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UNDERSTANDING THE ROLE OF INFORMATION AND DIGITAL TECHNOLOGIES OF INDUSTRY 4.0 ON LAST-MILE LOGISTICS: CURRENT STATE AND PROSPECTIVE RESEARCH AVENUES

COMPRENSIÓN DEL PAPEL DE LAS TECNOLOGÍAS DE LA INFORMACIÓN Y DIGITALES DE LA INDUSTRIA 4.0 EN LA LOGÍSTICA DE ÚLTIMA MILLA: ESTADO ACTUAL Y FUTURAS LÍNEAS DE INVESTIGACIÓN

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Abstract

This work aims to provide an overview of the current state of the literature linking Information and Digital Technologies of Industry 4.0 (IDT of I4.0) and last-mile logistics. The systematic literature review (SLR) was used to identify, select, and evaluate papers covering the period from 2001 to 2022, inclusively. Due to the large number of identified articles, inclusion criteria prioritized those recognized among the highest-rated journals according to the AJG (ABS) classification resulting 97 papers. The paper provides a novel classification of the literature into three lines of research: (1) Mature IDT in last-mile logistics, (2) Emerging IDT in last-mile logistics, and (3) General approach in last-mile logistics. The study identifies and proposes future lines of research to address gaps.

Keywords: information and digital technologies, industry 4.0, logistics.

Resumen

Este trabajo tiene como objetivo ofrecer una visión general del estado actual de la literatura que vincula las Tecnologías de la Información y Digitales de la Industria 4.0 (TID de I4.0) con la logística de última milla. Se utilizó una revisión sistemática de la literatura (RSL) para identificar, seleccionar y evaluar artículos que abarcan el período desde 2001 hasta 2022, inclusive. Debido al gran número de artículos identificados, se priorizaron criterios de inclusión que seleccionaron aquellos reconocidos entre las revistas de mayor calificación según la clasificación AJG (ABS),

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resultando en 97 artículos. El trabajo proporciona una clasificación novedosa de la literatura en tres líneas de investigación: (1) TID maduras en la logística de última milla, (2) TID emergentes en la logística de última milla, y (3) Enfoque general en la logística de última milla. El estudio identifica y propone futuras líneas de investigación para abordar las lagunas existentes.

Palabras clave: tecnologías de la información y comunicación, industria 4.0, logística.

JEL classification: M11, M15

1. INTRODUCTION

Supply chain is undergoing a digital transformation driven by the emergence of advanced Information and Digital Technologies (IDT) (Núñez-Merino *et al.*, 2020). IDT of Industry 4.0 (I4.0) refers to applying technologies intensively in industry, to achieve more effective and efficient processes. These technologies are related to the digital transition, whose scope extends beyond organizational boundaries and involves intelligent supply chain and connected customers (Ghobakhloo, 2018; Gilchrist, 2016). So, IDT of I4.0 includes the application of e-commerce tools such as Electronic Data Interchange (EDI); the adoption of Advanced Manufacturing Technologies (AMT) such as Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Engineering (CAE), Industrial Simulation, and Enterprise Resource Planning (ERP); and the most advanced IDT such as the Internet of Things (IoT), Augmented Reality (AR), Additive Manufacturing, Blockchain, Cloud Computing, and Big-Data analytics, among others (Ghobakhloo, 2020; Gilchrist, 2016).

IDT of I4.0 can enable logistics service providers, for example to add goods for ad hoc return to a planned delivery route and to schedule ad hoc reverse logistics stops on a pre-existing route, while ensure simultaneous environmental impact and cost minimization, and customer service maximization (Agnusdei *et al.*, 2022). IDT of I4.0 enhance logistics by improving operational efficiency and enabling real-time data analysis, which leads to optimized supply chain management and more effective decision-making. These technologies afford a better understanding of consumers and offer options to improve their satisfaction level while simultaneously providing businesses with the capability to adapt to market changes (Lasi *et al.*, 2014).

Last-mile logistics is identified as the final stage of a Business-to-Consumer service involving goods delivery to end customers (Lim *et al.*, 2018). As online purchases become more popular, new challenges arise for last-mile scheduling and vehicle routing services. Inefficiencies in delivery services lead to high costs for logistics providers. In turn, customers expect more flexibility in alternative collection points or the timeliness of deliveries (e.g., same-day deliveries) (Özarık *et al.*, 2021). In contrast to traditional urban distribution, customers with small daily delivery demands and different availability schedules are widely spatially distributed, making last-mile distribution a complex and costly issue (Lim *et al.*, 2018). Last-mile distribution is considered the most expensive, most polluting, and least efficient part of the e-commerce supply chain, accounting for between 13% and 75% of total supply chain costs (Gevaers *et al.*, 2009). In this context, technology plays a pivotal role in mitigating negative externalities and transforming last-mile logistics into a more sustainable and efficient system. Strategies based on IDT of I4.0 use could enhance the efficiency of the last-mile logistics delivery process (Muñoz-Villamizar *et al.*, 2021). Further, research on emerging technology use could help improve the resilience and sustainability of last-mile logistics (Agnusdei *et al.*, 2022).

Previous literature has explored the interrelationship between various technologies and last-mile logistics, offering both theoretical insights and empirical evidence. An analysis of

previous literature reviews reveals a rich tapestry of diverse contributions. De Mello Bandeira *et al.* (2019) conducted a systematic literature review to identify the primary vehicle types enhancing sustainability in urban last-mile distribution, while Gee *et al.* (2020) reviewed existing literature on the environmental implications of e-commerce. Janjevic *et al.* (2019) employed a combination of literature review and case study analysis to establish an integrated conceptual framework characterizing last-mile urban e-commerce distribution strategies in mature and emerging markets. Pan *et al.* (Pan *et al.*, 2021) analysed literature, proposing a new conceptual framework for smart city logistics and its relevant key perspectives. Boysen *et al.* (2021) examined established and novel last-mile concepts, such as drones or robots, emphasizing decision problems in configuring and operating each concept, albeit with minimal consideration of I4.0 technologies. Other authors conducted an SLR linking I4.0 technologies, offering insights into other segments of the logistics chain, like first-mile logistics (Agnusdei *et al.*, 2022). Additionally, some works explored the impact of I4.0 technologies alongside lean management, addressing the entire supply chain (Núñez-Merino *et al.*, 2020), or focused on the digital transformation's impact on the entire e-commerce-linked supply chain, without specific emphasis on last-mile logistics (Mashalah *et al.*, 2022).

As observed, literature reviews exploring the dynamic interplay between the IDT of I4.0 and last-mile logistics have exhibited a range of perspectives, yet often with a narrow focus or emphasis on distinct aspects. It is evident that numerous studies delve deeper into the impact of various IDT of I4.0 on last-mile logistics. However, these valuable insights are scattered across the literature landscape, existing as isolated islands rather than cohesive narratives interconnected with one another. Our work proposes a systematic literature review that holistically addresses the effects and consequences of IDT of I4.0 for last-mile logistics while identifying existing gaps and proposing lines of future research to be undertaken.

The remainder of this work is organized as follows. The next section describes the methodology used. Then, the main results of our analysis are discussed and gaps and lines of future research are identified. Finally, some conclusions are drawn in the last section.

2. METHODOLOGY

Systematic literature review (SLR) was used to identify, select, and evaluate published research. This method ensures a structured, repeatable, and scientific process that allows existing information to be rigorously synthesized (Denyer & Tranfield, 2009; Tranfield *et al.*, 2003). The SLR process is composed of the following five phases (Denyer & Tranfield, 2009): (1) formulating the research question; (2) locating studies; (3) selecting and evaluating relevant studies; (4) analysing and synthesising the results obtained; and (5) reporting the results.

Starting with the first phase, this SLR aims to answer the following research question (see Figure 1):

RQ. What is the current state of knowledge on the relationship between IDT of I4.0 and last-mile logistics?

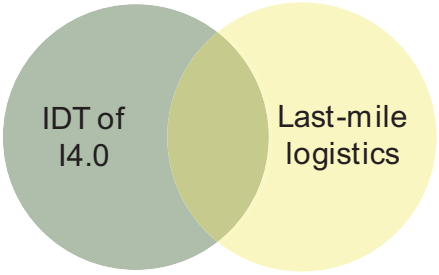
This general question is subdivided into the following specific questions:

RQ1. What current literature addresses the IDT of I4.0 and last-mile logistics relationship?

RQ2. How could the works that link IDT of I4.0 and last-mile logistics be classified?

RQ3. What gaps and challenges exist for future research on the relationship that links IDT of I4.0 and last-mile logistics?

FIGURE 1. OBJECTIVE OF THE SLR



Source: Authors' own elaboration

The second phase is the location of the literature. This step is based on the construction of search strings that allow the identification of precisely linked studies, and the selection of search engines where it is possible to explore large volumes of documents related to the subject under investigation (Denyer & Tranfield, 2009; Tranfield *et al.*, 2003). This study used the Web of Science (WoS) search engine, a widely utilized database in operations management studies (Garcia-Buendia *et al.*, 2021), to locate the literature on articles linking IDT of I4.0 and last-mile logistics (Núñez-Merino *et al.*, 2020; Oliveira-Dias, Maqueira-Marín, *et al.*, 2022).

The search strings were constructed by combining representative keywords from each of the two sets of research objects (IDT of I4.0 and last-mile logistics), taking into account synonyms and related words, and finding the intersection zone of the two sets (Table 1). The search strings allow for results that are specific enough to locate studies related to the search topic, but broad enough not to restrict possible results. Keywords were determined and selected in conjunction with the participating researchers in this study. Once the keywords were established, search strings were constructed using logical and boolean operators to ensure that the documents found contained at least one of the keywords belonging to each of the two research areas, either in the title, abstract, author keywords or expanded keywords. In addition, repeated pilot searches were carried out to refine the selection of words used, eliminating those that were not relevant or that generated ambiguous results. So, search strings were meticulously designed to retrieve documents encompassing IDT of I4.0 and last-mile logistics (see Figure 1 and Table 1), retrieving 1,254 identified articles.

In the third phase of the study, the objective was to refine the selection of relevant documents for the research. Inclusion and exclusion criteria were set to ensure the articles' relevance. In this work, the search was initially limited to all documents obtained in the WoS database from the search strings detailed in the previous phase (inclusion criteria), and subsequently the search was limited to specific research areas: engineering, computer science, business economics, transport, operations research, management science, telecommunications, environmental science, ecology and science and technology. This first filtering reduced the results from 1,254 to 1,244 documents.

Subsequently, a language and document type filter were implemented, searching only for articles written in English (1,237 articles) and documents of type "Article", "Early access" and "Review Article", reducing the results from 1,237 to 828 articles. Finally, the search

TABLE 1. KEYWORDS AND SEARCH STRING

WoS search keywords	***IDT keywords***: ("information system*" OR "information technolog*" OR "information and communication* technolog*" OR "digital technolog*" OR ict OR "technological innovation" OR "internet of things" OR iot OR cloud OR "web" OR "e-business" OR "e-commerce" OR "enterprise resource planning" OR "erp" OR "material* requirement* planning" OR "mrp" OR "electronic data interchange" OR edi OR "radio-frequency identification" OR "rfid" OR "business intelligence" OR "software" OR "artificial intelligence" OR "big data" OR "industry* 4.0" OR "e-procurement" OR "cyber physical system*" OR "blockchain" OR "augmented reality" OR "virtual reality" OR "additive manufacturing" OR robotic* OR "3D print*" OR "cybersecurity" OR "industrial simulation" OR "warehouse management system" OR "transportation management system"). ***Last-mile logistics keywords***: ("last-mile" OR "smart routing" OR "urban* logistic*" OR "cit* logistic*").
WoS search string	TS = (("information system*" OR "information technolog*" OR "information and communication* technolog*" OR "digital technolog*" OR ict OR "technological innovation" OR "internet of things" OR iot OR cloud OR "web" OR "e-business" OR "e-commerce" OR "enterprise resource planning" OR "erp" OR "material* requirement* planning" OR mrp OR "electronic data interchange" OR edi OR "radio-frequency identification" OR rfid OR "business intelligence" OR software OR "artificial intelligence" OR "big data" OR "industry* 4.0" OR e-procurement OR "cyber physical system*" OR blockchain OR "augmented reality" OR "virtual reality" OR "additive manufacturing" OR robotic* OR "3D print*" OR cybersecurity OR "industrial simulation" OR "warehouse management system" OR "transportation management system") AND ("last-mile" OR "smart routing" OR "urban* logistic*" OR "cit* logistic*")).

Source: Authors' own elaboration.

concentrated on papers published between 2001 and 2022 inclusive, resulting in a total of 704 articles. The search was concentrated on this period of time as the first articles related to the topic under investigation were detected from 2001 onward (George & Morin, 2001; Reich & Rosenbaum, 2001).

To ensure the quality of the selected papers, a selection was made by classifying the journals in which the articles were published according to their Journal Citation Report (JCR) Journal Impact Factor (JIF). This classification showed that, out of the 704 articles obtained in the previous step, 147 were not published in journals with impact factor, so they lacked the necessary quality. After the application of this filter, 557 articles remained.

Given the large number of articles for an SLR, we applied a more restrictive filter, following the approach of Danese, Manfè, & Romano (2018). This filter focused on the quality and reputation of the journals where the articles were published, using the Academic Journal Guide ranking system by ABS, which classifies journals from 1 to 4*, with 4* representing the highest-ranked titles. In this sense, the ABS ranking provides a more comprehensive assessment of journals compared to the JCR, as it not only considers the journal's impact factor but also incorporates expert evaluations of its reputation. In this way, we focus only on the highest-ranked journals in this classification (levels 3, 4 and 4*) in its 2021 edition (Chartered Association of Business Schools, 2021). This left 109 articles.

Finally, the remaining articles were evaluated to determine whether the papers were closely related to the topic, discarding those that were not related to the research question (exclusion criteria). To do this, the title, abstract and keywords of each of these articles were examined, discarding a total of 12, resulting in a total of 97 articles to be analysed.

The fourth phase consisted of analyzing and synthesizing these 97 articles through a thorough reading. In this phase, a predefined codification and structured classification of the content of the articles was carried out in order to extract information of interest in each of the studies. The codification and classification parameters were extensively discussed among all researchers, reaching a consensus on which variables should be considered for coding the articles.

During the classification process, a database was implemented using an Excel spreadsheet, in which the articles' authors, title, year, journal/source, abstract, technology used, contribution, logistics function involved, supply chain members affected and last-mile strategy used were captured for each of the 97 articles.

To group the articles, we applied a framework from existing literature, specifically focusing on the Technology Life Cycle (TLC) and I4.0 technologies (Núñez-Merino *et al.*, 2020; Oliveira-Dias, Maqueira-Marín, *et al.*, 2022). The TLC illustrates the progression of technology over time, marking phases of introduction, growth, maturity, and eventual decline. Technologies are considered mature when their usage becomes widespread (maturity stage) and are classified as emerging when they are newly introduced to the market (introduction and growth stages) (Oliveira-Dias, Maqueira Marín, *et al.*, 2022; Taylor & Taylor, 2012).

The articles were grouped into research sublines according to the specific technology or groups of technologies used to further analyse the role and implications of IDT of I4.0 in last mile logistics. Gartner's Hype Cycle for emerging technologies and previous literature on I4.0 technologies (Núñez-Merino *et al.*, 2020; Oliveira-Dias, Maqueira-Marín, *et al.*, 2022) were used to determine where each of the technologies is positioned in the TLC. Previous literature has found that mature technologies are enablers of efficiency and agility-oriented supply chain strategies while emerging technologies require a consolidation process to be a useful mechanism to achieve efficiency and/or agility in the supply chain (Oliveira-Dias, Maqueira Marín, *et al.*, 2022). In this context, it would be valuable to analyse the differing roles of mature and emerging technologies in last-mile logistics.

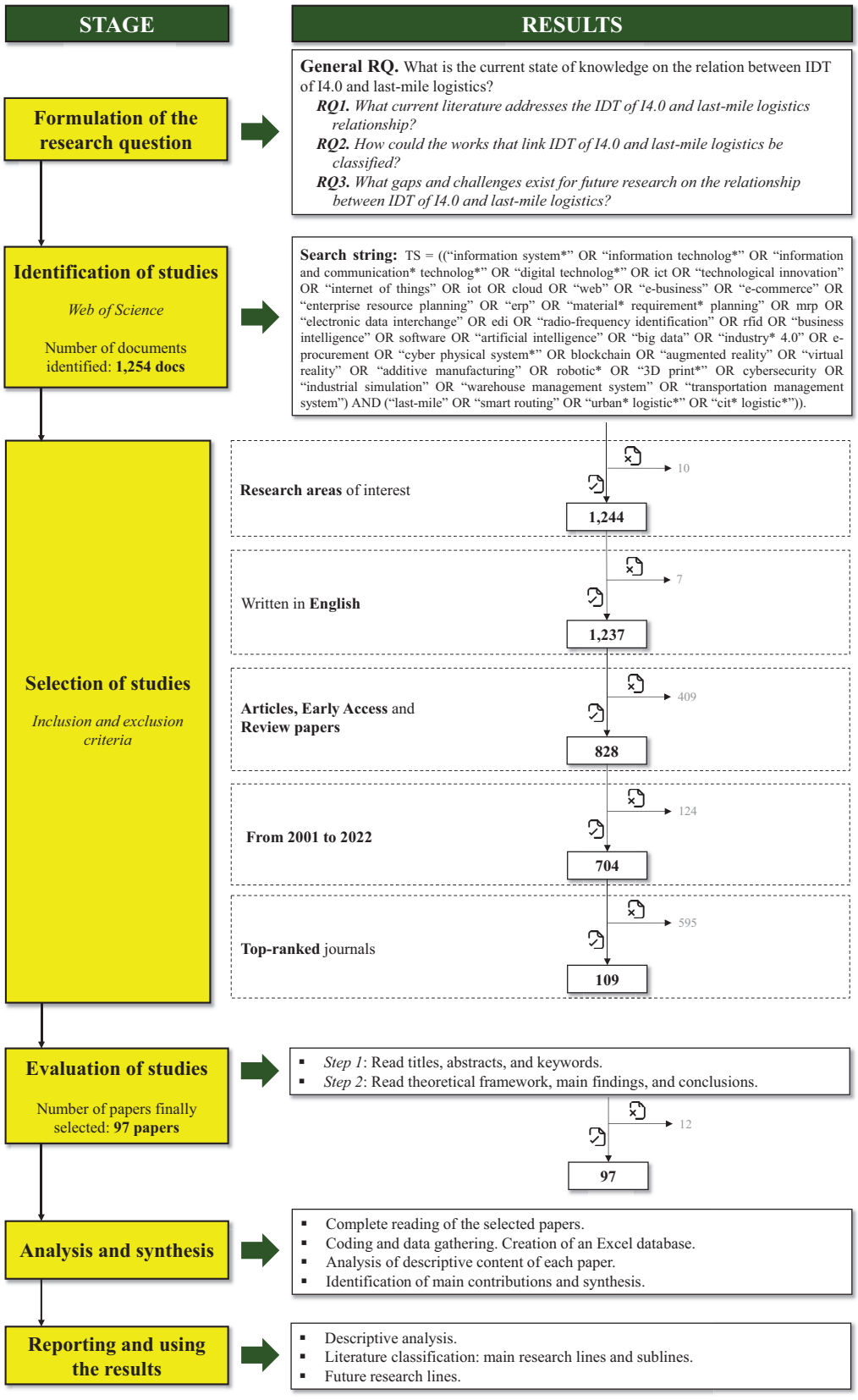
The literature analysis and synthesis not only allowed for the identification of potential research avenues concerning the relationship between IDT of I4.0 and last-mile logistics but also highlighted existing research gaps within the various lines of research.

The final phase involved preparing a report on the results of the analysis of the selected literature to provide a general overview of the articles and their characteristics and highlight clear trends. Grouping based on the previous phase's detailed classification identified underexplored and unexplored areas to outline how future research can address these gaps. The process was supported by the researchers discussing the findings.

Thus, our aim is to offer a comprehensive overview of what has been explored within each identified line of research, highlighting how the main contributions of individual works relate to one another. This approach allows for a clearer understanding of the added value brought by the classification and offers insight into the role of the technologies analysed in the context of last-mile logistics within each research line.

Figure 2 was prepared to illustrate the methodological procedure followed in this study and described in this section.

FIGURE 2. SUMMARY OF THE SLR



Source: Authors' own elaboration.

3. FINDINGS

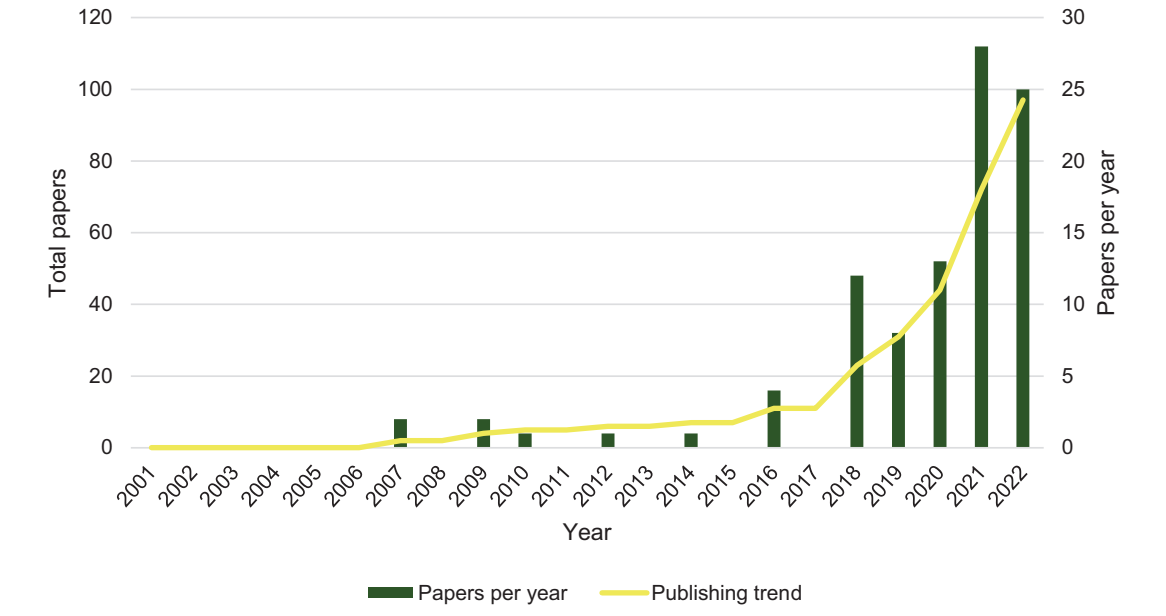
This section presents a descriptive analysis of the 97 identified papers on the relationship between IDT of I4.0 and last-mile logistics. It also offers a novel classification of the literature on the IDT of I4.0 and last-mile logistics, based on the technology lifecycle (TLC). This approach aligns with recent studies examining the impact of I4.0 technologies on supply chain strategies (Núñez-Merino *et al.*, 2020; Oliveira-Dias, Maqueira-Marín, *et al.*, 2022).

3.1. Descriptive analysis of IDT of I4.0 and last-mile logistics literature

Figure 3 shows the chronological evolution of the literature related to IDT of I4.0 and last-mile logistics. It can be seen that the number of publications has gone hand in hand with the importance of IDT of I4.0 over time. Thus, the research interest in this field was very residual in the 2001-2015 period, with only 7 papers, followed by moderate growth in the 2016-2019 period (24 papers), and then exponential growth from 2020 onwards (66 publications). The evolving trend in the research area highlights that the implications of IDT of I4.0 in last-mile logistics are gaining increasing attention from the scientific community. This growing interest underscores the importance of thoroughly exploring the existing studies on this topic to provide a comprehensive view of the latest research advancements.

Regarding the journals in which the studies in this field have been published, it is worth highlighting the importance of the *Transportation Research Part E: Logistics and Transportation Review* journal, with almost 23% of all papers. Table 2 gives a distribution of the journals with most published studies on IDT of I4.0 and last-mile logistics literature.

FIGURE 3. EVOLUTION OF IDT OF I4.0 AND LAST-MILE LOGISTICS LITERATURE



Source: Authors' own elaboration

TABLE 2. MOST PROLIFIC JOURNALS ON IDT OF I4.0 AND LAST-MILE LOGISTICS LITERATURE

Journal	ABS classification	Papers	% of total
Transportation Research Part E: Logistics and Transportation Review	3	22	22.7
International Journal of Production Research	3	7	7.2
European Journal of Operational Research	3	6	6.2
Transportation Research Part B: Methodological	4	6	6.2
Transportation Research Part D: Transport and Environment	3	6	6.2
Annals of Operations Research	3	5	5.2
International Journal of Production Economics	3	5	5.2
Transportation Science	3	5	5.2
Environmental Science & Technology	3	4	4.1
Journal of Business Logistics	3	4	4.1
Journal of Business Research	3	3	3.1
IEEE Transactions of Engineering Management	3	2	2.1
International Journal of Operations and Production Management	4	2	2.1
Omega-International journal of management science	3	2	2.1
Production and Operations Management	4	2	2.1
Production Planning & Control	3	2	2.1
Transportation Research Part A: Policy and Practice	3	2	2.1
Others (12 journals with one paper)	3 (8), 4* (4)	12	12.4
Total		***97***	***100***

Source: Authors' own elaboration.

3.2. Research lines in IDT of I4.0 and last-mile logistics literature

The Technology Life Cycle (TLC) illustrates the progression of technology over time, highlighting its phases of introduction, growth, maturity, and eventual decline. Technologies are classified as "mature" when their adoption becomes widespread (maturity stage) and as "emerging" when they first enter the market during the introduction and growth stages (Oliveira-Dias, Maqueira Marín, *et al.*, 2022; Taylor & Taylor, 2012).

Previous literature has found that mature technologies are enablers of efficiency and agility-oriented supply chain strategies while emerging technologies require a consolidation process to be a useful mechanism for achieving efficiency and/or agility in the supply chain (Oliveira-Dias, Maqueira Marín, *et al.*, 2022). In this context, it would be valuable to analyse the differing roles of mature and emerging technologies in last-mile logistics.

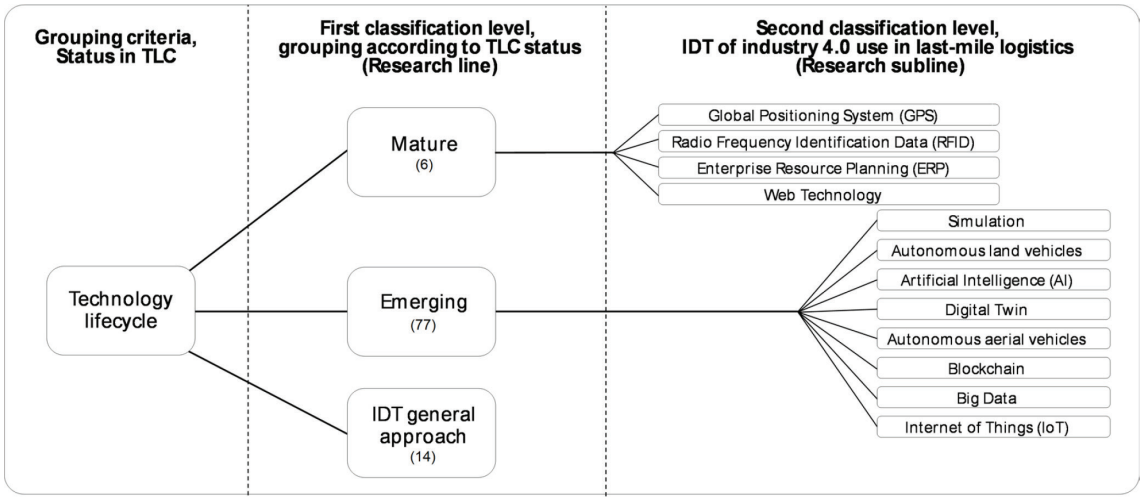
The papers were grouped into research sublines according to the specific technology or groups of technologies used to analyse the role and implications of IDT of I4.0 in last-mile logistics in greater depth. The Gartner Hype Cycle for emerging technologies (Gartner, 2016) and the previous literature on I4.0 technologies (Núñez-Merino *et al.*, 2020; Oliveira-Dias, Maqueira-Marín, *et al.*, 2022) have been used to determine the position of each technology within the TLC. Consequently, a two-level literature classification framework was defined, as

shown in Figure 4, with each research line and subline containing papers addressing the IDT of I4.0 and last-mile logistics from different perspectives.

The first classification level was based on the TLC stage of the technology addressed in the paper. The newest technologies most recently launched onto the market were grouped as emerging technologies, while relatively consolidated technologies according to the TLC were classified as mature technologies. However, there exists a subset of papers where the technologies discussed are not distinctly identified or cannot be categorized into a specific stage of the TLC. These studies have been classified as taking a general approach to IDT, as placing them in any other research line would lack rigor.

The second level of classification was established based on the specific type of IDT addressed in each study, with emerging and mature technologies being referred to in the first level classification. This approach allowed for the creation of distinct research subcategories based on the type of IDT examined in relation to last-mile logistics, thus providing a more comprehensive understanding of the interplay between specific technologies and last-mile logistics. Figure 4 shows the proposed literature classification on IDT of I4.0 and last-mile logistics.

FIGURE 4. PROPOSED LITERATURE CLASSIFICATION



Source: Authors' own elaboration.

3.2.1. Mature IDT of I4.0 in last-mile logistics

The works identified in this line, which address the impact of consolidated IDT of I4.0 on last-mile logistics, were categorized into distinct research sublines based on the specific types of technologies studied: (1) Global Positioning System (GPS), (2) Radio Frequency Identification Data (RFID), (3) Enterprise Resource Planning (ERP), and (4) Web technologies. This research line encompasses 6 out of the 97 studies reviewed. This suggests that the interest in IDT of I4.0 and last-mile logistics has not been predominantly centered on the implications of these mature technologies during the period considered in this literature review.

(1) GPS and (2) RFID. The first and last mile deliveries are an increasingly important and costly component of supply chains, especially those requiring transportation within city centers. Both GPS and RFID technologies enable product traceability. When combined, RFID

identifies the product itself, while GPS tracks the means of transport in which the product moves. This makes it possible to know where the product is at all times, preventing it from getting lost. It also makes it possible to assign pick-ups flexibly and efficiently to the means of transport. Particularly, GPS has enhanced the precision of last-mile deliveries in large cities, particularly during the "capillary" phase —when a package departs from a distribution center and reaches the final consumer, requiring a highly intricate distribution network (van Lopik *et al.*, 2020). Additionally, RFID technology has significantly reduced logistics costs in ubiquitous cities (integrated, high-tech urban environments) (Kim & Sohn, 2009). With the application of these technologies, a significant reduction in overall logistics costs can be expected.

(3) ERP. ERPs are essential for automatizing and integrating different logistics processes and are key facilitators that provide the support required by future urban logistics (Ahmad & Mehmood, 2016) as they achieve more efficient and less costly operations. Having a single database that interconnects all the company's functions avoids errors of various kinds and makes the logistical process take off sooner (Ahmad & Mehmood, 2016). For example, the ERP automates the order management process that is connected to the warehouse management process, so that after the purchase is made, the warehouse already receives the preparation order. This avoids many of the typical errors associated with the last-mile, such as delivery of different products than those purchased.

(4) Web technologies. Web technologies, meanwhile, have played a key role in the development of IDT in last-mile logistics. Studies underline the role of e-commerce web sites in efficiency gains in order fulfilment through the learning capability of websites designed for this purpose directly impacting customer satisfaction (Kull *et al.*, 2007) and loyalty (Ramanathan, 2010). Web technologies can be used to keep congestion and pollution under control and to achieve more optimal delivery routes proposing solutions such us urban consolidation centers managed by web sites to pool shipments from multiple carriers prior to last-mile delivery or peer-to-peer platform for operators to share delivery capacity (Deng *et al.*, 2021).

3.2.2. Emerging IDT of I4.0 in last-mile logistics

The research line focusing on emerging IDT of I4.0 and last-mile logistics is the most extensive, with 77 out of 97 papers dedicated to examining the impact of these technologies on last-mile logistics. This indicates that, compared to other research lines, the primary research interest lies in exploring the role of emerging technologies in this area. Similar to the previous research line, the sublines within this extensive category are centered on the impact and implications of specific technologies on last-mile logistics.

(1) Simulation. Simulation in last-mile logistics enables tests in simulated scenarios where parameters and variables can be adjusted to compare outcomes. Simulation allows to analyse possible scenarios to determine the most optimal ones, before implementing them on a large scale, incurring in significant cost savings. This influences the design of algorithms to optimize efficiency and delivery costs (for example, optimizing the "traveling salesman problem") while considering factors such as time windows (Giménez-Palacios *et al.*, 2022; Torres *et al.*, 2022), crowdsourcing implementation (Xiao *et al.*, 2021; Zhen *et al.*, 2021), delivery slots (Leung *et al.*, 2023; Lin *et al.*, 2022), and collaborative logistics (Ouyang *et al.*, 2022). This directly enables solutions adapted to current challenges. Thus, Pahwa & Jaller (2022) use simulation to explore electric truck competitiveness against diesel truck, low volume and low emission vehicles such as cargo bicycles, and the advantages and disadvantages of last-mile

outsourcing to a collaborative delivery fleet. Further, simulation allows dynamic interactions to be examined and future system states to be predicted, which enables more sustainable and efficient distribution strategies (Melkonyan *et al.*, 2020).

(2) Autonomous land vehicles. Autonomous land vehicle use for delivery is conspicuous for offering flexibility and helping to better protect both the driver and customers by minimizing contact (C. Chen *et al.*, 2021), efficiency improvements and cost reduction thanks to personnel reductions, and improved effectiveness container transportation (R. Chen *et al.*, 2022; Peppel *et al.*, 2022). These vehicles are effective for delivery in high-traffic areas (Simoni *et al.*, 2020) and significantly contribute to reductions in carbon emissions, especially compared to internal combustion when a short route are made (Figliozzi, 2020). However, security remains the main concern, especially in complex urban traffic environments (C. Chen *et al.*, 2021). The Autonomous land vehicles are robotic systems. Some authors have studied the viability of applying robots with AI to delivery (W. Wang *et al.*, 2024). As for warehouse management, implementing robots to classify the pieces to be picked and reduce the expanse and size of the reserve area for manual order-picking operations (Jiang & Huang, 2022).

(3) Artificial Intelligence (AI). AI enables the implementation of robotic delivery systems in last-mile logistics with improvements to security through multi-level authentication (W. Wang *et al.*, 2024). Applying machine learning (ML) in this area enables more precise demand forecasts, which facilitates planning and operations and directly impacts delivery costs and customer satisfaction (Praet & Martens, 2020). It also helps for the improvement of implemented solutions in terms of vehicle requirements, journey distance, and service times (Rincon-Garcia *et al.*, 2020; Sandoval *et al.*, 2022; Schaap *et al.*, 2022). Other AI applications in last-mile delivery contexts include optimizing joint order fulfillment and replenishment operations in cyber-connected hubs (Leung *et al.*, 2022), optimizing operational container management (R. Chen *et al.*, 2022), and performing a reverse optimization to obtain an appropriate cost matrix by learning from the experience of experts (L. Chen *et al.*, 2021).

(4) Digital Twins. According to the literature, digital twin implementation in combination with other technologies can formulate total information synchronization for order replenishment and delivery optimization (Leung *et al.*, 2022).

(5) Autonomous aerial vehicles. Drone use in logistics offers a new option for package delivery and pick-up, especially for small and short-distance items, and can potentially reduce costs and externalities in last-mile operations (Li *et al.*, 2021). However, its effectiveness can vary by region and regional characteristics (Lemardelé *et al.*, 2021). Drones are essential for making last-mile deliveries in emergency or disaster situations (Koshta *et al.*, 2022).

(6) Blockchain. This technology provides new opportunities for more transparent and secure information-sharing solutions. It can be used to optimize drone operations (Xia *et al.*, 2023), evaluate customer satisfaction in urban logistics contexts (Tian *et al.*, 2021), and facilitate information exchange on the state of containers and reservation spaces between the different interested parties, which can optimize last-mile deliveries between ports and factories (R. Chen *et al.*, 2022).

(7) Big Data. Big Data enables the development of realistic optimal solutions to several last-mile logistics problems by optimizing operations and facilitating effective decision-making (Onal *et al.*, 2018) and expedited identification of potential locations (Singh *et al.*, 2018). It improves coordination and collaboration among rescue teams

for humanitarian aid efforts (Nagendra *et al.*, 2022) by optimizing the humanitarian aid chain (Zhang *et al.*, 2022), and, thereby, streamlining resource delivery logistics to disaster victims.

(8) IoT. IoT implementation enables access to information required to develop logistics solutions, offers last-mile deliveries, and manages diverse customer demands and demand volatility (Borgström *et al.*, 2021). IoT also improves operations visibility and asset control (Ambra *et al.*, 2021).

3.2.3. General IDT focus on last-mile logistics

This research line delves into the broad impact of IDT of I4.0 on last-mile logistics. Unlike the previous lines that focused on either mature or emerging IDT of I4.0, this group takes a comprehensive view, addressing the general influence of IDT without focusing on specific technologies. Specifically, 14 out of the 97 papers have investigated the overall impact of IDT of I4.0 on last-mile logistics.

Within this research line, a diverse array of studies explores various aspects concerning the utilization of technologies in last-mile logistics. Some works emphasize the importance of logistics service providers understanding how online customer behavior affects both the company's and the electronic retailer's quality performance (Vakulenko *et al.*, 2019). Allen *et al.* (2018) state that providing adequate logistics centers at urban sites from which last-mile deliveries can be made to reduce mileage is a great initiative for increasing last-mile e-commerce delivery efficiency.

Centered on the customer perspective, the role of consumers as active co-creators of logistics value and its impact on their service experience is similarly emphasized (X. Wang *et al.*, 2021). Rai, Broekaert, Verlinde, & Macharis (2021) highlight the potential of consumer behavior for improving sustainability as providing information on different delivery methods' digital footprints is the most decisive non-financial incentive for driving consumers' purchasing decisions.

Emphasizing information management aspects, prior literature has shown that open information systems can be used to conduct studies of electric light commercial vehicles and their potential as a promising low-emission solution (Tsakalidis *et al.*, 2020). Similarly, Lim & Srai (2018) highlight the influence of effective resource orchestration and the visibility of global information on last-mile supply chain configuration and performance.

4. CONCLUSIONS

This study offers a comprehensive insight into the role of the IDT of 4.0 on last-mile logistics and presents an innovative classification of the current literature on this subject through content analysis. This classification spotlights different technologies' utility for improving the processes involved in last-mile logistics according to the stage reached in the technology lifecycle. Moreover, the study offers a summary of existing literature regarding this subject, which researchers can utilize to promptly find pertinent material and identify potential avenues for future research.

The classification has also identified some gaps that research lines must address in the future. Mature IDT can be observed to have a limited potential for impacting last-mile logistics. As technologies such as GPS and RFID exist that complement technology roll-out by facilitating information exchange, it would be interesting to explore further the costs involved in implementing said technologies, and the opportunity to replace them or fully integrate them

with other more recent technologies such as RAIN-RFID, which combines RFID technology with cloud computing. A comparison of SaaS (Software as a Service) systems and ERP needs to be established in terms of last-mile logistics efficiency. Also, a study is needed on the integration of web technologies and IoT, robots, and Blockchain along the entire logistics process to achieve higher flexibility levels in last-mile logistics contexts.

Regarding the research line on the impact of emerging IDT on last-mile logistics, no studies have been observed on the difficulties of implementing these technologies or their impact on employees in this particular context. Further exploration is therefore required of the difficulty of implementing this type of technologies and its long-term impact considering costs, quality, service level, and flexibility. In this sense, and considering recent findings (Núñez-Merino *et al.*, 2024), it would be necessary to analyse the impact of quantum computing to optimize transportation scheduling for parcel delivery and identify the optimal routes in terms of time and distance while considering constraints such as arrival times, vehicle loads and carrier uptime. The role of employee acceptance and adaptation in the implementation of these technologies in last-mile logistics context should also be studied. It would also be interesting to analyse the impact of emerging technology sets on last-mile logistics. This would enable us to understand how one technology enhances another and how this ultimately impacts last-mile logistics processes.

Diverse future research lines are proposed to explore the impact of specific technologies on last-mile logistics. In the area of simulation, analyzing the system's dynamic interactions and predicting its evolution are suggested, and evaluating profitability and flexibility considering common variables such as delivery times, costs, emissions, traffic, etc. Applying autonomous vehicles to picking and warehousing processes is proposed to reduce times and product localization errors. Secure delivery is a great concern with autonomous vehicles and should be studied with the integration of different technologies to enhance the security of these means of transport, such as sensors or Blockchain. AI is another technology that can be leveraged with other IDT, such as Big Data, and algorithms should be developed that consider external real-time variables, such as traffic or weather conditions, to decide on optimal delivery routes.

Regarding autonomous aerial vehicles, it is suggested that the difficulties associated with the transition to a fleet of delivery drones should be investigated considering a range of contextual factors such as cargo weight, weather conditions, population density, economic aspects, and also operative training to identify the technology's drivers and inhibitors in the last-mile logistics. Exploring IoT applications in last-mile logistics is also proposed, particularly regarding real-time interconnection between transportation means, warehouses, and systems. In other regards, supercharging AI with Big Data is also recommended to improve real-time decision-making, considering, for example, the state of traffic or the weather to determine optimal delivery routes. Lastly, further exploration is suggested of the application of digital twins and Blockchain to last-mile logistics, especially in warehouses, by integrating other technologies such as IoT with the former and data management between logistics chain agents in the case of Blockchain.

Finally, from the general perspective of IDT's impact on last-mile logistics, it is necessary to continue exploring the integration of information system functions with emerging technologies to achieve greater information management efficiency. Systems make structured information available and easy to process, which makes it ideal for feeding into AI systems or simulators.

Our study yields practical implications worth considering. From a managerial point-of-view, this study provides managers with a broad understanding of the IDT of I4.0 applications and how they influence on last-mile logistics. It compiles a diverse array of mature and emerging I4.0 technologies that have demonstrated their influence on various aspects of last-mile logistics.

Thus, this research will assist managers in pinpointing the specific IDT of I4.0 that can enhance the processes linked to last-mile logistics. By highlighting key insights in the field, this work encourages managers and practitioners to consider implementing these technologies to improve the efficiency and flexibility of last-mile logistics operations.

Our SLR exhibits strengths as well as certain limitations. As regards the strengths, we adopted a clear and rigorous literature review approach and, in particular, a careful selection of journals following the criteria previously used in the literature (Danese *et al.*, 2018). Regarding limitations, it is important to acknowledge that the criteria used for selecting journals may have excluded high-quality and impactful articles published in journals deemed lower in quality and reputation according to the ABS ranking. Another limitation could arise from the subjective nature of paper categorization. Nonetheless, we have followed the established phases in the SLR methodology and utilized classification taxonomies from previous studies to address this concern. Moreover, article classification was a collaborative effort involving a team of researchers, further enhancing its reliability.

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AUTHORS' CONTRIBUTION

All authors contributed to the conceptualization, methodology, data collection, data analysis, drafting of the original manuscript, reviewing and editing, as well as supervision.

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