no. 1, pp. 97–104, 2022.

[165] K. Filter, C. Kuang, and X. Zheng, "Space Trajectory Planning of Electric Robot Based on Unscented," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 15, no. 1, pp. 29–38, 2021.

[166] M. Al-khawaldah, O. Badran, and I. Al-adwan, "Exploration Algorithm Technique for Multi-Robot Collaboration," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 5, no. April, pp. 177–184, 2011.

[167] P. Mora and C. A. S. Araujo, "Delivering blood components through drones: a lean approach to the blood supply chain," *Supply Chain Forum*, vol. 23, no. 2, pp. 113–123, 2022, doi: 10.1080/16258312.2021.1984167.

[168] M. H. Naseem and J. Yang, "Role of industry 4.0 in supply chains sustainability: A systematic literature review," *Sustain.*, vol. 13, no. 17, 2021, doi: 10.3390/su13179544.

[169] É. Beke, A. Bódi, T. G. Katalin, T. Kovács, D. Maros, and L. Gáspár, "The Role of Drones in Linking Industry 4.0 and ITS Ecosystems," in *18th IEEE International Symposium on Computational Intelligence and Informatics, CINTI 2018 - Proceedings*, 2018, pp. 191–197. doi: 10.1109/CINTI.2018.8928239.

[170] P. Zhang, C. Wang, Z. Qin, and H. Cao, "A multidomain virtual network embedding algorithm based on multiobjective optimization for Internet of Drones architecture in Industry 4.0," *Softw. - Pract. Exp.*, vol. 52, no. 3, pp. 710–728, 2022, doi: 10.1002/spe.2815.

[171] M. B. Hatoum and H. Nassereddine, "The Use of Drones in the Construction Industry: Applications and Implementation," *Proc. Int. Symp. Autom. Robot. Constr.*, vol. 2022–July, no. Isarc, pp. 542–549, 2022, doi: 10.22260/isarc2022/0077.

[172] Y. J. and Y. G. Jia Tao, "Intelligent Remote Monitoring System for Minor Faults of Intelligent Unmanned Vehicle," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 14, no. 1, pp. 61–70, 2020.

[173] R. Stefanini and G. Vignali, "Environmental and economic sustainability assessment of an industry 4.0 application: the AGV implementation in a food industry," *Int. J. Adv. Manuf. Technol.*, vol. 120, no. 5–6, pp. 2937–2959, 2022, doi: 10.1007/s00170-022-08950-6.

[174] C. Li, "Design of Intelligent Obstacle Avoidance System for Fully Automated Unmanned Vehicle Based on Laser Ranging," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 14, no. 1, pp. 81–88, 2020.

[175] J. Theunissen, H. Xu, R. Y. Zhong, and X. Xu, "Smart AGV System for Manufacturing Shopfloor in the Context of Industry 4.0," *Proc. 2018 25th Int. Conf. Mechatronics Mach. Vis. Pract. M2VIP 2018*, pp. 1–6, 2018, doi: 10.1109/M2VIP.2018.8600887.

[176] J. Mehami, M. Nawi, and R. Y. Zhong, "Smart automated guided vehicles for manufacturing in the context of Industry 4.0," *Procedia Manuf.*, vol. 26, pp. 1077–1086, 2018, doi: 10.1016/j.promfg.2018.07.144.

[177] Y. Tang, "Monitoring Algorithm for Speed Information of Autonomous Vehicles Based on Magnetoresistive Sensor," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 14, no. 1, pp. 43–52, 2020.

[178] A. Moldabekova, R. Philipp, A. A. Satybaldin, and G. Prause, "Technological Readiness and Innovation as Drivers for Logistics 4.0*," *J. Asian Financ. Econ. Bus.*, vol. 8, no. 1, pp. 145–156, 2021, doi: 10.13106/jafeb.2021.vol8.no1.145.

[179] M. Javaid, A. Haleem, R. P. Singh, S. Rab, and R. Suman, "Significance of sensors for industry 4.0: Roles,

capabilities, and applications," *Sensors Int.*, vol. 2, no. May, p. 100110, 2021, doi: 10.1016/j.sintl.2021.100110.

[180] M. Borghetti, E. Cantù, E. Sardini, and M. Serpelloni, "Future sensors for smart objects by printing technologies in Industry 4.0 scenario," *Energies*, vol. 13, no. 22, 2020, doi: 10.3390/en13225916.

[181] O. Kanoun *et al.*, "Prospects of wireless energy-aware sensors for smart factories in the industry 4.0 era," *Electron.*, vol. 10, no. 23, 2021, doi: 10.3390/electronics10232929.

[182] M. Umar, S. A. R. Khan, M. Yusoff Yusliza, S. Ali, and Z. Yu, "Industry 4.0 and green supply chain practices: an empirical study," *Int. J. Product. Perform. Manag.*, vol. 71, no. 3, pp. 814–832, 2022, doi: 10.1108/IJPPM-12-2020-0633.

[183] M. F. Mubarak, S. Tiwari, M. Petraite, M. Mubarik, and R. Z. Raja Mohd Rasi, "How Industry 4.0 technologies and open innovation can improve green innovation performance?," *Manag. Environ. Qual. An Int. J.*, vol. 32, no. 5, pp. 1007–1022, 2021, doi: 10.1108/MEQ-11-2020-0266.

[184] S. Jayashree, M. N. H. Reza, C. A. N. Malarvizhi, and M. Mohiuddin, "Industry 4.0 implementation and Triple Bottom Line sustainability: An empirical study on small and medium manufacturing firms," *Heliyon*, vol. 7, no. 8, p. e07753, 2021, doi: 10.1016/j.heliyon.2021.e07753.

[185] A. Ferrari, G. Mangano, A. Corinna, and C. Alberto, "I4.0 technologies in city logistics : an empirical investigation of contextual factors," pp. 345–362, 2023.

[186] E. G. and R. EROL, "THE TRANSITION TO INDUSTRY 4.0 IN ONE OF THE TURKISH," *Int. J. 3D Print. Technol. Digit. Ind.*, vol. 2, no. 1, pp. 76–85, 2018.

[187] H. D. Khoa, T. Thi, and B. Nhung, "GREEN LOGISTICS APPLICATION TO REDUCE OPERATING COSTS FOR VIETNAM LOGISTICS ENTERPRISES," *J. Bus. IT*, vol. 1, pp. 2–11, 2020.

[188] P. B. and L. I. Mohamad Nehme, "GREEN LOGISTICS IN LIFE CYCLE MANAGEMENT: THE THEORETICAL ASPECT," vol. 2, no. 26, pp. 36–42, 2022, doi: 10.31471/2409-0948-2022-2(26)-36-42.

[189] D. A. M. NESAN, "THE RELATIONSHIP AND IMPACT OF SERVICES QUALITY TOWARDS GREEN LOGISTICS," Universiti Utara Malaysia, 2023.

[190] N. K. K. and N. M. N. Chen Chiaw Fen, "Drivers and Barriers Implementing Green Logistics Among Logistics Companies in," *Res. Manag. Technol. Bus.*, vol. 1, no. 1, pp. 41–54, 2020.

[191] A. K. Henryk Dźwigoł, Nataliia Trushkina, "The Organizational and Economic Mechanism of Implementing the Concept of Green Logistics," *Cent. East. Eur. Online Libr.*, vol. 2, pp. 41–75, 2021.

[192] M. Išoraitė, "Green Logistics and Marketing Features: Literature Review," in *International Conference TRANSBALTICA: Transportation Science and Technology*, 2023, pp. 618–626.

[193] G. K. Akubia *et al.*, "Ijsom 2024," *Int. J. Supply Oper. Manag.*, 2024, doi: 10.22034/ijsom.2024.110506.3185.

[194] N. M. Kuruvilla, R. Saju, S. B. Chandramana, and S. Ramesh, "Driving towards Sustainable Development through Green Logistics," in *ResearchGate*, 2020. doi: 10.6084/m9.figshare.13332302.v2.

[195] N. Dang *et al.*, "ROLE OF GREEN LOGISTICS IN THE CONSTRUCTION," *Sciendo*, vol. 30, no. 3, pp. 191–211, 2023.

[196] P. L. Mareddy, S. R. Narapureddy, V. R. Dwivedula, and S. V. Prayagi, "Simultaneous Scheduling of Machines, Tool Transporter and Tools in a Multi Machine Flexible Manufacturing System Without Tool Delay Using Crow Search Algorithm," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 16, no. 3, pp. 403–419, 2022.

[197] E. Glistau and N. I. Coello Machado, "Logistics Concepts and Logistics 4.0," *Adv. Logist. Syst. - Theory Pract.*, vol. 12, no. 1, pp. 37–46, 2018, doi: 10.32971/als.2019.003.

[198] S. Sapper, M. Kohl, and J. Fottner, "Future Competency Requirements in Logistics Due to Industry 4.0: A Systematic Literature Review," *Proc. - 2021 10th Int. Conf. Ind. Technol. Manag. ICITM 2021*, pp. 94–105, 2021, doi: 10.1109/ICITM52822.2021.00025.

[199] N. I. C. M. Elke Glistau, "Industry 4.0, Logistics 4.0 and Materials - Chances and Solutions," *Mater. Sci. Forum*, vol. 919, pp. 307–314, 2018.

[200] M. Busu and A. Nedelcu, "Sustainability and Economic Performance of the Companies in the Renewable Energy Sector in Romania," *Sustainability*, vol. 10, no. 2, p. 8, 2017, doi: 10.3390/su10010008.

[201] A. Sartal, R. Bellas, A. M. Mejías, and A. García-Collado, "The sustainable manufacturing concept, evolution and opportunities within Industry 4.0: A literature review," *Adv. Mech. Eng.*, vol. 12, no. 5, 2020, doi: 10.1177/1687814020925232.

[202] T. Tesfaymezgebe, "Lean Production Principle for Improving Productivity : Empirical Case Study in Garment Industry in Ethiopia," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 1, no. 1, pp. 241–250, 2024.

[203] A. Bettley and S. Burnley, *Towards Sustainable Operations Management Integrating Sustainability Management into Operations Management Strategies and Practices*. 2008. doi: 10.1007/978-1-84800-131-2_53.

[204] N. Hami, M. R. Muhamad, and Z. Ebrahim, "The impact of sustainable manufacturing practices and innovation performance on economic sustainability," *Procedia CIRP*, vol. 26, pp. 190–195, 2015, doi: 10.1016/j.procir.2014.07.167.

[205] A. Belhadi, S. Kamble, A. Gunasekaran, and V. Mani, "Analyzing the mediating role of organizational ambidexterity and digital business transformation on industry 4.0 capabilities and sustainable supply chain performance," *Supply Chain Manag.*, vol. 27, no. 6, pp. 696–711, 2022, doi: 10.1108/SCM-04-2021-0152.

[206] O. Mokhiamar, D. O. Masara, and H. El Gamal, "Performance Enhancement of Multi-Modal Piezoelectric Energy Harvesting Through Parameter Optimization," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 16, no. 5, pp. 677–688, 2022.

[207] A. Warhurst, "Sustainability indicators and sustainability performance management," *Sustain. Indic. Sustain. Perform. Manag.*, vol. 43, no. 43, pp. 1–129, 2002, [Online]. Available: https://doi.org/10.1016/j.scitotenv.2019.133699%0Ahttps://doi.org/10.1016/j.solener.2017.10.073%0Ahttps://doi.org/10.1016/j.scienta.2019.01.023%0Ahttps://doi.org/10.1016/j.cropro.2019.04.003%0Ahttp://dx.doi.org/10.1016/j.njas.2010.02.002%0Ahttps://doi.org

[208] C. Bai, J. Sarkis, X. Wei, and L. Koh, "Evaluating ecological sustainable performance measures for supply chain management," *Supply Chain Manag.*, vol. 17, no. 1, pp. 78–92, 2012, doi: 10.1108/13598541211212221.

[209] S. H. Abdul-Rashid, N. Sakundarini, R. A. Raja Ghazilla, and R. Thurasamy, "The impact of sustainable manufacturing practices on sustainability performance: Empirical evidence from Malaysia," *Int. J. Oper. Prod. Manag.*, vol. 37, no. 2, pp. 182–204, 2017, doi: 10.1108/IJOPM-04-2015-0223.

[210] M. D'Agostini, V. A. G. Tondolo, M. E. Camargo, A. I. dos S. Dullius, R. da R. P. Tondolo, and S. L. Russo, "Relationship between sustainable operations practices and performance: a meta-analysis," *Int. J. Product. Perform.*

Manag., vol. 66, no. 8, pp. 1020–1042, 2017, doi: 10.1108/IJPPM-11-2015-0168.

[211] N. Piercy and N. Rich, "The relationship between lean operations and sustainable operations," *Int. J. Oper. Prod. Manag.*, vol. 35, no. 2, pp. 282–315, 2015, doi: 10.1108/IJOPM-03-2014-0143.

[212] E. Afum, Y. Agyabeng-Mensah, Z. Sun, B. Frimpong, L. Y. Kusi, and I. S. K. Acquah, "Exploring the link between green manufacturing, operational competitiveness, firm reputation and sustainable performance dimensions: a mediated approach," *J. Manuf. Technol. Manag.*, vol. 31, no. 7, pp. 1417–1438, 2020, doi: 10.1108/JMTM-02-2020-0036.

[213] L. Jraisat, M. Jreissat, F. Sajjad, L. Batista, and T. Ghalia, "No Actor is an Island: The Role of Partnerships in Sustainable Value Chains," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 16, no. 2, pp. 163–174, 2022.

[214] S. D. Al-Shobaki, R. H. Fouad, and A. Al-Bashir, "The Implementation of Total Quality Management (TQM) for The Banking Sector in Jordan," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 4, no. 2, pp. 304–313, 2010.

[215] A. N. Wassan, M. S. Memon, S. I. Mari, and M. A. Kalwar, "Impact of Total Quality Management (TQM) practices on Sustainability and Organisational Performance," *J. Appl. Res. Technol. Eng.*, vol. 3, no. 2, pp. 93–102, 2022, doi: 10.4995/jarte.2022.17408.

[216] B. K. Sovacool, M. Iskandarova, and J. Hall, "A thematic analysis of conceptual frameworks and typologies for industrial sociotechnical change in a low-carbon future," *Energy Res. Soc. Sci.*, vol. 97, no. December 2022, p. 102954, 2023, doi: 10.1016/j.erss.2023.102954.

[217] I. S. Khan, M. O. Ahmad, and J. Majava, "Industry 4.0 and sustainable development: A systematic mapping of triple bottom line, Circular Economy and Sustainable Business Models perspectives," *J. Clean. Prod.*, vol. 297, p. 126655, 2021, doi: 10.1016/j.jclepro.2021.126655.

[218] V. B. and V. Clarke, "Thematic analysis," in *Research methods in psychology*, 1st ed., K. J. S. H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf, Ed., America: American Psychological Association, 2012.

[219] B. Machado, L. Teixeira, A. L. Ramos, and C. Pimentel, "Conceptual Design of an Integrated Solution for Urban Logistics using Industry 4.0 principles," *Procedia Comput. Sci.*, vol. 180, no. 2019, pp. 807–815, 2021, doi: 10.1016/j.procs.2021.01.330.

[220] S. K. T. and S. F. W. Ameshwar Dubey, Angappa Gunasekaran, Thanos Papadopoulos, Stephen J. Childe, "Sustainable supply chain management: framework and further research directions.," *J. Clean. Prod.*, vol. 142, pp. 1119–1130, 2017.

[221] S. Wang, J. Wan, D. Li, and C. Zhang, "Implementing Smart Factory of Industrie 4 . 0 : An Outlook," *Int. J. Distrib. Sens. Networks*, vol. 12, no. 1, p. 3159805, 2016, doi: 10.1155/2016/3159805.

[222] G. Atilla, "Industry 4 . 0 and sustainable business models : An intercontinental sample," *Bus. Strateg. Environ.*, vol. 33, no. 4, pp. 3142–3166, 2023, doi: 10.1002/bse.3634.

[223] A. B. Lopes de Sousa Jabbour, C. J. C. Jabbour, M. Godinho Filho, and D. Roubaud, "Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations," *Ann. Oper. Res.*, vol. 270, no. 1–2, pp. 273–286, 2018, doi: 10.1007/s10479-018-2772-8.

[224] A. Lardo and G. Russo, "The perspective of capability providers in creating a sustainable I4 . 0 environment," *Manag. Decis.*, vol. 58, no. 8, pp. 1759–1777, 2020, doi: 10.1108/MD-09-2019-1333.

[225] S. Bag, S. Gupta, and S. Kumar, "Industry 4.0 adoption and 10R advance manufacturing capabilities for sustainable development," *Int. J. Prod. Econ.*, vol. 231, no. C, p. S0925527320302103, 2021, [Online]. Available: https://econpapers.repec.org/RePEc:eee:proeco:v:231:y:2021:i:c:s0925527320302103

[226] M.-P. Pacaux-Lemoine and D. Trentesaux, "ETHICAL RISKS OF HUMAN-MACHINE SYMBIOSIS IN INDUSTRY 4.0: INSIGHTS FROM THE HUMAN-MACHINE COOPERATION APPROACH," *IFAC-PapersOnLine*, vol. 52, no. 19, pp. 19–24, 2019, [Online]. Available: https://api.semanticscholar.org/CorpusID:213958153

[227] J. C. De Man and J. O. Strandhagen, "An Industry 4.0 Research Agenda for Sustainable Business Models," *Procedia CIRP*, vol. 63, pp. 721–726, 2017, doi: 10.1016/j.procir.2017.03.315.

[228] A. Gunasekaran and Z. Irani, "Sustainable operations management: Design, modelling and analysis," *J. Oper. Res. Soc.*, vol. 65, no. 6, pp. 801–805, 2014, doi: 10.1057/jors.2014.26.

[229] I. S. Khan, M. O. Ahmad, and J. Majava, "Industry 4.0 and sustainable development: A systematic mapping of triple bottom line, Circular Economy and Sustainable Business Models perspectives," *Iqra Sadaf Khan, Muhammad Ovais Ahmad, Jukka Majava*, vol. 297, p. 126655, 2021, doi: 10.1016/j.jclepro.2021.126655.

[230] S. Matarneh, A. Z. Piprani, R. M. Ellahi, D. N. Nguyen, T. Mai Le, and S. Nazir, "Industry 4.0 technologies and circular economy synergies: Enhancing corporate sustainability through sustainable supply chain integration and flexibility," *Environ. Technol. Innov.*, vol. 35, no. June, p. 103723, 2024, doi: 10.1016/j.eti.2024.103723.

[231] B. Bigliardi, E. Bottani, and G. Casella, "Enabling technologies, application areas and impact of industry 4.0: A bibliographic analysis," *Procedia Manuf.*, vol. 42, no. 2019, pp. 322–326, 2020, doi: 10.1016/j.promfg.2020.02.086.

[232] B. Surajit and A. Telukdarie, "Business Logistics Optimization Using Industry 4.0: Current Status and Opportunities," in *IEEE International Conference on Industrial Engineering and Engineering Management*, IEEE, 2018, pp. 1558–1562. doi: 10.1109/IEEM.2018.8607556.

[233] R. Zhou and X. Wang, "Impact Evaluation of Industrial Energy Consumption Based on Input-output Complex Network," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 15, no. 1, pp. 83–91, 2021.

[234] K. D. Thoben, S. A. Wiesner, and T. Wuest, "'Industrie 4.0' and smart manufacturing-a review of research issues and application examples," *Int. J. Autom. Technol.*, vol. 11, no. 1, pp. 4–16, 2017, doi: 10.20965/ijat.2017.p0004.

[235] L. A. Kumaran, M. Ramasubramaniam, and K. Sivakumar, "Logistics 4.0 for Sustainable Manufacturing Supply Chain," in *Industry 4.0 Technologies: Sustainable Manufacturing Supply Chains: Volume 1---Theory, Challenges, and Opportunity*, K. E. K. Vimal, S. Rajak, V. Kumar, R. S. Mor, and A. Assayed, Eds., Singapore: Springer Nature Singapore, 2024, pp. 47–59. doi: 10.1007/978-981-99-4819-2_4.

[236] R. S. and G. L. T. Hadi Balouei Jamkhaneh, "Analysis of Logistics 4.0 service quality and its sustainability enabler scenarios in emerging economy," *Clean. Logist. Supply Chain*, vol. 04, p. 100053., 2022.

[237] M. Zoubek and M. Simon, "Logistics 4.0: Readiness and Technology of Internal Logistics Processes of Companies and Design of a Maturity Model for Warehousing," in *Proceedings of the 35th International Business Information Management Association Conference, Seville, Spain*, 2020, pp. 1–2.

[238] Y. Tsao, F. Arril, S. Barus, T. Vu, and G. P. Sari, "Evaluation of sustainability and technological management for Logistics 4 . 0," *Int. J. Logist. Res. Appl.*, pp. 1–21, 2024, doi: 10.1080/13675567.2024.2411392.

[239] B. D. Sarkar and R. Shankar, "Understanding the barriers of port logistics for effective operation in the Industry 4.0 era: Data-driven decision making," *Int. J. Inf. Manag. Data Insights*, vol. 1, no. 2, p. 100031, 2021, doi: 10.1016/j.jjimei.2021.100031.

[240] S. W. Doh, F. Deschamps, and E. P. D. E. Lima, "Systems Integration in the Lean Manufacturing Systems Value Chain to Meet Industry 4 . 0 Requirements," *Transdiscipl. Eng. Crossing Boundaries*, pp. 642–650, 2016, doi: 10.3233/978-1-61499-703-0-642.

[241] S. K. Tiwari, R. K. Singh, and B. Kumar, "Optimizing PM Intervals for Manufacturing Industries Using Delay-time Analysis and MOGA," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 16, no. 3, pp. 327–332, 2022.

[242] S. Catarina, G. Gomes, S. Catarina, M. Bouzon, and S. Catarina, "Lean Logistics 4 . 0 : concepts and key performance indicators Logística Lean 4 . 0 : conceitos e indicadores-chave de desempenho," *Brazilian J. Dev.*, vol. 9, no. 7, pp. 22172–22197, 2023, doi: 10.34117/bjdv9n7-071.

[243] S. J. Mwafak Shakoor, Mohamed Rafik Qureshi, "Applying Management Principles of Lean Manufacturing for," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 13, no. 4, pp. 291–299, 2019.

[244] M. R. C. D. Amjad Khalili , Md Yusof Ismail , A.N.M.Karim, "Critical Success Factors for Soft TQM and Lean Manufacturing Linkage," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 11, no. 2, pp. 129–140, 2017.

[245] M. Balaji, V. Velmurugan, M. Prapa, and V. Mythily, "A fuzzy approach for modeling and design of agile supply chains using interpretive structural modeling," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 10, no. 1, pp. 67–74, 2016.

[246] A. Jayant and P. Gupta, "Perspectives in Reverse Supply Chain Management(R-SCM): A State of the Art Literature Review," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 6, no. 1, pp. 87–102, 2012.

[247] R. Marudhamuthu and D. Moorthy, "The Development and Implementation of Lean Manufacturing," vol. 5, no. 6, pp. 527–532, 2011.

[248] O. T. R. Almeanazel, "Total Productive Maintenance Review and Overall Equipment Effectiveness Measurement," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 4, no. 4, pp. 517–522, 2010.

[249] I. Yusuf, A. Sanusi, and N. M. Usman, "Copula Approach to Performance Evaluation of Manufacturing System," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 16, no. 5, pp. 701–715, 2022.

[250] K. Wang, "Logistics 4.0 Solution-New Challenges and Opportunities," *Atl. Press*, pp. 68–74, 2016, doi: 10.2991/iwama-16.2016.13.