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Strategic insights into last-mile delivery: modelling the industry 4.0 enabler for e-commerce industry

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Abstract

Purpose – Excellent customer experience with doorstep delivery is one of the motivations for online purchasing and e-commerce. Optimal technology-driven last-mile delivery is the backbone of this business model. This paper aims to identify industry 4.0 (I4.0) technology-based enablers for efficient e-commerce logistics for last-mile delivery (LMD) operations.

Design/methodology/approach – This study adopts an empirically grounded quantitative approach for defining and analysing the I4.0 technology enablers for efficient LMD operations. It adopts interpretive structural modelling and matrice d'impacts croisés multiplication appliquée á un classement analysis to identify the dependency and relationship among the identified enablers.

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Findings – The transformation technologies of I4.0 offer a comprehensive package to handle LMD and e-commerce business challenges. This research identified that LMD and logistics will be dominated by autonomous running vehicles, drones and robots; apart from that, in I4.0 adoption cases, the implementation of radio-frequency identification was found suitable for efficient logistics networks. In addition, digitalisation through digital twins, robots, autonomous vehicles and Internet of Things adoption was found to drive the system and is crucial for strategic action.

Research limitations/implications – The findings of this research help companies and the e-commerce industry to evaluate strategic technological investments in promising I4.0 for LMD. The study also helps managers to focus on initiating and integrating digital technologies and autonomous vehicles, drones and robots focused on LMD improvement.

Practical implications – The findings of this research help companies and the e-commerce industry to evaluate strategic technological investments in promising I4.0 for LMD. The study also helps managers to focus on initiating and integrating digital technologies and autonomous vehicles, drones and robots focused on LMD improvement.

Social implications – Industry 4.0 technologies enable more efficient route planning, reducing fuel consumption and lowering carbon emissions. Optimised delivery networks reduce waste and ensure more efficient use of resources by using suggested technologies.

Originality/value – This study presents strategic insights into LMD and I4.0 enablers for the e-commerce environment. It proposes a theoretical framework that can serve as a roadmap for implementing I4.0 technologies to address unaddressed bottlenecks in LMD operations, lowering the logistics network's efficiency.

Keywords Last-mile delivery, E-commerce logistics, Interpretive structural modelling, Industry 4.0, Technology adoption

Paper type Research paper

1. Introduction

Demand for door-to-door delivery is growing due to the rise in e-commerce (Yu, Lian, & Yang, 2021). Over the past few years, the global share of these e-commerce companies has increased from $1,548bn in 2015 to $4,890bn in 2021 (Keenan, 2021). Due to high consumer demand, developing countries are also getting significant improvements in the logistics sector. For example, the Indian logistics market was worth around $274bn in 2022 and is forecast to reach $563bn by 2030 (IBEF, 2023). In India, companies like Amazon and Flipkart enjoy a duopoly in the country's e-commerce business. Many other players in this space are gaining ground, such as Nykaa, Reliance Digital, Tata CLiQ, Myntra, Meesho and IndiaMART. Major e-commerce companies see many opportunities to support the expansion of the Indian e-commerce market. The world's largest retailer, Walmart, acquired a $1.4bn stake in Flipkart, one of India's most famous e-commerce companies, from Tiger Global (Mukati, 2023). Fast delivery is the most effective method many retail industry leaders use to remain competitive and constantly improve their logistics.

Logistics management in the e-commerce sector manages product flow in the supply chain. The network links every step of the product delivery cycle in an ideal flow, guaranteeing improved customer satisfaction and a productive supply chain. The logistics processes of an e-commerce company are complex to optimise, so every step must be optimised for the entire system. However, last-mile delivery (LMD) accounts for about 30% of the total cost (Yu et al., 2021). LMD operations are complex for commercial companies. Hiring self-delivery units for e-commerce companies is also a costly and challenging task. Many Indian startup e-commerce companies rely on logistics organisations to handle their inbound and outbound operations and provide quick solutions to compete with established companies like Amazon and Walmart (Parameswar & Dhir, 2022). The LMD is usually managed by a third party that is not the direct trading authority of the e-commerce company. Therefore, the customer gets the third-party service at their doorstep, so the e-commerce organisation needs to focus on LMD operations (Liao, 2022). Security and timeliness are the two crucial factors that must be strictly considered in contract and analysis studies of e-commerce companies before outsourcing the task to third parties (Zennaro, Finco, Calzavara, & Persona, 2022). Although the packaging of the product is carried out carefully by the trading companies, the responsibility for its safe transport also lies with the logistics company. The logistics managers cannot entirely rule out the chance of inaccurate damaged, defective or delayed merchandise, which happens frequently. There are also other inquiries and problems about customers that must be handled. It was found that during the shipment transportation, the LMD component sustained most of the damage (Bai & Sarkis, 2020). Even for the most established logistics companies, LMD is a challenging task as there are many difficulties at the organisational and customer levels.

Logistics systems at LMD must be improved through technology in the process or system to build better customer relationships. About 50% of transportation companies still use legacy technology for their distribution systems (Martínez-Estupiñan, Delgado, Muñoz, & Watkins, 2023; Conway, Joshi, Leach, García, & Senecal, 2021). Global access has created many options for customers to purchase the same product, and using outdated technology can ultimately lead to large-scale loss of orders (Van Veldhoven & Vanthienen, 2022). It is recommended for such organisations to introduce new technologies and update their existing technologies from time to time. Many research articles show that technological deficiencies increase LMD costs by approximately 28% of total logistics costs (Ostermeier, Heimfarth, & Hübner, 2022; Leon, Chen, & Ratcliffe, 2023). In the case of e-commerce, at certain times of the year, such as festivals, irregular demands must be addressed with appropriate technological reforms to remain competitive. Therefore, LMD needs to adopt the latest technological tools in logistics infrastructure.

At the beginning of the 21st century, the fourth industrial revolution occurred. I4.0 was christened at the World Economic Forum by Klaus Schwab, CEO and founder of the World Economic Society (Schwab, 2015). I4.0 relates to the digitalisation and integration of all technologies that enable automation and multi-level system and process optimisation. Digitalisation improves business performance and serves as a useful tool for logistics management. The logistics process digitises the entire process, from material packaging to storage to LMD to the consumer (Corbato, Bharatheesha, Van Egmond, Ju, & Wisse, 2018). I4.0 includes many technologies, such as the Internet of Things (IoT), artificial intelligence (AI), blockchain, data analytics, cloud computing and robotics, which can lead to digitalisation, transparency and security on a larger scale. Implementing and incorporating innovative technologies in logistics management policies is becoming a key focus area for the retail and e-commerce industries (Raji, Rossi, & Strozzi, 2021). The organisation needs an updated transparent management system with a secure tracking system that could allow customers to easily track product status and condition updates (Bai & Sarkis, 2020). This makes the entire logistics network more responsive, agile and efficient. The requirements make it easier for the logistics industry to meet customers' needs in the 21st century.

The complexity of LMD due to multiple delivery centres or doorstep delivery is related to many independent and dependent variables where congestion occurs due to insufficient information transmission (Corbato et al., 2018). The implementation of I4.0 technology into last-mile logistics adds substantial complexity. Advanced technologies like the IoT, AI and robots can potentially improve operational efficiency, but they need complex collaboration between automated systems and human operators. A major problem is managing real-time data, which is critical for dynamic route planning and satisfying changing client expectations. Furthermore, greater communication between digital systems compounds cybersecurity risks (Kumar, Singh, Mishra, & Wamba, 2022). I4.0 can manage the complete logistics process and design a feedback system based on previous data analysis. Hence, there is a need for an empirical model that enables the entire logistics process to achieve efficient LMD operations.

It is necessary to investigate potential ways to improve the LMD process's effectiveness and economy by exploring a variety of I4.0 technology enablers. Therefore, a detailed study is required to determine the importance of each enabler for LMD and its role in improving the logistics process. A limited number of research studies are dedicated to applying I4.0 enablers in LMD and logistics (Kumar et al., 2022). Most of the available literature focuses on the need to develop the framework with existing I4.0 enablers; however, there is a need to align these I4.0 enablers with LMD. It is also important to understand the role of each technology in the logistics system and its impact on LMD. Research directions, dependencies and priorities of these I4.0 enablers in logistics operations specifically for LMD must be carried out using empirical and mathematical approaches. Many empirical and mathematical models are well established. Interpretive structural modelling (ISM) is among the most effective tools for similar studies (Bashir & Ojiako, 2020). This study uses ISM for efficient and responsive LMD operations. It will help spark a discussion about minimising the challenges in LMD and the challenges faced by customers. This article attempts to answer the following research questions (RQs):

RQ1. Which I4.0 technology enablers potentially contribute to improving the LMD in the logistics sector?

RQ2. What complex relationships and dynamics exist between LMD and I4.0 technology enablers in the e-commerce business environment?

Section 1 is an introduction to the study. Section 2 discusses the relevant published literature review and examines key I4.0 enablers for LMD. Section 3 explains the methodology chosen to conduct the study. This section presents the ISM implementation to determine the relationships and levels between the I4.0 enabling elements for LMD operations in the e-commerce industry. Sections 4 and 5 present the results and conclusions. The future scope and research directions to extend the current study are listed in Section 6.

2. Literature review

The concept of e-commerce via electronic media arose from a banking system that used electronic transfers and electronic data exchange interfaces. This e-commerce trend was introduced at the organisational level in the 1970s to enable the storing and transmitting of data and information through electronically generated invoices (Kabugumila, Lushakuzi, & Mtui, 2016). The commercialisation of e-commerce came in the late 1990s with the development of the information and technology sectors when new software with easy-to-use techniques became available. This software initially required moderate hardware and system capacity to carry out its operations. Banking system technologies initially formed the basis for the global e-commerce business. The position of developing countries was, however, different. For example, for most Indians, the internet remained a luxury until the 1990s. People started recognising the internet as useful in 2002 when the IRCTC railway portal released an online reservation system. E-commerce began to boom in India with the entry of Amazon, the largest retailer in the world. Flipkart, the indigenous company, contributed significantly to this e-commerce boom.

E-commerce firms must meet high customer expectations in today's competitive scenario. This has resulted in the e-commerce sector adopting efficient and fast solutions to meet customer demands. The delivery and distribution system for any e-commerce business plays a crucial role in its market position. On-time delivery with negligible or no fees has made

Amazon the leading e-commerce shopping giant, with annual net sales of $574bn in 2023 (Ghavami, 2024). This shows the importance of optimising the supply chain and logistics management for an e-commerce company to maintain market share and beat the competition.

Logistics management is a process that helps organise stored goods and distribute them to the desired location. The logistics of e-commerce is a complex process that requires a lot of resources and infrastructure. LMD is the key factor in the overall logistics and distribution service for the e-commerce sector. LMD is the biggest bottleneck for any logistics system in distributing goods and services. The performance of LMD operations varies from city to city, region to region and locality to locality. As observed in the case of Chicago, it ranges from 0% to 91.79%, with a mean of 49.82% and a standard deviation of 61.61% (Chen, Yan, Pan, & Deal, 2021). Internet services have empowered consumers to engage in various online activities, including browsing and comparing products, making purchases and facilitating returns. Despite considerable technological advancements in the e-commerce sector, there remains a need for further enhancements to align with customer expectations and address challenges in LMD. E-commerce has become a global business model, demanding robust organisational digitisation. The foundation of modern e-commerce lies in automated and digital supply chains, especially in the logistics industry's pursuit of efficient doorstep delivery systems. E-commerce in India is poised to grow significantly, with projections reaching US$16–20bn by FY25 and a compound annual growth rate of 55%–60%. Anticipated market growth from US$111bn in 2024 to US$325bn in 2030 (IBEF, 2024), levelling the playing field through the recent influx of I4.0 technology and increased investments in e-commerce. Given this shift, the flexibility of logistics 4.0 becomes pivotal for businesses seeking prominence in the market. Logistics 4.0, on a broader scale, involves networking and technology integration within and beyond retail companies' supply chains (Kupriyanovsky et al., 2018).

Literature studies based on recent publications have been instrumental in identifying logistics management enablers. For e-commerce, it decentralises command systems and adapts processes to evolving order statuses. These studies underscore the adoption of I4.0 technology enablers for efficient LMD. The roles of key contributors to the I4.0 revolution are determined, with a need to explore and understand the importance of each enabler further.

2.1 I4.0 enablers of last-mile delivery

This study identifies 16 I4.0 enablers crucial for the technological advancement of LMD logistics. These factors are distilled from published research in LMD logistics and informed by collaborative brainstorming sessions with a specialised expert team. The team comprises ten seasoned professionals, including academicians, industry managers and consultants, each with at least 10 years of experience in supply chain and logistics. Initially, 24 enablers were identified in the literature, refined to 16 based on expert advice. The I4.0 enablers deemed effective for enhancing logistics management efficiency in LMD include digitalisation, smart objects, IoT adoption, radio-frequency identification (RFID), AI, big data, cloud computing, Global System for Mobile Communications (GSM), blockchain technology, virtual and augmented reality (VAR), digital twins, robots, autonomous vehicles, autonomous drones, cyber-physical system (CPS) and technology integration. An overview of these identified I4.0 enablers is presented in Table 1.

Digitisation is a crucial facet of I4.0 technology, representing the next generation of logistics management that can exert control over product turnover in the e-commerce sector. Smart objects, connected to sensors capable of gathering data and adapting rapidly based on real-time information, serve as rapid response mechanisms to enhance the time efficiency of

Table 1. Enablers of I4.0 technologies for LMD

S.no.	Enablers	Sources	Definition	Role in logistics management for LMD
1	Digitisation	Zhong et al. (2015), Alexopoulos, Makris, Xanthakis, Sipsas, & Chryssolouris (2016), Hermann, Bücker, & Otto (2020)	It is described as the process of transferring physical data and information into a digital format that computers can store and analyse	• It is the most critical element of technology-driven logistics since the concept of I4.0 is only possible if data and services are fully digitised • Digitisation upsurges the significance of the time and security dimensions of the intelligent transport system for optimisation at all levels of the logistics network • Digitisation provides all the data and information ready for access to supply chain managers for quick utility and transparency
2	Smart objects	Miorandi, Sicari, De Pellegrini, & Chlamtac (2012), Wang et al. (2016), Lu (2017), Hermann et al. (2020)	A smart object is a device connected to IoT and cloud computing that can collect, store and transmit data to the source centre. It can react by itself using data simulations	• The incorporation of smart objects into logistics, such as smart containers, smart packaging and smart pallets, is transforming the traditional shipping industry • Smart objects will integrate the data in real-time with no/minimal delay with fast access to suppliers and collect customers with global communication infrastructure
3	IoT adoption	Lu (2017), Tu, Lim, & Yang (2018), Rajput & Singh (2019)	Connect sensors such as RFID to the cloud through a gateway to collect continuous data to enable the smooth functioning of the business environment via internet services	• IoT adoption is an important task for a logistics company that connects smart devices on factory floors of warehouses, distribution centres and customer destinations • The smart home is the most classic scenario for IoT adoption, which will be a boon for LMD, where monitoring, localisation and identification are integrated functions

(*continued*)

Table 1. Continued

S.no.	Enablers	Sources	Definition	Role in logistics management for LMD
4	Radio frequency identification (RFID)	Miorandi et al. (2012), Zhong et al. (2015), Chy et al. (2022)	RFID refers to the application of a wireless, non-contact technology that sends information from a tag linked to an object for automated identification and tracking using radio frequency electromagnetic fields	• RFID enables data collection in the physical system at the primary level and is suitable for product tracking and delivery up to the final stage • RFID enables product tracking, monitoring and tracing, eliminating excessive time spent on billing, staffing and space management
5	Artificial intelligence (AI)	Klumpp (2018), Lee, Azamfar, & Singh (2019), Guha et al. (2021)	Making decisions by smart devices like robots without human intervention by applying data analytics to act like humans, depending on the situation	• Many service providers in the logistics industry can work with third parties to provide optimised solutions for LMD systems. AI develops safe and high-quality delivery systems, reducing all previous garbage values in the system • AI provides data filtering and detection by studying the trends and customer behaviour to provide the best deals and delivery times to improve the business prospects of e-commerce companies • AI as a self-learning technology enabler makes crucial decisions about the delivery process in quick time with many approvals, leading super-fast decision-making and efficient LMD operations
6	Big data	Zhong et al. (2015), Demir et al. (2019), Chen et al. (2021), Chy et al. (2022)	Big data is data that is generated in the amount of several gigabytes per second and requires a high storage capacity like the cloud. Big data is large subsets of unstructured and structured data from many sources	• E-commerce companies have been in the doorstep delivery business for quite some time and have accumulated customer data that can help the company take a tailored approach • Delivery operations and services can be integrated using big data to optimise LMD time and customer requirements

(continued)

Table 1. Continued

S.no.	Enablers	Sources	Definition	Role in logistics management for LMD
7	Cloud computing	Zhong et al. (2015), Zhang & Li (2018), Lee et al. (2019)	Cloud computing has popularised the term on-demand computing, which involves hosting the necessary services on the internet to connect to the main service provider/source	The I4.0 system enabled by cloud computing helps e-commerce companies to create a self-delivery and self-picking transshipment. Similarly, it offers customers the same cloud-based delivery tracking and feedback platforms
8	GSM (Global System for Mobile Communications)	Matthew et al. (2021), Wang et al. (2022), Chy et al. (2022)	To transmit mobile voice and data services, GSM is an open, digital mobile communications technology	• Mobile technology is the backbone for the implementation of I4.0 in logistics, especially in the case of LMD as GSM is widely used to provide connectivity and communication • Mobile connectivity has now arrived at remote locations, allowing customers, suppliers and delivery people to connect and enabling access to the last mile of telecommunications
9	Blockchain technology	Demir et al. (2019), Lee et al. (2019), Badhotiya et al. (2021), Li, Lim, & Wang (2022)	Blockchain is an encrypted distribution technology that enables secured transactions across the network with undeniable cryptographic initials	• Blockchain helps logistic companies keep records of all transhipments and containers through a public decentralised system that makes the LMD of e-commerce companies more sufficient • E-commerce companies are equipped with this data, which can be used in fast delivery systems and eliminate unnecessary steps without security problems by implementing blockchain technology
10	Virtual and augmented reality (VAR)	Interrante et al. (2018), Guha et al. (2021), Blaga, Militaru, Mezei, & Tamas (2021)	VAR is the technology capable of integrating the real world with virtual actions and interpreting them in reverse for real-time quality assessment	• VAR can improve logistics by visualising and modelling transportation problems for LMD • It provides logistics service providers and buyers with omni channel retail system controls for insourcing and outsourcing activities involved in online shopping

(*continued*)

Table 1. Continued

S.no.	Enablers	Sources	Definition	Role in logistics management for LMD
11	Digital twin	Moldabekova, Philipp, Satybaldin, & Prause (2021), Demir et al. (2019), Khan et al. (2020)	A virtual model of a physically engineered system that includes all dependent and independent resources, that can be automatically updated as the physical environment changes and that can be organised and expanded in near real-time from anywhere, anytime	• Digital twin works on the concept of a hyper-connected smart city with the capacity of a physical internet network. It creates the connection between the regional and city hubs for the LMD of the products • It creates a virtual environment to control the logistic functions and map the actions on the real ground without human involvement
12	Robots	Corbato et al. (2018), Boysen, Schwerdfeger, & Weidinger (2018), Lee et al. (2019), Rai, Touami, & Dablanc (2022)	Robots are programmed machines capable of collecting, analysing and simulating data to perform the required tasks quickly and efficiently	• Mobile robots can pick items from one shelf (a picker) and another (a van) that can quickly deliver all items from the picking list to the packing station • Autonomous robots are emerging as an option in the COVID-19 situation to manage delivery services without human contact in e-commerce
13	Autonomous vehicles	Leon & Aoyama (2022), Ostermeier et al. (2021), Chy et al. (2022)	An autonomous car is a vehicle capable of sensing its surroundings and functioning without human intervention	• A variety of autonomous vehicles working on the concept of I4.0 at goods delivery and service levels that offer futuristic, reliable and safe solutions amidst COVID-19
14	Autonomous drones	Lemardelé, Estrada, Pagès, & Bachofner (2021), Leon & Aoyama (2022), Shukla, Wanganoo, & Tiwari (2022)	Autonomous drones will be part of the overall I4.0 system and can periodically collect and retrieve data for product delivery	• Autonomous drones will be controlled with AI and IoT to create a system for LMD with improved cost, time and service efficiencies by avoiding connections in traffic • As there is a variation in population density across the region, e-commerce businesses will benefit from autonomous drones in sparsely populated areas as they lower operational costs

(continued)

Table 1. Continued

S.no.	Enablers	Sources	Definition	Role in logistics management for LMD
15	Cyber-physical system	Lee et al. (2019), Fatorachian & Kazemi (2021), David-West (2022)	A cyber-physical system is an intelligent electronic system that works with computerised algorithms and can control the entire logistics management system	• CPS can replicate the physical world into a virtual entity, monitoring and digitising the entire system to make decentralised decisions in the logistics network • CPS provides real-time solutions to customer and warehouse distribution problems to avoid logistics delays and improve the efficiency of the LMD e-commerce industry with a unique identity
16	Technology integration	Zhong et al. (2015), Neal, Sharpe, Conway, & West (2019)	Technology integration combines hardware, software and firmware to assist logistics management functions like scheduling, coordinating and tracking, through valid information flow	• Logistics 4.0 is essentially based on technological integration, which can bring together all available I4.0 technologies to create an intelligent logistics management system. It creates a network in the logistics operations between manufacturers, suppliers, dealers, shippers and end-users

Source(s): Authors' own work

LMD within intelligent logistics management systems for e-commerce (Seyedghorban, Tahernejad, Meriton, & Graham, 2020; Lu, 2017). The adoption of the IoT can intelligently alter offers by generating vast amounts of data, helping identify logistics bottlenecks and improving LMD cost exposure due to unnecessary failed delivery attempts (Rejeb, Keogh, & Treiblmaier, 2019; Khan et al., 2020). Warehouse system automation achieved through RFID replaces outdated package tracking methods, making product receipt and shipping more convenient, rational and precise. AI acts as a human-like intelligent system that gathers data from past customer behaviour and practices. AI implements machine learning on the collected data, assisting in selecting suitable suppliers and distribution centres for efficient LMD (Guha et al., 2021). Big data analysis processes large real-time data sets to predict upcoming customer trends and manage logistic operations based on requirements to meet customer needs. Big data provides necessary information for patterns based on product type demand, seasonal demand, holiday demand and customer sentiment (Chy, Amzad, Masum, Sayeed, & Uddin, 2022). Logistic systems in smart supply chains can track the customer's position in real time and optimise the distance and route of shipments during LMD through cloud computing and third-party mapping (Zhang & Li, 2018). Cloud computing facilitates access to customer data and information from different locations, providing logistic resources for end-users to achieve efficient LMD (Wang, Wan, Zhang, Li, & Zhang, 2016). Mobile technology serves as the backbone for LMD deployment, with GSM networks at 4G and 5G levels accessible globally. This technology enables delivery workers and consumers to communicate efficiently to receive the ordered product (Matthew, Kumar, & Subramanian, 2021). Deploying cellular networks and technology allows access to rural areas where communication is challenging.

Blockchain technology addresses trust issues in e-commerce platforms, providing security features and a digital mechanism for obtaining permission between partners. Using encrypted technology, it horizontally authenticates organisational data, ensuring secure transactions (Elhidaoui, Benhida, El Fezazi, Kota, & Lamalem, 2022; Badhotiya, Sharma, Prakash, Kalluri, & Singh, 2021). VAR also provides interactive user guides that boost customer confidence in purchasing through e-commerce platforms (Guha et al., 2021). Digital twin technology serves as the physical prototype of the original product, allowing customers to experience its functionality. It also replicates the entire logistics management system, efficiently managing supply and distribution operations (Narula, Prakash, Dwivedy, Talwar, & Tiwari, 2020; Santos, de Queiroz, Leal, & Montevechi, 2022). Moreover, robots have become indispensable in various logistics operations, from manufacturing to final delivery in the e-commerce sector. They play a vital role in handling raw materials, packaging, and distributing packages to warehouses, enhancing precision and speed in logistics activities. Technological advancements further enrich the e-commerce sector, introducing innovative options for connecting LMD to end-users through autonomous vehicles and aerial drones (Moadab, Farajzadeh, & Fatahi Valilai, 2022). Autonomous vehicles and drones exhibit exceptional adaptability to challenging weather conditions and ensure safe deliveries to customers without direct contact. Implementing an autonomous drone delivery system extends the reach of e-commerce businesses, potentially enhancing efficiency and promoting sustainable LMD solutions by reducing pollutant emissions (Pinto & Lagorio, 2022). CPS represents the comprehensive physical system capable of seamlessly integrating various logistics operations with advanced technologies like the IoT, AI, blockchain and cloud computing.

Therefore, I4.0 enablers like IoT, AI and data analytics are revolutionising the e-commerce industry's LMD operations. These technologies improve fleet utilisation, route optimisation and improve package tracking. IoT sensors provide real-time data on parcel conditions and truck position (Ramasamy et al., 2022). LMD time is minimised using AI algorithms that dynamically modify routes in response to traffic or demand spikes. I4.0 technologies provide personalised client service and more accurate timelines for LMD. However, handling massive amounts of data from various e-commerce platforms and safeguarding networked systems present difficulties, and establishing proper cybersecurity-based supervision to guarantee smooth logistical operations is required.

3. Methodology

This research study collects data through a rigorous review of the literature of 75 relevant research publications. In Step 1, we identified the 24 enablers based on the available literature (Khorasani et al., 2022; Kumar et al., 2022). In Step 2, brainstorming meetings were held amongst the authors and three experts to finalise the 16 identified enablers with professional support and suggestions. This reduction is based on determining the similarity and richness of specific concepts to avoid overlaps in the technology carriers. In Step 3, the function of each enabler for LMD for logistics was specified in the context of I4.0. To prioritise the factors under study, researchers conduct similar studies using various approaches such as the analytic hierarchy process (AHP), analytic network process (ANP), decision-making trial and evaluation laboratory (DEMATEL), ISM and technique for order preference by similarity to ideal solution (TOPSIS). These optimisation strategies helped in the formation of relationships and the determination of priority variables. AHP and ANP helped establish criteria for prioritisation based on the usefulness of each element responsible for a particular condition. On the other hand, DEMATEL and TOPSIS offered many decision-making options but could not provide different phases of a complete logistics management system.

ISM is ideally suited to this type of LMD problem where the elements are interconnected and require interactive decision-making (Malone, 1975; Sindhu, 2022). ISM can rank the priority and provide relationships between the various factors with effective driving capabilities of each factor. ISM can rank factors and propose models based on these factors' contributions to the overall system (Bashir & Ojiako, 2020). Therefore, the ISM technique was found more suitable for establishing the enabler of I4.0 for LMD. Since LMD is a complicated undertaking and I4.0 combines multiple technologies, ISM emerges as the most effective tool. Therefore, in Step 3, the tools to carry out the analysis were selected. In Step 4, calculations and results were obtained. Finally, in Step 5, conclusions were drawn after analysing the results. In Figure 1, the 16 factors discussed above are linked and integrated into a product's life cycle.

3.1 Interpretive structural modelling implementation

ISM is an interpretive method of evaluating the variables or elements to establish a relationship between them. The steps for implementing ISM and introducing I4.0 in logistics management are shown in Figure 1. The relevant elements are first identified through interaction with the experts or a literature search. A contextual relationship between the elements is then developed, followed by the structural self-interaction matrix (SSIM) development. RM is then created from SSIM and converted to canonical form, followed by layer partitioning. The ISM diagram is then created based on the values achieved. Refer to Appendix for the implementation of the ISM methodology. The input and final output obtained from the implementation of ISM are presented in Tables 2 and 3, respectively.

The one-to-one relation between enablers is established in Table 2. Under the I4.0 framework, enablers revolutionise LMD in e-commerce logistics by reducing expenses, time and energy consumption while optimising operational effectiveness.

According to Table 3, I4.0 technologies enablers in logistics may be organised, with robotics, autonomous vehicles and digital twins serving as the main drivers of automation

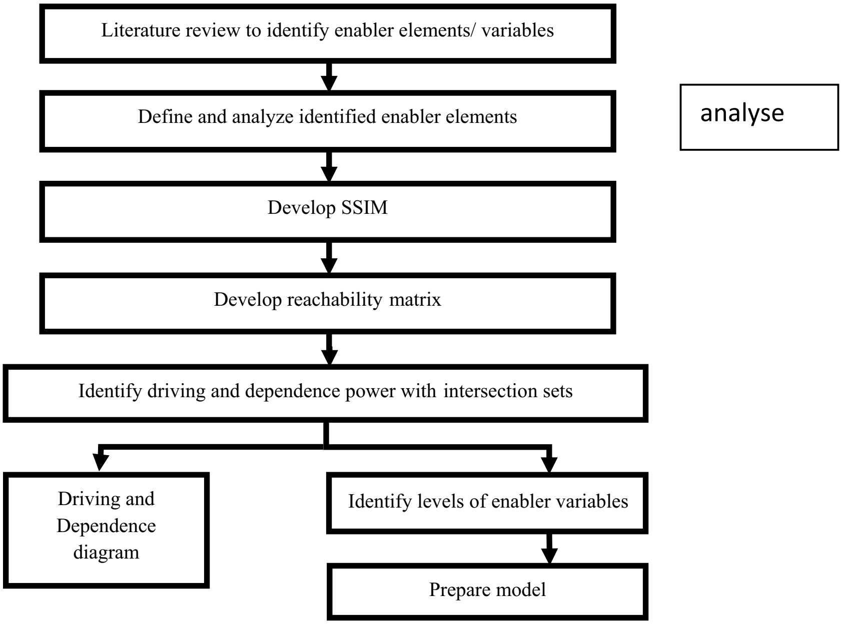

Figure 1. Steps to implement ISM for I4.0 adoption in logistics management
Source: Authors' own work

and optimisation. While advanced technologies like RFID and blockchain enable safe and effective logistics networks, transitional technologies like AI and big data improve decision-making. With the help of this hierarchy, logistics firms can integrate these technologies more effectively and efficiently in e-commerce.

4. Results and discussion

4.1 Interpretive structural modelling diagraph

The ISM digraph developed after the level is shown in Figure 2. It explains the different levels and contexts for the enablers for better customer experience and LMD operations. Autonomous vehicles, drones and robots are crucial and full-fledged I4.0 implementation in LMD operations. The integration of RFID and technology is the basic need reflected in the ISM.

4.2 MICMAC analysis

The driving and dependence diagram analyses the variables' driving and dependence power, as shown in Figure 3.

In the driving and dependence diagram, the variables are separated into four groups: autonomous clusters, dependent clusters, link clusters and independent clusters. The variables in the autonomous cluster are assumed to have weak driving and dependence power. Only two variables, 6 and 8, i.e. cyber-physical system and big data, partially belong to this cluster. Dependent variables with little or no driving force but substantial dependency on other factors make up a dependent cluster. Variables 2, 5, 6 (partial), 7, 8 (partial), 10, 14, 15 and 16, i.e. smart objects, digital twin, cyber-physical system (partial), AI, big data

Table 2. SSIM for I4.0 in logistics management implementation

	Enablers															
S.No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	x	V	V	A	V	V	V	V	V	V	O	O	A	V	V	V
2		x	A	A	V	V	A	A	A	A	O	A	A	V	V	V
3			x	A	V	V	V	V	V	V	A	A	A	V	V	V
4				x	V	V	V	V	V	V	O	O	O	V	V	V
5					x	A	A	A	A	A	A	O	O	V	V	V
6						X	O	O	O	O	A	A	A	V	V	V
7							x	A	A	V	A	A	A	V	V	V
8								X	A	V	A	A	A	V	V	V
9									x	V	A	A	A	V	V	V
10										x	A	A	A	V	V	V
11											x	O	O	V	V	V
12												x	O	V	V	V
13													x	V	V	V
14														x	X	X
15															x	X
16																x

(1) Digitisation
(2) Smart objects
(3) IoT adoption
(4) Technology integration
(5) Digital twin
(6) Cyber-physical system
(7) AI
(8) Big data
(9) Cloud computing
(10) VAR
(11) Blockchain technology
(12) GSM
(13) RFID
(14) Robotics
(15) Autonomous vehicles
(16) Autonomous drones

Source(s): Authors' own work

Table 3. Every variable and its levels achieved after iterations for the logistics adoption of I4.0

Levels	Variables
1	14, 15, 16
2	5
3	6
4	2
5	10
6	7
7	8
8	9
9	3
10	1, 11, 12
11	4, 13

Source(s): Authors' own work

(partial) VAR, robotics, autonomous vehicles and autonomous drones come under this category. The third cluster's variables have high driving and dependent solid powers. Variable 8, i.e. big data, partially belongs to this cluster. This indicates that most decision-making will be data-controlled for efficient operational activities in the I4.0 era.

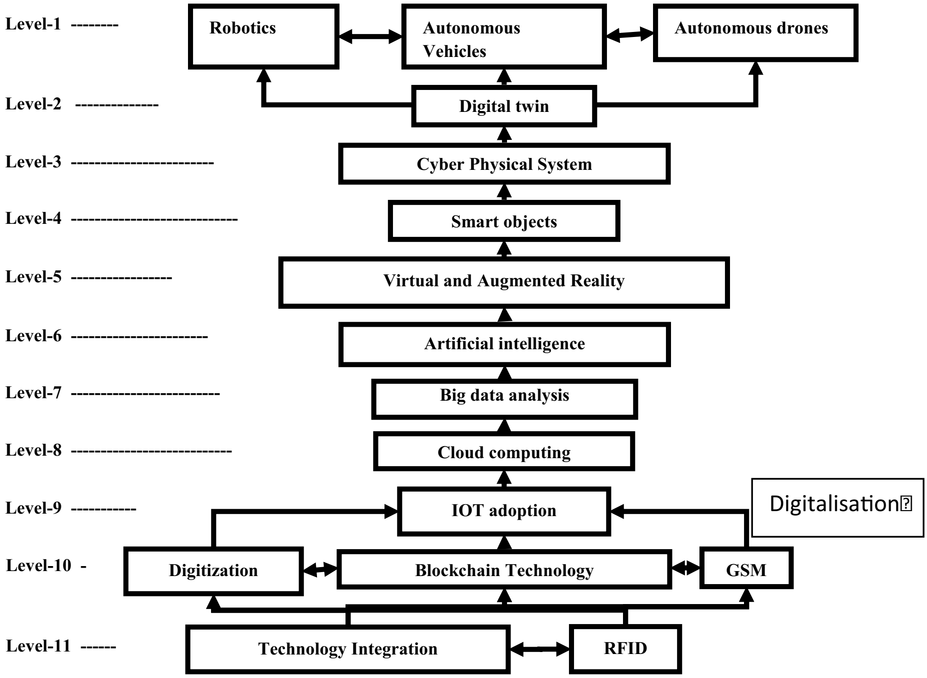

Figure 2. ISM diagraph based on the achieved level
Source: Authors' own work

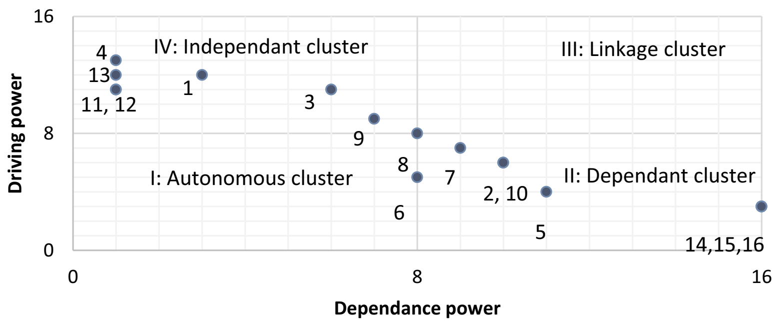

Figure 3. Driving and dependence diagram
Source: Authors' own work

The independent variables in the fourth cluster have a high driving force and little dependency. Variables 1, 3, 4, 8 (partial), 9, 11, 12 and 13, i.e. digitisation, IoT adoption, technology integration, cloud computing, big data (partial) blockchain technology, GSM and RFID belong to this cluster.

Based on their ability to drive and depend on I4.0, technologies were categorised by matrice d'impacts croisés multiplication appliquée á un classement (MICMAC) analysis, which affects the logistics of e-commerce. Although they lack inherent drive, autonomous technologies such as cyber-physical systems and big data are essential to automation. Although they are dependent on other systems, dependent technologies like digital twins, robots and AI improve logistical processes. Supply chains are optimised by the power of big data impact on decision-making, while efficiency and connection are facilitated independently by I4.0 technologies like IoT, blockchain and cloud computing. This implementation creates a more computerised, data-driven and receptive e-commerce environment.

4.3 Proposed model

The model below is proposed for the I4.0 enabler-led logistics system to improve LMD operations. Significantly, the enablers were integrated into the product journey, starting from collecting raw materials in the I4.0 industrial setup. Then, the technology umbrella was configured using IoT for all transportation activities. Inbound and outbound logistics were monitored and carried out using GSM, cloud computing, AI and robotics. This results in fully digitalised and controlled manufacturing and distribution from raw materials to production units and from production units to various distribution centres or warehouses. These warehouses store all the data, and LMD operations are carried out using machine learning and data analytics to find the cheapest and shortest route. This results in equipped user interfaces for e-commerce organisations, increasing the operational efficiency of the logistics system and customer satisfaction. Customers can organise their delivery requirements in an advanced I4.0-enabled logistics network with proper monitoring and a better delivery experience. Figure 4 (adapted from Sharma, 2023) shows the integrated I4.0-enabled model. It shows the integration and implementation of all critical I4.0 technologies for efficient logistics processes.

The convergence of IoT, AI and big data increases logistics network efficiency by enabling real-time monitoring and better decision-making for faster delivery. Autonomous vehicles and drones reduce operational costs by decreasing human participation and improving route efficiency. RFID and blockchain technology provide secure and transparent item tracking, enhancing inventory management. Robotics helps logistics by automating tasks at pickup points, reducing bottlenecks. These I4.0 enablers enhance cost efficiency, speed and predictability in LMD operations.

4.4 Discussion

Variables falling into the third cluster possess a high driving force with substantial dependency on other variables, necessitating proactive consideration. Big data, partially residing in this cluster, demands attention regarding protection, security, storage requirements and the duration for which data must be stored. In addition, factors like technology integration must be proactively addressed. Most of our factors align with cluster 4, indicating high driving forces with low dependence − 8 out of 16 variables fall into this category. Extensive literature and empirical analysis have unveiled IoT-enabling elements crucial for deployment in LMD by e-commerce organisations. IoT stands out as a critical technical asset that synergises with various technologies in a digital environment (Khan, Singh, Haleem, da Silva, & Ali, 2022), serving as the foundational requirement for any I4.0 technology-enabled logistics system. Cloud computing and big data analyses act as intermediaries for enabling technologies, establishing an environment for I4.0 setup in logistics management (Ertz, Sun, Boily, Kubiat, & Quenum, 2022). AI and VAR serve

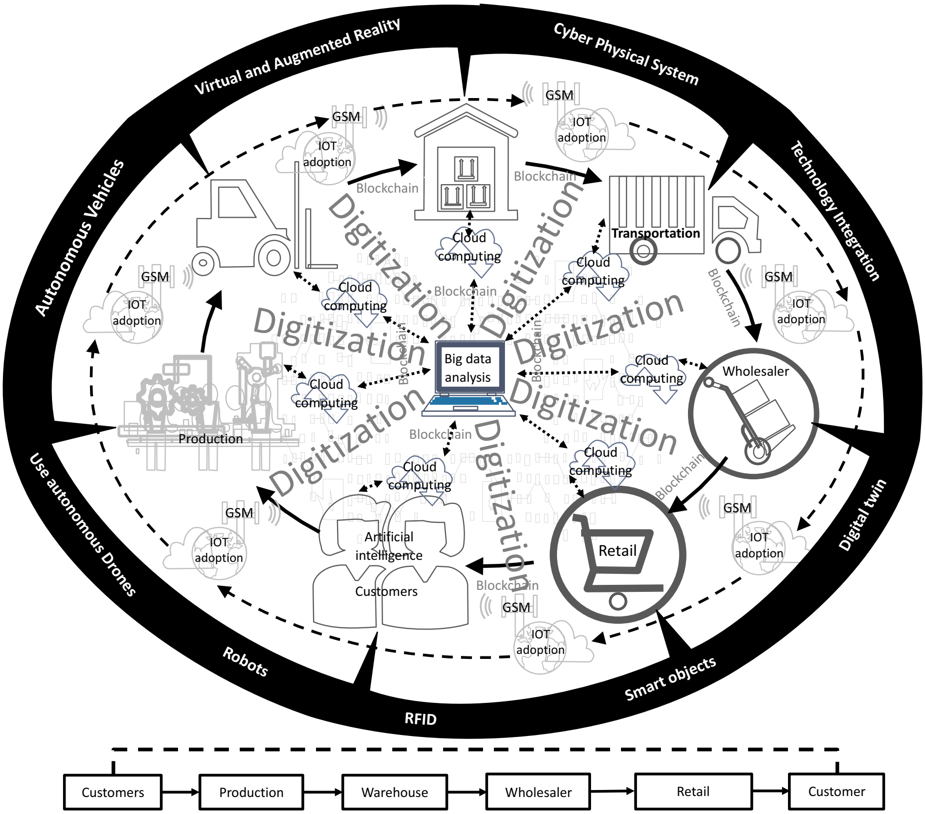

Figure 4. Integrated I4.0 enabled model
Source: Authors' own work

as technology enablers, offering additional features for the supply chain, facilitating self-optimisation and control over the entire process of e-commerce companies (Arena, Collotta, Pau, & Termine, 2022) and enhancing the dependability and performance orientation of the I4.0 system. This research study aids supply chain managers and e-commerce firms comprehend the utility and implementation of I4.0 technologies, providing a roadmap for their adoption in the competitive landscape of the growing e-commerce business. Furthermore, the study underscores the potential of technology implementation in the e-commerce industry, enhancing consumer services.

Managers may dynamically modify their real-time sourcing strategies in response to supply channel disruptions, demand variations or shifts in vendor efficiency by using AI and big data (Chen et al., 2021). Multi-sourcing methods, material processes and dynamic routeing are all greatly improved by I4.0 technology. Robotics and self-driving cars are examples of automation technologies that improve routeing and streamline materials handling. Digital twins, autonomous vehicles, drones and autonomous robots can upgrade existing LMD processes, making them more efficient and fruitful (Demir, Turetken, & Ferwom, 2019). The adoption of I4.0 to optimise online business operations depends heavily on customisation. Businesses may increase productivity and customer happiness by customising technology like automation, big data and AI to meet their unique demands. The present research establishes a sequence and priority order for achieving economic and technologically efficient LMD operations. Motivated by research findings and the potential of I4.0 technologies, it is recommended that enablers be integrated with e-commerce freight flow to improve logistics operations and LMD efficiency.

5. Conclusion

After analysing the complex relationship and dynamics between LMD and I4.0 technology enablers in the e-commerce business environment, we proposed a conceptual model with identified enablers for LMD. Structural analysis was carried out by comparing these factors, followed by ISM and MICMAC analysis. In particular, robots, autonomous vehicles and drones directly impact LMD, which is a significant finding. Their increasing role in LMD services, especially drones due to their cost-effectiveness, is expected to increase exponentially. Robots and autonomous vehicles are proving valuable for pickup stations (Conway et al., 2021). Our detailed study identified the most effective I4.0 enablers for LMD in e-commerce, including digitalisation, smart objects, IoT adoption, RFID, AI, big data, cloud computing, GSM, blockchain technology, VAR, digital twins, robots, autonomy vehicles, autonomous drones, CPS and technology integration, as mentioned in similar research articles (Demir et al., 2019; Chen et al., 2021). Having played a crucial role in industry 3.0, robots are crucial for I4.0 implementation, especially for intra-company logistics and LMD services (Khan et al., 2020; Zhong et al., 2015). RFID and technology integration are considered triggering factors for IoT in LMD implementation in e-commerce organisations. The remaining 11 enablers serve as back-end technology enablers and ensure the security, monitoring and control of the logistics system for LMD. Among these enablers, digitalisation, IoT adoption, technology integration, cloud computing, big data, blockchain technology, GSM and RFID exhibit high driving power with low dependency, indicating limited interaction between them.

Conversely, smart objects, digital twins, CPS (partial), AI, big data, VAR, robotics and autonomous vehicles and drones exhibit high dependence and limited driving power, suggesting sophisticated interaction among them. The efficiency, reliability and outcomes of the IoT system highly depend on these factors. Adopting I4.0 improves decision-making, increases computerisation and improves real-time flexibility, all revolutionising operations. It makes simplified procedures possible, lowers expenses and boosts general productivity. Improved client experiences, streamlined supply chains and more precise forecasts are examples of valuable advantages (Conway et al., 2021). The study emphasises the possibility of ongoing operations and efficient transfer of information, resulting in an evolutionary shift in traditional supply chain techniques. Furthermore, the study develops a conceptual structure that can be adapted to the e-commerce category, which provides insights into the strategic use of I4.0 technologies.

6. Future scope and research implications

An interesting research avenue in the future would be to investigate the disruptive aspects of I4.0 in various logistics industries and their impact on their operations. Extending the proposed methodology to other supply chains facing LMD challenges, such as the cold and perishable food supply chain, health care and hospitality, could provide valuable insights. The effectiveness of the identified enablers and the proposed model could be further validated through applied studies to increase the efficiency of LMD in the e-commerce sector. Exploring a combination of different methods to predict customer satisfaction parameters would enable a more comprehensive connection to key technologies. The use of I4.0 technology should not be limited to larger industries. In the future, solutions must be developed to overcome the limitations in small and medium-sized industries. Given that LMD is inherently a customer-centric process, efforts should be made to bring the benefits of enabling technologies to a broader global population. Companies in the logistics industry are encouraged to invest in breakthrough technologies that meet regulatory requirements and changing customer needs. Future research could focus on optimising these integrated technologies to improve system efficiency and competitiveness in the international e-commerce ecosystem.

6.1 Research implications

This research highlights the crucial role of I4.0 technologies in improving LMD efficiency in the e-commerce sector. Therefore, companies in the e-commerce industry should consider strategic technology investments to integrate and optimise autonomous vehicles, drones and robots into their logistics operations (Corbato et al., 2018). Managers could explore strategies and frameworks for optimising the interconnected dependencies of these technologies to improve overall system performance. The study highlights that an excellent customer experience is a key motivator for purchasing online; thus, firms should examine customers' evolving expectations of LMD while considering the impact of I4.0 technologies. The study can help e-commerce companies adapt their services to changing customer preferences, and it will help identify the training and development needs of the workforce in the e-commerce logistics sector and ensure a smooth transition to I4.0-driven technology operations.

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Appendix. Interpretive structural modelling (ISM)

This appendix provides details of the implementation of the ISM methodology. The following implementation steps must be taken along with the tables discussed in Section 3.1.

Structural self-interaction matrix (SSIM)

In the second round of expert discussion and brainstorming sessions, the SSIM matrix is formed. By element-to-element mapping, SSIM is designed to show linkages between enablers for I4.0 deployment in the logistics. These are:

V: Obtaining factor j implies factor i.

A: Obtaining factor i implies factor j.

X: Factors i and j are dependent on each other.

O: Factors i and j have no relation.

Table 2 in the research paper shows SSIM for I4.0 in logistics management implementation. This is a well-known technique for modelling the factors.

IoT, RFID and GSM make real-time tracking of cars and cargo possible, which minimises idle time and maximises resource utilisation. Artificial intelligence and big data examine demand and traffic trends to generate cost-efficient, dynamic delivery routes. Robotics, drones and autonomous cars save labour costs and delivery times, while cyber-physical systems and digital twins offer real-time monitoring for preventive maintenance. Blockchain guarantees transparent and safe transactions, while cloud computing provides large-scale data storage. These technologies come together to form a logistical operation that is sustainable and incredibly efficient.

Reachability matrix (RM) and canonical matrix

RM sets the basis for analysing hierarchical structures by demonstrating how diverse components are linked, resulting in better system comprehension and deciding complicated frameworks. A canonical matrix reduces the structure of the interactions across parts, enabling it to be simpler to grasp complicated interdependencies and assisting with structure design and analysis for the effective execution of logistics management strategies. By replacing V, A, X and O with 0s and 1s, the above-developed SSIM matrix is transformed into a binary form known as an RM. The following guidelines are applied:

If (i, j) entry in the SSIM is V, then (i, j) entry in the RM becomes 1, and the (j, i) entry becomes 0

If (i, j) entry in the SSIM is A, then (i, j) entry in the RM becomes 0, and the (j, i) entry becomes 1

If (i, j) entry in the SSIM is X, then both (i, j) and (j, i) entries in the RM become 1.

If (i, j) entry in the SSIM is O, then both (i, j) and (j, i) entries in the RM become 0.

This is used to develop a canonical form of the matrix. Most elements in the upper triangle are 0, and in the lower triangle, they are 1, from which a digraph was then prepared to represent enabler elements with their relationships and hierarchical levels graphically. It shows the final RM with driving power and dependence (conical matrix). The sum of the ones along the row gives the drive and dependency power across the column. Table A1 presents the final RM with driving power and dependence (conical matrix).

Table A1. Final RM with driving power and dependence (conical matrix) for implementation of I4.0 in the logistics management system

S.No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Driving power
1	1	1	1	0	1	1	1	1	1	1	0	0	0	1	1	1	12
2	0	1	0	0	1	1	0	0	0	0	0	0	0	1	1	1	6
3	0	1	1	0	1	1	1	1	1	1	0	0	0	1	1	1	11
4	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	13
5	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	4
6	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	1	5
7	0	1	0	0	1	0	1	0	0	1	0	0	0	1	1	1	7
8	0	1	0	0	1	0	1	1	0	1	0	0	0	1	1	1	8
9	0	1	0	0	1	0	1	1	1	1	0	0	0	1	1	1	9
10	0	1	0	0	1	0	0	0	0	1	0	0	0	1	1	1	6
11	0	0	1	0	1	1	1	1	1	1	1	0	0	1	1	1	11
12	0	1	1	0	0	1	1	1	1	1	0	1	0	1	1	1	11
13	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	12
14	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3
15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3
16	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3
Dependence power	3	10	6	1	11	8	9	8	7	10	1	1	1	16	16	16	

Source(s): Authors' own work

Level partitioning

The next step is to classify the elements into different interpretive structural modelling (ISM) structure levels. Reachability (R_i) and antecedent (A_i) sets are associated with each element of the RM. The set of elements that can be reached from the element (E_i) is termed a reachability set. The set of elements through which an element (cap E sub i.) can be reached is called an antecedent set. These sets, i.e. R_i and A_i, are developed from the RM. The factors that aid in forming the reachability set for a given variable are included in the reachability set and the variable itself. The variable and the additional factors that aid in accomplishing it, make up the antecedent set. Then, for all variables, the intersection of these sets is determined. The variables that achieve the levels are then eliminated from the remaining variables. The iteration is carried out until the levels of each variable are obtained. It streamlines the system by slicing complicated associations, grasping the model's framework by prioritising critical parts and strategically treating its elements one at a time. The first iterations (level 1) for implementing I4.0 in logistics management are shown in Table A2. Enabler serial numbers 14, 15 and 16, i.e. robotics, autonomous vehicles and autonomous drones, come at level 1. Table A2 presents the first iterations (level 1) for implementing I4.0 in logistics management.

Similarly, the second iteration (level 2) for implementing I4.0 in logistics management is derived at variable 5, i.e. digital twin. In the third iteration (level 3), variable number 6, i.e. cyber-physical system, is obtained. The fourth iteration (level 4) extracted variable number 2, i.e. smart objects. The fifth iteration (level 5) was discovered at variable 10, i.e. VAR. The sixth iteration (level 6) is derived at variable 7, i.e. AI. The seventh iteration found variable number 8, i.e. Big Data, is derived at level 7. The eighth iteration (level 8) obtained variable number 9, i.e. cloud computing. The ninth iteration (level 9) extracted variable number 3, i.e. IoT Adoption. The tenth iteration (level 10) determined variable numbers 1, 11 and 12, i.e. digitisation, blockchain technology and GSM. The eleventh and final iteration has variable numbers 4 and 13, i.e. technology integration and RFID, is derived at level 11.

Table A2. First iterations (level 1) for the implementation of I4.0 in the logistics management

S.No.	Reachability set (Ri)	Antecedent set (Ai)	Intersection set	
1	1, 2, 3, 5, 6, 7, 8, 9, 10, 14, 15, 16	1, 4, 13	1	
2	2, 5, 6, 14, 15, 16	1, 2, 3, 4, 7, 8, 9, 10, 12, 13	2	
3	2, 3, 5, 6, 7, 8, 9, 10, 14, 15, 16	1, 3, 4, 11, 12, 13	3	
4	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 14, 15, 16	4	4	
5	5, 14, 15, 16	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	5	
6	5, 6, 14, 15, 16	1, 2, 3, 4, 6, 11, 12, 13	6	
7	2, 5, 7, 10, 14, 15, 16	1, 3, 4, 7, 8, 9, 11, 12, 13	7	
8	2, 5, 7, 8, 10, 14, 15, 16	1, 3, 4, 8, 9, 11, 12, 13	8	
9	2, 5, 7, 8, 9, 10, 14, 15, 16	1, 3, 4, 9, 11, 12, 13	9	
10	2, 5, 10, 14, 15, 16	1, 3, 4, 7, 8, 9, 10, 11, 12, 13	10	
11	3, 5, 6, 7, 8, 9, 10, 11, 14, 15, 16	11	11	
12	2, 3, 6, 7, 8, 9, 10, 12, 14, 15, 16	12	12	
13	1, 2, 3, 6, 7, 8, 9, 10, 13, 14, 15, 16	13	13	
14	14, 15, 16	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16	14. 15, 16	Level-1
15	14, 15, 16	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16	14. 15, 16	Level-1
16	14, 15, 16	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16	14. 15, 16	Level-1

Source(s): Authors' own work

Every variable and its levels for the logistics adoption of I4.0 are presented in Table 3 in the main manuscript/research article. Referring to Table 3 of the article, I4.0 technology enablers in logistics may be organised, with robotics, autonomous vehicles and digital twins serving as the main drivers of automation and optimisation. While advanced technologies like RFID and blockchain enable safe and effective logistics networks, transitional technologies like AI and big data improve decision-making. With the help of this hierarchy, logistics firms can integrate these technologies more effectively and efficiently in e-commerce.

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