ISSN 1648-4142 / eISSN 1648-3480

TRANSPORT

2025
Volume 40
Issue 2
Pages 141–157
https://doi.org/10.3846/transport.2025.22883

Original Article

VIABILITY OF AUTOMATION, ROBOTIZATION AND INTELLIGENT SYSTEMS IN THE LAST-MILE DELIVERY: A ROADMAP FOR FUTURE RESEARCH

Adriana SARACENI[✉], Rozali OLEKO, Lisi GUAN, Lieven QUINTENS

School of Business and Economics, Maastricht University, The Netherlands

Highlights:

- identifies viable automation, robotization, and intelligent systems for last-mile delivery;
- proposes a framework of three clusters for last-mile innovation analysis;
- highlights opportunities for internal development and social spill-over effects;
- discusses challenges from technical requirements and societal concerns;
- provides a roadmap for future research and managerial implications.

Article History:

- submitted 17 May 2022;
- resubmitted 20 September 2023;
- accepted 19 November 2023.

Abstract. Cutting-edge technologies in automation, robotization and intelligent systems are emerging in last-mile delivery. However, lacking knowledge on viability is limiting the application and transformation in the final stage of logistics chains. The aim of this article is to identify viable automation, robotization and intelligent solutions and discuss their association for last-mile delivery optimization. This article therefore presents a systematic review of automation, robotization and intelligent solutions, followed by empirical data collected from a workshop with practitioners and representatives of logistic companies, seeking to identify associated opportunities and challenges. The analysis resulted in 3 clusters of innovative solutions discerned upon functional characteristics. Furthermore, the acquired empirical data enabled co-relation from theory and practice to both ensuing opportunities and challenges. By analysing the input by practitioners in the field, we propose internal development and spillover effects as deriving opportunities, technical requirements, and societal concerns as emanating challenges. Based on the diversity of opportunities and challenges associated to each solution, this study proposes a roadmap for future research.

Keywords: automation, robotization, intelligent systems, last-mile delivery, big data, *Logistics 4.0*.

[✉]Corresponding author. E-mail: *a.saraceni@maastrichtuniversity.nl*

Notations

ADR – autonomous delivery robot (ground-based robotic vehicle);
B2B – business to business;
B2C – business to consumer;
CO_2 – carbon dioxide;
GDP – gross domestic product;
GHG – greenhouse gas;
GPS – global positioning system;
ICT – information and communication technologies;
MSc – master of science;
R&D – research and development;
SCM – supply chain management;
UAV – unmanned aerial vehicle (aerial drone for parcel delivery);
VRP – vehicle routing problem.

1. Introduction

Innovative solutions based on automation, robotization and intelligent systems appear promising in logistics, given that their employment can contribute to cost-reduction, operational competitiveness and environmental sustainability.

The conceptualization in our approach brings forth a distinction among automation, robotization, and intelligent systems, highlighting their distinct implications prior to dispatch of an order, delivery transport and delivery destination location. Even if, it is crucial not to overlook the interconnected operation of these innovations. In that sense, automation, robotization, and intelligent systems are all considered as innovative solutions. Consequently, although could be argued that various stages of the logistics chain are undergoing increasing levels of innovation, the ultimate phase of delivery – known as the last-mile delivery – is grappling with unparalleled challenges.

Online purchases have been increasing with a rapid pace (Mucowska 2021; Tsai, Tiwasing 2021; Simoni *et al.* 2020; Zhou *et al.* 2020; Leung *et al.* 2018), triggered, largely, by COVID-19 pandemic. According to the US Chamber of Commerce (2025), transportation and logistics represent 7.7% of US GDP; by comparison, logistics costs represent 16% of China's GDP and 12% of India's GDP. Moreover, growing attention has been given to existing customers' demands relevant to last-mile delivery. Companies are called to address increasing consumers' expectations related to a delivery's timeliness, costs or environment impact (Comi, Savchenko 2021; Rossolov *et al.* 2021; Letnik *et al.* 2019; Lukinskiy *et al.* 2018; Paddeu *et al.* 2018). Introducing automation, robotization and intelligent systems in the last-mile delivery has the potential to contribute towards enhanced efficiency and effectiveness of supply chain and address the existing delivery challenges (Tsai, Tiwasing 2021; Fosso Wamba 2022; Saetta, Caldarelli 2020; Simoni *et al.* 2020; Xu *et al.* 2020; Dubey *et al.* 2019; Hahn 2020; Shan *et al.* 2019).

Regarding the last-mile delivery per se, such innovations have been identified to have a beneficial impact in minimizing the related costs (Ghaderi *et al.* 2022; Moshref-Javadi, Winkenbach 2021; Bosona 2020; Sarma *et al.* 2020; Seghezzi *et al.* 2021; Maghazei, Netland 2020; Mangiaracina *et al.* 2019). Likewise, certain innovative solutions are more environmentally friendly when compared to conventional trucks, given that there are likely to minimize the carbon footprint ascribed to the transport sector by reducing CO_2 emissions. In relation to drones for instance, "<…> the prospect of replacing the gasoline/diesel requirements of a delivery vehicle with a battery-powered UAV for customer deliveries can provide substantial benefits in fuel cost as well as pollutant emission <…>" (Chiang *et al.* 2019). Automation, robotization and intelligent systems can therefore contribute into achieving the goal of sustainable supply chains (Kiba-Janiak *et al.* 2021; Mucowska 2021; Comi 2020; Elsayed, Mohamed 2020; Lazarević, Dobrodolac 2020, Silvestri *et al.* 2019).

Nonetheless, manifold implications are associated to the implementation of autonomization in last-mile, from regulatory specificities (Hoffmann, Prause 2018; Elsayed, Mohamed 2020), passing by customers' acceptance (Mangiaracina *et al.* 2019; Tsai, Tiwasing 2021), to job losses paradigm (Willcocks 2020), social impact (Feng *et al.* 2017) and beyond.

This article does not have the ambition to deconstruct these several narratives, but to contribute with a clear roadmap for future research by providing an in-deep construct of the emerging intelligent solutions for the last leg of the logistic chain taking into consideration the associated opportunities and challenges. To do so, this work provides a comprehensive synopsis of the innovation track of automation, robotization and intelligent solutions for last-mile delivery, aiming to answer the question: "*How to propose a roadmap of automation, robotization and intelligent systems associated to viable implementation in the last-mile delivery?*". Accordingly, 2 fundamental assumptions are proposed:

- ***assumption 1:*** *Automation, robotization and intelligent solutions are viable in last-mile logistics*. Recent academic literature was explored with the purpose of identifying viable automation, robotization and intelligent solutions, understanding each solution's properties and the benefits of application. The assessment resulted in a functional categorization allowing for further evaluation;
- ***assumption 2:*** *Making automation, robotization and intelligent systems viable in last-mile logistics is influenced by opportunities and challenges related to the implementation*. In order analyse the assumptions and answer the main research question, insights of both the academia and company practitioners in the form of qualitative data were assessed, with the purpose of providing a holistic framework valuable for both future research and practical implementation.

The remainder of the article is organized as follows. Section 1 (current) – introduction to the research. In Section 2, we 1st conduct an assessment of the recent literature in order to form an inventory of automation, robotization and information technologies applicable as solutions for the last-mile delivery, as identified by researchers. As a 2nd step, we perform a conceptualization of literature analysis on the solutions found, and provide a framework based of functional considerations, in order to facilitate further analysis. In Section 3, the methodology of this article is presented, by elaborating on the undertaken methodology of investigation during the literature search, the literature analysis and the workshop with practitioners in the field. In Section 4, the acquired results are presented. In addition to the inventory of innovative solutions and the functional framework created, we now provide a set of opportunities and a set of challenges tied to those solutions, from a logistics provider' perspective. In Section 5, we discuss the workshop's results in conjunction with the findings acquired by means of the literature assessment. This research adds to the existing discussion regarding innovative solutions for the last-mile, by attesting perceived opportunities for internal development and beneficial social spill-over effects, as well as perceived technical and societal challenges for each given solution. Lastly, Section 6 discloses some concluding remarks on the research performed.

2. Literature review

Logistics providers have been gradually starting to implement innovative delivery methods and means in the last-mile, as a solution to address the inefficiencies documented in traditional human delivery. Similarly, the potential of such technological innovations in addressing several inefficiencies that characterise last-mile delivery has captured the attention of the scientific community as evidenced by the growing literature on the topic. Last-mile delivery is regarded as one of the most critical logistics processes, given that its ensuing costs can amount up to half of the total logistic costs (Vanelslander *et al.* 2013) with a direct impression to the final consumer (Lim *et al.* 2018).

The last-mile delivery includes the delivery of several types of goods such as food and groceries (Bjørgen *et al.* 2021), online retails (Shi *et al.* 2019), pharmaceuticals (Jackson, Srinivas 2021), etc., in a worldwide B2C market (Mangiaracina *et al.* 2019).

In the realm of last-mile delivery, autonomous or robotics solutions offer a distinct geographical advantage. These innovations facilitate access to remote locations and address vulnerabilities in transportation routes or networks. Notably, a significant reduction in CO_2 emissions can be underscored, primarily due to the elimination of long-haul journeys with laden vehicles to distant areas. This advantage is particularly pronounced considering the complete electric power source of drones for example. To enhance the comprehension variables encompassing locational context, security concerns in specific regions or countries, and cultural factors can be integrated. This expanded perspective contributes to a more comprehensive evaluation of security and spatial dynamics of automation and robotics for delivery. Thus, the adoption of autonomous or robotics solutions presents a promising avenue for alleviating road congestion and promoting sustainable practices (Fehling, Saraceni 2023; Saraceni *et al.* 2022; Shi *et al.* 2019).

In tackling the last-mile logistics challenge, VRP intelligent solutions proves indispensable. This problem necessitates strategic decisions by logistics companies regarding the selection of vehicle types and quantities, the sequence of customer service, and the specific customers to be served. This operational puzzle can be effectively addressed through methodologies such as those proposed by Corentin & Saraceni (2022).

The utilization of innovative technologies transformed into automation, robotization and intelligent solutions appears prominent, given the anticipated positive impact on efficiency, effectiveness and sustainability. The aim of this research is to provide a structured, in-depth overview of the available innovations related to the last-mile, and assess the feasibility and challenges of their application (Emmens *et al.* 2021). The use of smart technologies has several implications on SCM (Hahn 2020) and is expected to result in new configurations within supply chains (Hoffmann, Prause 2018; Ranieri *et al.* 2018), especially given the feasibility of real time information collection and dissemination (Saetta, Caldarelli 2020). Moreover, understanding each solution's properties is fundamental, in order for companies to make informed decisions when considering which among the various innovative solutions available would be advantageous to implement.

By performing an interdisciplinary assessment of existing literature, this research was able to assemble a number of viable last-mile innovative solutions recently identified by researchers, namely UAV, autonomously driving robots, underground delivery, parcel lockers, reception boxes, customer's car trunks. Based on the literature search, it was also identified that big data, dynamic pricing and crowdsourcing logistics can be considered as enabling solutions for the automation of the last-mile (Kiba-Janiak *et al.* 2021; Ranieri *et al.* 2018). In the following section, the new technologies as solutions to optimize the last-mile delivery process identified in recent literature will be discussed.

UAV, commonly referred as *drones*, can be employed to deliver a parcel to a final destination (Bosona 2020; Di Puglia Pugliese *et al.* 2021; Elsayed, Mohamed 2020; Seghezzi *et al.* 2021; Aurambout *et al.* 2019; Maghazei, Netland 2020; Zhu 2019; Ranieri *et al.* 2018). Drones can navigate to such a destination and deposit a parcel by means of an embedded GPS (Mangiaracina *et al.* 2019), and subsequently return to their point of departure following the delivery. Researchers have assessed both stable optimal locations of such departures and returns (Aurambout *et al.* 2019), as well as the feasibility of moving locations via the use of trucks (Moshref-Javadi, Winkenbach 2021; Di Puglia Pugliese *et al.* 2021; Mangiaracina *et al.* 2019). Except from the benefits of the UAVs solution in minimizing last-mile delivery costs, a number of insights are also available regarding their contribution towards environmental sustainability and their potential to reduce the GHG emissions (Elsayed, Mohamed 2020; Mangiaracina *et al.* 2019).

Autonomously driving robots, can be defined as "<…> self-driving road vehicles that, moving on determined and controlled paths <…>" (Mangiaracina *et al.* 2019). Researchers have distinguished between semi-autonomous and fully-autonomous vehicles (Badue *et al.* 2021; Ranieri *et al.* 2018) and have assessed possibilities for the optimization of existing ground robot prototypes such as FURBOT (Silvestri *et al.* 2019). Except from the benefits of the robotic solution in minimizing last-mile delivery costs, insights are also available regarding the existing regulatory challenges associated to their application, for instance obstacles that may hinder the vehicle's movement (Seghezzi *et al.* 2021), tortious or product liability (Hoffmann, Prause 2018).

Underground delivery, refers to the use of an underground pipeline system through which parcels packed in suitable capsules are distributed (Seghezzi *et al.* 2021), by employing an electromagnet technology, which allows "<…> for shell cases inside the hyperloop to go faster and move with little or no friction <…>" (Ewedairo 2019). While the benefits of this solution in minimizing last-mile delivery costs as well as in contributing towards environmental sustainability have been identified (Seghezzi *et al.* 2021; Viu-Roig, Alvarez-Palau 2020; Mangiaracina *et al.* 2019; Zhu 2019), further research regarding the combined use of such a system with other innovative solutions could be insightful (Seghezzi *et al.* 2021).

Parcel lockers or cabinets, refer to "<…> a form of self-service technology used for customer pick-up and return of e-purchased goods <…>" (Vakulenko *et al.* 2019). Specifically, "<…> a locker can be opened with a unique pick-up code sent by e-mail or short message service on one's own phone <…>" (Ranieri *et al.* 2018). Researchers have established the existence of facilitating conditions related to the usage of parcel lockers as a factor increasing this solution's acceptance (Tsai, Tiwasing 2021; Zhou *et al.* 2020). The benefit of this solution in minimizing last-mile delivery costs is straightforward (Kiba-Janiak *et al.* 2021; Bosona 2020; Mangiaracina *et al.* 2019; Zhu 2019; Florio *et al.* 2018), as it eradicates face-to-face human interaction of customers and couriers and thus can be distinguished from the similar solution of pick-up points (Mucowska 2021; Mangiaracina *et al.* 2019).

One other solution pertains to the use of destination locations owned by a consumer. Such locations can be either fixed, namely *reception boxes* situated in a customer's residence (Hoffmann, Prause 2018), or shifting, by means of delivery in a *customer's car trunk*. During the latter, "<…> couriers unlock the trunk through a one-time-use digital key associated to the specific order <…>" (Mangiaracina *et al.* 2019). While the value of those solutions in minimizing last-mile delivery costs is straightforward (Mangiaracina *et al.* 2019; Florio *et al.* 2018), as they eradicate face-to-face human interaction, additional insights may be gained through the application of quantitative research methods (Mangiaracina *et al.* 2019).

Big data appears as a well-established intelligent system solution regarding last-mile delivery within the literature explored. While no uniform definition of the concept appears to exist, the application of big data analytics has been frequently associated with innovation, based on its "<…> ability to transform entire business processes <…>" (Feng *et al.* 2017) in order to increase performance efficiency (Kiba-Janiak *et al.* 2021; Bosona 2020; Fosso Wamba 2022; Sarma *et al.* 2020; Dubey *et al.* 2019; Hahn 2020; Feng *et al.* 2017). Their application forms a significant aspect of *Logistics 4.0*, as it is directly associated to digital technologies that enable the formation of (semi) autonomous networks. Similarly, big data has been considered as one of the "<…> human-centred digital technologies that combine intelligence and networked collaboration to improve individuals' productivity within business processes <…>" (Hahn 2020).

Regarding the last-mile delivery phase, big data can be employed "<…> in analysing a specific parameter that is correlated to the presence of the customer at home <…>" (Mangiaracina *et al.* 2019). Via such use, the efficiency can be improved, for instance "<…> by analysing electricity consumption during the day and throughout the week, a probability distribution of the customer's presence at home can be derived <…>" (Viu-Roig, Alvarez-Palau 2020). Researchers have also explored the use of ICT tools in order to consolidate the shipment of different parcels to be delivered to a single customer (Kiba-Janiak *et al.* 2021; Zhang *et al.* 2019). Likewise, big data can be utilized to create load consolidation centres, a solution that contributes towards environmental sustainability in addition to cost minimization (Bosona 2020; Saetta, Caldarelli 2020; Leung *et al.* 2018). In the domain of humanitarian supply chain in particular, researchers have identified the value of real-time social media data in disaster management (Shan *et al.* 2019). Additionally, researchers have established the importance of big data application in the creation of trust-based collaborative networks (Fosso Wamba 2022; Dubey *et al.* 2019), and their contribution towards decision-making processes optimization (Fosso Wamba 2022).

Dynamic pricing, namely "<…> associating different delivery prices to different time windows <…>" (Mangiaracina *et al.* 2019), aims to optimize the last-mile delivery process by taking into account customers' preferences. While the benefits of this solution in minimizing last-mile delivery costs of e-grocery delivery have been established, the application of this solution in different contexts remains under-exanimated (Mangiaracina *et al.* 2019).

Crowdsourcing logistics is a term referring to the possibility of engaging people directly in the last-mile delivery process per se, by "<…> outsourcing the delivery of the goods to "common" people that give their availability for bringing the parcel from a point of collection, generally a warehouse or a store, to a point of delivery <…>" (Lazarević, Dobrodolac 2020). While the benefits of this solution in minimizing last-mile delivery costs have been established (Ghaderi *et al.* 2022; Kiba-Janiak *et al.* 2021; Bosona 2020; Lazarević, Dobrodolac 2020; Mangiaracina *et al.* 2019; Zhu 2019), further research is needed in order to better assess the value of different crowdsourcing logistics business models (Mangiaracina *et al.* 2019), given that the application of this solution may incur negative externalities (Simoni *et al.* 2020; Zhu, 2019).

Arguably, dynamic pricing and crowdsourcing logistics cannot be considered as automation technology delivery solution per se, given that the former employs pricing strategies, and the latter relies on human rather than technological capital. However, the utilization of software-based systems, especially the use of big data, has been strongly associated with innovation. According to McKinsey, "<…> The use of big data – large pools of data that can be brought together – will become the key basis of competition and growth for individual firms, enhancing productivity and creating significant value for the world economy <…>" (Chui *et al.* 2011). Hence, big data applications will be examined in this study, even though their use aims to optimize the delivery process before a parcel's dispatch.

Conceptualization

In order to analyse the previous findings provided by the literature search, we organised the 3 distinct clusters deduced upon functional considerations. The proposed categorization was based on pragmatic considerations regarding where the value of a given innovation lies. Among the various existing technology solutions identified, some appear more related to the movement of parcels, introducing innovative transportation means, while others are more related to the final parcel delivery destination location. At the same time, emerging technologies are being increasingly used in several business processes, with a view on optimizing the last-mile delivery. Such fundamental differences in function should be taken under consideration when attempting to make meaningful comparisons. Based on the aforementioned and aiming to facilitate a comprehensive understanding of each solution's potential, we have framed the 3 rationally deduced clusters as:

- *autonomous/semi-autonomous delivery transport*;
- *autonomous/semi-autonomous final delivery destination location*;
- *automation prior to dispatch*.

Autonomous/semi-autonomous delivery transport – the 1st cluster of innovative solutions is discerned based on the employments of complex machines operating autonomously or semi-autonomously during the delivery act. In particular, researchers have explored the use *UAV*, *autonomously driving robots and underground delivery*.

The use of both UAVs and robots as optimization solutions has been frequently examined in recent years. Researchers have created analytical models based on the employment of drones or robots, with the aim of minimising last-mile delivery costs (Di Puglia Pugliese *et al.* 2021; Aurambout *et al.* 2019; Silvestri *et al.* 2019) or introducing a sustainable delivery solution (Elsayed, Mohamed 2020). Nonetheless, insights on UAVs' practical application are lacking, either in the form of surveys or interviews. Research involving collaboration with companies that have opted for the use of drones or robots (Hoffmann, Prause 2018) is fundamental in order to identify the practical challenges of their application. Moreover, given that the beneficial impact of this solution towards reducing last-mile delivery costs appears well-established, further research focusing on customer acceptance as well as on their societal impact could identify unforeseen complexities of their use.

Autonomous/semi-autonomous final delivery destination location – the 2nd cluster of automation solutions to optimize the last-mile delivery process, is distinguished based on applicable parcel drop-off location. Among those, the most frequently studied appear to be the use of *parcel lockers or cabinets*, *reception boxes and customers' car trunks*.

The use of parcel lockers appears to be the most frequently studied automation solution. Surveys and interviews focusing on the customers' behaviour, offers valuable insights regarding factors that impact on their initial intention to adopt this solution (Tsai, Tiwasing 2021; Zhou *et al.* 2020), as well as factors that impact the continuation of its use in the future (Vakulenko *et al.* 2019). Nonetheless, further research is needed as the majority of the existing literature is based on data from Asia. Furthermore, future research could benefit from insights derived from service providers in order to identify the practical challenges of their application. Lastly, additional research is needed in relation to destination locations owned by customers. Although customer owned reception boxes and car trunks can be assumed to have a direct impact on last-mile delivery cost-minimization, by eliminating the costs related to parcel lockers provided by the company, the solutions currently remain understudied.

Automation prior to dispatch – the 3rd cluster is discerned based on the employment of automated data processing as a means to optimize the last-mile delivery process. Big data applications have the potential of strengthening innovation, by taking into account customer-related information in order to map customer behaviour.

This cluster is perceived as substantially distinct; given that it relates to processes aiming at delivery optimization performed before the shipping of a parcel. Moreover, the use of large amounts of customer-related information, suggests that the involvement of customers is pronounced to a greater extent when compared to the previous 2 clusters. Big data applications in particular have been thoroughly studied by the academia. Within the literature examined, the Internet of Things has been identified as the principal application of *Logistics 4.0* (Winkelhaus, Grosse 2019), and attention has been given to the increasing dependence of SCM on big data use, the importance of data manipulation capacity as well as on questions regarding data quality (Feng *et al.* 2017). Regarding the last-mile, researchers have established that their use has a positive impact towards cost minimization (Kiba-Janiak *et al.* 2021; Bosona 2020; Fosso Wamba 2022; Sarma *et al.* 2020; Dubey *et al.* 2019; Hahn 2020; Feng *et al.* 2017) based on the creation of analytical and simulation models (Sarma *et al.* 2020; Shan *et al.* 2019; Zhang *et al.* 2019) as well as on survey data. Regarding the latter, future research oriented on customers' behaviour could be valuable given that existing survey data are retrieved from companies and organizations (Dubey *et al.* 2019; Hahn 2020; Saetta, Caldarelli 2020). At the same time, differences between established and start-up companies (Hahn 2020) imply that the existing knowledge can be further refined based on insights from company practitioners. On a different direction, the use of ICT has been associated with collaborative urban logistics, the optimization of transport management and routing city logistics as well as innovative mobility infrastructure (Ranieri *et al.* 2018). Further examination of the combined application of ICT with drones and ground robots in the last-mile delivery process, will contribute to a better understanding of the *Logistics 4.0* potential. Regarding crowdsourcing logistics, future research on customers' acceptance as well as insights from company practitioners will be valuable, given that the solutions are currently under-examined (Mangiaracina *et al.* 2019). Figure provides a schematic representation of the constructs from 3 clusters proposed, reflecting the function that each solution identified is capable to optimize.

The construct on the new technologies as solutions to optimize the last-mile delivery process was identified in order to provide an initial overview of their application in practice and their deriving merits as discussed in recent literature. It appears straightforward that company-specific capabilities, as well as various contextual elements, are likely to impact concomitantly on a company's ability to employ a given solution. Table 1 provides an overview of the automation, robotization and intelligent solutions identified in the literature explored. The volume of the scientific output reflects the scientific community's interest on such innovations. Each study listed below provides valuable insights on a given solution's properties, as well as associated benefits and challenges of application. Upon examination, those insights resulted in the proposed functional categorization.

The proposed categorization between *autonomous/semi-autonomous delivery transport*, *autonomous/semi-autonomous final delivery destination location* and *automation prior to dispatch* appears well founded, primarily, based on the fact that the clusters employ diverse technologies. There was not sufficient evidence from literature to score or compare the undergoing different degrees of automation, robotization, and intelligent systems integration in the last-mile, as the 3 innovative solutions may be integrated to a greater or lesser extent at any of the clusters. Nevertheless, the categorization is based in higher predominance at each cluster.

In the 1st 2 clusters, robotics is directly interacting with the end-customer introducing a significant shift in traditional last-mile transactions. The societal impact of each cluster appears to be distinct, and as such can be assumed to have a different effect on both industry and public acceptance, raising different questions of environmental and regulatory implications. More importantly, given that access to customer-related information or 3rd party involvement may be required, the 3rd cluster is likely to prompt diverse effects in relation to individuals, triggering questions of privacy and safety. Table 2 provides a summary of the associated opportunities and challenges tied to each innovative solution, as identified in the literature assessed.

From our literature findings, most highlights go to the opportunities although each solution is tied to a different set of opportunities and challenges. *Autonomous/semi-autonomous delivery transport* appears as the most complex among the 3 clusters, given that it is associated to a wider range of associated obstacles. In line with the remarks made by Willcocks (2020) about the assumptions embedded in the narrative that technology will provide solutions to multiple problems, bringing massive benefits with few barriers are corroborated by our findings. The aforementioned narrative trigged the aim of a twofold methodology to embrace the argument side from practitioners and researchers, given voice not only about opportunities but also about challenges associated to automation, robotization, and intelligent solutions in last-mile delivery.

3. Methodology

In order to identify which automation, robotization and intelligent solutions technologies are viable as solutions to address last-mile delivery inefficiencies, as well as the ensuing opportunities and challenges associated to each particular solution, a number of distinct steps were undertaken.

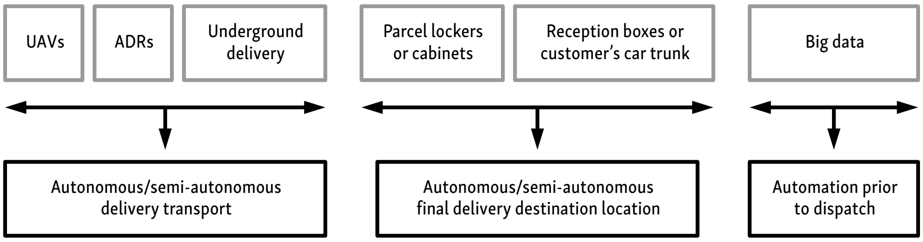

Figure. Construct based on automation, robotization and intelligent solutions for last-mile delivery

Table 1. Construct description

Robotization	*Autonomous/semi-autonomous delivery transport*		
	UAVs: ■ aerial transport; ■ unmanned vehicles	Robots: ■ ground transport; ■ semi-autonomous/fully-autonomous vehicles	Underground delivery: ■ underground transport; ■ unmanned vehicles
	Sources: Bosona (2020); Di Puglia Pugliese *et al.* (2021); Elsayed & Mohamed (2020); Xu *et al.* (2020); Aurambout *et al.* (2019); Maghazei & Netland (2020); Mangiaracina *et al.* (2019); Silvestri *et al.* (2019); Zhu (2019); Hoffmann & Prause (2018); Maditati *et al.* (2018); Ranieri *et al.* (2018)		
Automation and robotization	*Autonomous/semi-autonomous final delivery destination location*		
	Parcel locker/cabinets: ■ automated solution; ■ public location	Reception boxes: ■ automated solution; ■ customer owned location	Car trunks: ■ automated solution; ■ customer owned location
	Sources: Mucowska (2021); Tsai & Tiwasin (2021); Xu *et al.* (2020); Zhou *et al.* (2020); Mangiaracina *et al.* (2019); Vakulenko *et al.* (2019); Zhu (2019); Maditati *et al.* (2018); Ranieri *et al.* (2018).		
Automation and intelligent systems	*Automation prior to dispatch*		
	Big data: ■ human-centered digital technologies; ■ various applications	Dynamic pricing: ■ solution based on customers' preferences	Crowdsourcing: ■ solution based on people's direct engagement
	Sources: Ghaderi *et al.* (2022); Kiba-Janiak *et al.* (2021); Mucowska (2021); Bosona (2020); Fosso Wamba (2022); Lazarević & Dobrodolac (2020); Saetta & Caldarelli (2020); Sarma *et al.* (2020); Simoni *et al.* (2020); Shan *et al.* (2019); Viu-Roig & Alvarez-Palau (2020); Xu *et al.* (2020); Dubey *et al.* (2019); Hahn (2020); Mangiaracina *et al.* (2019); Winkelhaus & Grosse (2020); Zhang *et al.* (2019); Zhu (2019); Florio *et al.* (2018); Maditati *et al.* (2018); Ranieri *et al.* (2018).		

Table 2. Conceptualization of opportunities and challenges associated to automation, robotization, and intelligent solutions

	Automation, robotization, and intelligent solutions	Opportunities	Challenges
Autonomous/semi-autonomous delivery transport	UAV (drones)	▪ cost reduction; ▪ congestion reduction; ▪ carbon footprint reduction; ▪ autonomous/semi-autonomous navigation	▪ regulatory challenges; ▪ eradication of human-to-human interaction
	Autonomous driving robots	▪ cost reduction; ▪ carbon footprint reduction; ▪ autonomous/semi-autonomous navigation	▪ regulatory challenges; ▪ eradication of human-to-human interaction
	Underground delivery	▪ cost reduction; ▪ congestion reduction; ▪ carbon footprint reduction ▪ autonomous/semi-autonomous navigation	
Autonomous/semi-autonomous final delivery destination location	Parcel lockers/cabinets	▪ cost reduction	▪ eradication of human-to-human interaction
	Reception boxes / customer's car trunk	▪ cost reduction	▪ eradication of human-to-human interaction
Automation prior to dispatch	Big data	▪ cost reduction; ▪ congestion reduction (via order consolidation); ▪ carbon footprint reduction (via order consolidation, minimization of failed deliveries)	▪ regulatory challenges

The study followed a structured approach with the purpose of providing a literature assessment on existing innovative technologies as well as their feasibility as last-mile optimization solutions, based on existing scholarly understanding. Upon assessment of the findings from the studies examined, we were able to synthesize a framework based on considerations of functionality. The creation of this functional overview facilitated further evaluation of the acquired insights bot by academics and company practitioners. In the next step, the results were communicated and further insights were gained by means of a workshop, engaging MSc researchers in the field of SCM, and representatives of logistic companies. A scientific researcher and a project manager (involved in the production of this article) of an innovation institution acted as facilitators of the workshop and performed the data collection. The workshop was designed with the aim of initiating a dialogue among different stakeholders regarding the opportunities and challenges tied to each particular solution examined. The insights gained during the workshop were further assessed and utilized as input for the production of this research.

3.1. Phase A: literature search

Initially, the unit of analysis was defined as a scientific article, published in a peer reviewed international journal in 2019 or recently, written in English and excluding grey literature. Subsequently, a pre-selection of articles from library databases was performed, via the use of a set of keywords and their combination, namely *Logistics 4.0*; innovative solutions in last-mile delivery; automation in last-mile delivery; robotization in last-mile delivery. Among the articles found, the most cited were further distinguished, based on the assumption that "<…> the citation of an article reflects the acceptance degree of the research, which is viewed as a significant indicator to measure the influence of a publication<…>" (Feng *et al.* 2017). Further refinement was conducted via the examination of each article's abstract, allowing for the identification of content more relevant to the scope of the analysis, namely articles discussing particular solutions per se, rather than jointly. Following the identification of the more relevant and a subsequent detailed examination of their content, a snowball search was performed based on each article's references, while extending the period of publications to 2018. In total, 33 articles published in scientific journals were examined.

3.2. Phase B: literature analysis

Upon conclusion of the previous step, several automation, robotization and intelligent solutions had been identified. A more nuanced look on each solution's particular properties and characteristics revealed several points of convergence among some, primarily based on the type of technology used, as well as depending on distinct segments of last-mile delivery logistics. The examination resulted in a functional overview allowing for further evaluation. The proposed categorization comprises of 3 functional clusters, namely *autonomous/semi-autonomous delivery transport*, *autonomous/semi-autonomous final delivery destination location* and *automation prior to dispatch*. By examining the differences among the solutions found, we were able to gain a 1st indication of existing opportunities and challenges, which in turn acted as a measure of internal validity for the analysis of the workshop's results.

3.3. Phase C: workshop with practitioners

In order to facilitate the integration of theory and practice, a workshop was organized under the Holland Robotics Logistics Research Consortium. The main objective of the workshop was to identify opportunities and challenges of automation in the last-mile delivery, seeking to integrate the research pursued with practitioners and empiricism of technological innovations. Involving practitioners in academic studies is beneficial since they contribute in the sense making of the findings (Mangiaracina *et al*. 2019; Shani *et al*. 2017), and they allow to get useful insights about the results. Their contribution was twofold: they validated both the framework emerged from the literature (identify the effects of automation in last-mile delivery solutions) and the gaps (highlighting new opportunities and challenges that are interesting not only for academics but for companies).

Workshop design and tools: the workshop convenes a diverse array of participants, encompassing representatives from prominent industry players such as Stockspots, Probotics, UPS, IM Efficiency, and VinciTech. Notably, each of these companies is actively engaged in the development and/or deployment of automation, robotization, and intelligent solutions within the delivery domain. Complementing this industry presence were 6 adept MSc researchers hailing from the Maastricht University School of Business and Economics (SBE), their expertise finely tuned to the intricacies of last-mile logistics. Accompanying and moderating it was a dedicated post-doctoral researcher from SBE, alongside a project manager affiliated with the Maastricht University Brightlands Institute for Supply Chain Innovation (BISCI). Collectively, these researchers and industry stakeholders harbour a shared goal: to facilitate and enrich the comprehension of the potential, drivers, and hurdles entailed in the incorporation of robotics within logistics, with a particular emphasis on the nuances of last-mile delivery.

To identify appropriate actions required to foster the development and implementation of robotics solutions in logistics with attention to the last-mile delivery with the insights of both academics and practitioners, data were collected from transcripts of the discussions, *Jamboard* and *Mentimeter* tools outputs and subsequently analysed. This article's authors then analysed the data based on an iterative process with ATLAS.ti.8.0 (*https://atlasti.com*). 2 researchers independently coded and analysed the qualitative transcriptions in the database and compared coded data to ensure consistency (Barratt *et al*. 2011).

We 1st identified the core concepts of common knowledge from a managerial perspective, which helped us to clarify the gaps between academic and practical field. Subsequently, both opportunities and challenges were categorized and analysed, based on supply and demand perspectives for opportunity and challenges, separately. We classified the opportunities and challenges from our data set as "representation" (1st-order), and summarized the characteristic of the "opportunity impact" and "challenge requirement" as "Theme" (2nd-order). Accordingly, the overarching dimensions, for instance internal development or societal concern, were formulated based on the input data (Table 3). For example, the quotation "These technologies can improve, obviously, supply chain agility and cost savings and so on" addressed the opportunity with possible benefit of "agility" and "cost saving", is a "representation" coded as "1st-order". Regarding the "themes" mentioned, e.g., agility, cost saving, are identified as "2nd-order".

Table 3. Opportunities of automation, robotization and intelligent systems

Representations (1st-order)	Themes (2nd-order)	Overarching dimensions
The beneficial results and optimization in one part of the last-mile logistics. In general, it will have a positive effect on the other parts of the last-mile delivery. *Manager* A	structural efficiency	internal development
Logistics for delivery would be have a beneficial effect on the fulfilment, for example, the warehouses. *Manager* A	warehouse utility	
Robotization will accomplish deliver within 10...15 min. *Manager* B	distribution efficiency	
These technologies can improve, obviously, supply chain agility and cost savings and so on. *Manager* C	supply chain flexibility	
These technologies can improve, obviously, supply chain agility and cost savings and so on. *Manager C* There were a great opportunity for sustainability, less emissions, less costs. *Manager D*	cost and profit	
It will become so amazing and efficient what would be the impact on local shops, I mean it's already right now with COVID-19, we can see that. *Manager C*	competition and development	social spill-over effects
We were mostly talking about the parcel lockers, and so there were a great opportunity for sustainability, less emissions, less costs. *Manager D*	sustainability	
Now we're lucky in the human resources and what we can do with that and will the automation there will be the answer to this issue or not so that's what we were discussing you know. *Manager A*	human resource	

According to the stakeholders, the potential benefits, such like "cost & profit" and "structural efficiency" (2nd-order) are all contributing to a development within company ("Internal development"), while, "sustainability" and "human resource" (2nd-order) are influencing the external society ("social-spillover effect"). Therefore, "internal development" and "social spill-over effect" were categorized separately. Accordingly, the overarching dimensions, namely internal development and social-spillover effects were formulated based on the input data. In sum, 9 themes were identified.

Similar as opportunity part, we identified the challenges from our data set as "representation" (1st-order), and summarize the characteristic of the *challenge* requirement as "theme" (2nd-order). Accordingly, the overarching dimensions are illustrated, i.e., technical requirement, social concern are demonstrated on Table 4. For example, quotation "3 main challenges, so the 1st one being the vehicle one, for autonomous driving ground vehicles, if they are allowed, etc." addressed the challenge of uncertainty or risk "if they are allowed" from legal perspective, which is a "representation" coded as "1st-order". While the "theme" of it mentioned can be identified as "standard and permission", which is "2nd-order". In total, 5 themes are identified. According to the potential develop it required, "customer experience" and "safety reliability" are requiring a development of technic ("technical requirement"), while, "working opportunity" and "standard and permission," demand the concern of the whole society ("society concern"). Therefore, "technical requirement" and "society concern" are categorized separately.

4. Results

4.1. Results from the literature search and analysis

Following a systematic review approach, several existing automation, robotization and intelligent technologies adhering to last-mile delivery were identified, namely UAV, autonomously driving robots, underground delivery, parcel lockers, reception boxes, customer's car trunks, big data, dynamic pricing and crowdsourcing logistics. The aforementioned technological advancements manifest the state-of-art of technological innovations deemed viable as last-mile logistics solutions in recent literature. After thoroughly assessing each solution's properties and characteristics, a functional categorization is proposed as a framework for further evaluation. The proposed framework categorizes the literature findings by distinguishing among 3 clusters, namely *autonomous/semi-autonomous delivery transport*, *autonomous/semi-autonomous final delivery destination location* and *automation prior to dispatch*. This framework facilitates a better understanding of the different types of automation, robotization and intelligent solutions encountered via the literature assessment, by elaborating on how each innovation is expected to optimize supply chains. The solutions encountered impact distinct last-mile segments and are created to improve different aspects of the last-mile delivery process. The proposed framework facilitates a better understanding of the corresponding opportunities and challenges relevant to each innovation's implementation based on empirical results. Then from the workshop we identified the core opportunities of automation, robotization and intelligent systems as well as the core challenges of their application, as perceived from both scientific experts and company practitioners.

4.2. Results from the workshop

The qualitative data from the workshop was analysed, from transcripts of the discussions, *Jamboard* and *Mentimeter* tools outputs. The *Mentimeter* word cloud visualization assisted in swiftly gathering data from their audience. This technique effectively emphasizes the most prevalent responses and presents the information in a manner accessible to all. Visualization of the concepts explored the extension of the basic data with additional information and interactive features to transform it into a powerful

Table 4. Challenges of automation, robotization and intelligent systems

Representations (1st-order)	Themes (2nd-order)	Overarching dimensions
The mindset of the people in order to make flexible hypes. Less flexibility. *Manager D*	service flexibility	technical requirement
Whenever we automate this locker process, perhaps we need to redesign them for budget, and then we will also bring a better customer experience by human service. *Manager D*	customer experience	
Some other points we came up with like with these autonomous vehicles, the road safety and so on. *Manager C*	safety reliability	
I think some important challenges are probably like the social impacts of such technologies, let's say jobs. *Manager C*	working opportunity	societal concern
3 main challenges, so the 1st one being the vehicle one, for autonomous driving ground vehicles, if they are allowed, etc. *Manager D*	standard and permission	
Also legal constraints, for example, especially in Germany with drones. *Manager C*	standard and permission	

tool for text analytics. The word cloud is used to illustrate an overview by distilling text down to those words that appear with highest frequency (Heimerl *et al.* 2014). To capture the main characteristic of automation in last-mile deliver, a "word cloud" was created using the workshop data. Besides the main concepts of "last-mile" and "delivery", the main 3 recurring elements during the workshop discussion were "beneficial", "challenge" and "technologies". Trying to present a holistic framework from the concepts of practice to academic structural category, we make a usage of the results from theoretical conclusion to managerial application.

The advantages of automation, robotization and intelligent systems have also been noticed in the new stage of post-COVID-19. On the one hand, automation provides new solutions and methods to solve different versions of VRP, namely defining the optimal route to deliver a set of parcels to dispersed destinations, increasing the possibility of sustainability optimized (Geetha *et al.* 2013). On the other hand, automation solutions enable companies to overcome traditional limits, such as the inability to saturate the transportation mean, or the high probability of failed deliveries and less human contact/service (Mangiaracina *et al.* 2019; Lim *et al.* 2018). Although the advantages of automation, robotization and intelligent systems appear obvious, in order to implement a new technology, or adopt a systematic change in the last-mile delivery, clarifying what are the "benefits", i.e., opportunities, from a managerial perspective is fundamental.

By analysing the input obtained during the workshop, this research adds to the current discussion on the introduction of automation, robotization and intelligent systems in last-mile delivery, by identifying connected opportunities and challenges as perceived by logistics providers. As a 2nd contribution, relevant applications and suggestions are provided from a managerial perspective.

4.2.1. Opportunities: internal development and social-spillover effects

Internal development: In line with the previous research, innovative solutions aimed at increasing the efficiency of last-mile delivery, the improvement of efficiency that automation, robotization and intelligent systems brings is the 1st highlight (Mangiaracina *et al.* 2019). It reflects on not only the warehouse utility, but also distribution efficiency. As managers addressed, "logistics for delivery would have a beneficial effect on the fulfilment, for example, the warehouses", "robotization will accomplish deliver within 10…15 min". In addition, structural efficiency would develop according to the optimization of last-mile delivery, which was seen as a positive opportunity as systematic improvement. The MSc researchers participating in the workshop approved that the benefit of parcel lockers solution (automation in final destination) is straightforward, as it is minimizing last-mile delivery costs (Kiba-Janiak *et al.* 2021; Bosona 2020). Flexibility is another concerned opportunity from managers' perspective, as researchers approved that *UAVs*, i.e., drones, can navigate to such a destination and deposit a parcel by means of an embedded GPS (Dorling *et al.* 2016), and subsequently return to their point of departure following the delivery.

Social-spillover effects: Opportunities exist not only from the within-system development, but also the impact of the whole society, i.e., social-spillover effects. With higher performance expectancy from automation, robotization and intelligent systems, more competition emerged in the whole industry, that contributes to the development of the service quality and logistics efficiency (Kapser, Abdelrahman 2020). Except from the benefits of the UAVs solution in minimizing last-mile delivery costs, a number of insights are also available regarding their contribution towards environmental sustainability and their potential to reduce the GHG emissions (Elsayed, Mohamed 2020). As manager mentioned "there were a great opportunity for sustainability, less emissions, less costs". Likewise, big data can be utilized to create load consolidation centres (Bosona 2020; Saetta, Caldarelli 2020), triggering the solution that contributes towards lower energy usage, lower carbon emissions in addition to automated last-mile delivery.

4.2.2. Challenges: technical requirement and societal concern

Many scholars agree that the most critical logistic process is the last-mile delivery. In particular, due to the challenging target service levels, the small dimension of orders and the high level of dispersal of destinations, last-mile delivery is the least efficient and most expensive part of the delivery process (Macioszek 2018). Meanwhile, compared to B2B market, B2C opens new challenges for companies, which have to manage additional issues (Mangiaracina *et al.* 2019; Lim *et al.* 2018). One of these is the higher complexity of the logistics activities, and the intangibility of customer connection, which may lead to the whole failure or success of supply chain. In addition to this, as an uprising technique, the implementation of automation, robotization and intelligent systems in logistic industy itself already has a great space for improvement and a well concern for industry adaption (Mangiaracina *et al.* 2019; Ranieri *et al.* 2018). However, the complexity of last-mile delivery leads to more difficulty of adoption on this new technology. Companies are urgently desiring to better understand the challenges they are facing, which will help them, and even more stakeholders from all society, to understand how and what to contribute for automation, robotization and intelligent systems in last-mile delivery.

Technical requirement: Still some problems need to be solved from technic level, e.g., service flexibility, customer experience and safety reliability. Automation, robotization and intelligent solutions can be distinguished with the involvement of efficiency, but can also be challenged because of human factor. Researchers argued that such automation solutions may eradicate face-to-face human interaction of customers and couriers and thus can be distinguished from the similar solution of pick-up points. Consequently, the customer experience would be challenged (Mucowska 2021). A *Manager D* indicated: "whenever we automate this locker process, perhaps we need to redesign them for budget, and then we will also bring a better customer experience by human service". Results showed that managers considers flexibility as both opportunity and challenge (Table 3 and Table 4). "Robotization" and "human", which is more flexible to overcome obstacles, which is more reliable from safety concern when it comes to last-mile delivery? Debates as above are still advancing, if the technology development could overcome those weakness is a big challenge researchers and engineers are facing.

Societal concern: In fact, if not widely accepted by the public from safety and reliability, the development can be a substantial waste of resources for logistics service providers and vehicle developers alike (Chen *et al.* 2018; Davis 1989). Therefore, it is necessary for researchers to evaluate user acceptance in last-mile delivery early in the development process. *2 main societal concern are summarized according to our results*:

- *release human labour could be both opportunity and challenge*. With the release of human labour, some managers described their worry about the demand of human resource in labour market. *Manager C* addressed, "I think some important challenges are probably like the social impacts of such technologies, let's say jobs" Therefore, how the balance between the advantage of releasing human labour and disadvantage potential unemployed crisis still needs further research;
- *further standards of permission and regulations are needed for automation in last-mile delivery*. As manager pointed out, the 1st challenge "for autonomous driving ground vehicles" is "if they are allowed" and "legal constrains". In another word, legal permission and clear standard instructions are still lacking in automation and robotic implementation, especially in last-mile delivery.

5. Analysis and discussion: roadmap for future research

The joint participation of company practitioners and members of the scientific community in the workshop resulted in valuable insights on opportunities and challenges relevant to enable automation, robotization and intelligent systems in the last-mile delivery. Those findings were assessed in conjunction to the results acquired by means of the previously conducted literature review. The evaluation facilities a more comprehensive understanding of the complexities related to each solution's implementation, by identifying existing differences among *autonomous/semi-autonomous delivery transport*, *autonomous/semi-autonomous final delivery destination location* and *automation prior to dispatch*. The discussion in the sequence rationales the existing opportunities and challenges linked to each innovative solution found.

5.1. Opportunities: internal development and social-spillover effects

Representing the state of the art of innovative technologies viable in the last-mile delivery, it is not surprising to observe that the majority of the solutions identified are closely correlated with the majority of the opportunities discerned when analysing the qualitative workshop data. To be specific, the innovative solutions classified under the 1st cluster related to an *autonomous/semi-autonomous delivery transport*, namely the use of either drones, robots or underground delivery, are likely to contribute towards almost all the *internal development* opportunities relevant to the internal working of a company. Hence, these set of solutions demonstrated on Table 5 are expected to positively affect a company's structural efficiency, distribution efficiency, supply chain flexibility and cost and profit. While the employment of drones, robots or underground delivery does not appear to be related directly to warehouse utility, insights from company practitioners demonstrate that an autonomous delivery process is likely to contribute indirectly towards a more optimal use. Similarly, neither the innovations related to an *autonomous/semi-autonomous final delivery destination location*, nor *automation prior to dispatch* is directly linked to warehouse utility.

One applicable exception however appears to be the use of big data, which can be employed in the creation of load consolidation centres. The 2nd set of opportunities identified is associated with the broader society rather than the internal workings of a company, triggering a number of *social-spillover effects*. All the innovative solutions identified are likely to prompt both sustainable outcomes as well as competition and development, thus their value in optimizing last-mile logistics remains undisputed. Nonetheless, while assessing solutions of *autonomous/semi-autonomous final delivery destination location* and *software-based data processing systems*, it becomes evident that they are not strongly correlated to a more efficient and effective human resource management, in contention to an automated delivery process, which substitutes the human capital with robotics applications.

5.2. Challenges: technical requirements and societal concern

The differences between each innovative solution identified become more evident when examining the associated challenges, which are manifested diversely in each cluster. Regarding the challenges classified as *technical requirements*, service flexibility appears as the most crucial one, correlated to all the 3 clusters identified and the innovative solutions classified under those. This fact is not surprising given from a managerial perception, the challenge manifests the mindsets of people with regards to automation, robotization and intelligent systems. Equally important, customer experience is a challenge associated to both the *autonomous/semi-autonomous delivery transport* and *au-*

Table 5. Enabling opportunities for automation, robotization and intelligent systems in the last-mile delivery

Opportunity		Type		
Overarching dimension		*Autonomous/semi-autonomous delivery process*	*Autonomous/semi-autonomous final delivery destination location*	*Automation prior to dispatch*
Internal development	Structural efficiency	Optimization in one part of the last-mile logistics will have a positive effect on other parts via the use of UAVs, robots and underground delivery systems.	Parcel lockers, reception boxes and customer car trunks optimize structural efficiency of a final delivery destination location.	Big data, dynamic pricing and crowdsourcing are technological solutions to support structural efficiency.
	Warehouse utility			Logistics for delivery, big data applications in particular, would be have a beneficial effect on warehouse fulfilment.
	Distribution efficiency	Robotization via the use of UAVs, robots and underground delivery systems will accomplish delivery within 10...15 min.	Parcel lockers, reception boxes and customer car are solutions to distribution efficiency.	Big data, dynamic pricing and crowdsourcing can optimize distribution efficiency.
	Supply chain flexibility	The use of UAVs, robots and underground delivery systems can improve, obviously, supply chain agility and cost savings.	The use of parcel lockers, reception boxes and customer car trunks can contribute towards supply chain flexibility.	The employment of big data, dynamic pricing and crowdsourcing can contribute towards supply chain flexibility.
	Cost and profit	The use of UAVs, robots and underground delivery systems can improve supply chain agility and cost savings and so on, while there were a great opportunity for sustainability, less emissions, less costs.	The use of parcel lockers, reception boxes and customer car trunks has beneficial effects on cost and profit.	The employment of big data, dynamic pricing and crowdsourcing has beneficial effects on cost and profit.
Social spill – over effects	Competition and development	The use of UAVs, robots and underground delivery systems will become amazing and efficient, what would be the impact on local shops, especially in the COVID-19 era.	The use of parcel lockers, reception boxes and customer car trunks is likely to trigger competition and development.	The employment of big data, dynamic pricing and crowdsourcing is likely to trigger competition and development.
	Sustainability	The use of UAVs, robots and underground delivery systems is a great opportunity for sustainability, less emissions, less costs.	The use of parcel lockers, reception boxes and customer car trunks can achieve more sustainable outcomes compared to traditional delivery methods.	The employment of big data, dynamic pricing and crowdsourcing can achieve more sustainable outcomes compared to traditional delivery methods.
	Human resource	The use of UAVs, robots and underground delivery systems can answer issues related to shortage of labour.		

tonomous/semi-autonomous final delivery destination location, underlying the importance of customers' willingness to accept and use innovative solutions that has captured the interest of experts in the field. In contrast, customer experience does not manifest as a pivotal challenge regarding the application of Software-based data processing systems. This might be explained by the fact that the solutions being part of this cluster do not introduce direct human-machine interactions, thus the customers evidence the use of new technologies less forcefully. Safety reliability is another challenge associated with the direct employment of robotics during a parcel's delivery or acquisition. Although the application of drones and robots appears promising, safety issues, especially in urban areas is perceived as a critical challenge. In a similar angle, safety issues may also derive from big data applications, manifested as privacy safety of individual data as demonstrated on Table 6.

To overcome the challenges related to automation, robotization and intelligent solutions for last-mile delivery classified as *technical requirements*, namely service flexibility, customer experience and safety reliability of the, investment in R&D is still the main solution. When it comes to automation, robotization and information technology, more efficiency and less input solutions are expected naturally. To satisfy the higher expectations and overcome the weakness of lacking human hospitality service experience, more developed and innovative design is required based on technology supporting. To decrease the probability of failed delivery and increase the efficiency of logistics, not only the customer density, delivery automation, delivery-home distance, etc., but also last-mile service with reliability and robustness needs more technic support.

Table 6. Challenges of automation, robotization and intelligent systems in the last-mile delivery

Challenges		Type		
Overarching dimension		*Autonomous/semi-autonomous delivery transport*	*Autonomous/semi-autonomous final delivery destination location*	*Automation prior to dispatch*
Technical requirement	Service flexibility	The use of UAVs, robots or underground delivery systems is contingent to the mindset of the people in order to make flexible hypes.	The use of parcel lockers, reception boxes and customer car trunks is contingent on the mindset of the people in order to make flexible hypes.	The employment of big data is contingent on the mindset of the people in order to make flexible hypes.
	Customer experience	The use of UAVs, robots and underground delivery systems is contingent on customer satisfaction.	Redesigning parcel lockers, reception boxes and customer car trunks is contingent on customer satisfaction.	
	Safety reliability	The use of UAVs and robots may trigger safety questions.		The employment of big data may raise customer data privacy questions.
Societal concern	Working opportunity	Labour implications related to autonomous driving, etc.	Less human labour is demanded, which leads to a structural diminish of labour market.	
	Standard and permission	Legal constraints especially with drones impacts viability. Lacking of a clear instruction and permission from government contribute to the postponement of implementation.	Further regulations and standard should be explored to lead the behaviour in industry.	The employment of big data is contingent upon existing regulations and standards.

On a different angle, the analysis reveals that the innovative solutions classified under the 1st cluster, namely the *autonomous/semi-autonomous delivery transport*, are the ones likely to trigger *societal concern*. The employment of robotics is perceived as a challenge, on the basis that their use will make redundant the human capital traditionally performing the delivery of a parcel to the end-customer. On the contrary, similar concerns are less likely to be manifested less forcefully in relation to *autonomous/semi-autonomous final delivery destination location* innovations, or the application of software-based data processing systems. In a similar vein, the lack of standard and regulation is perceived as a challenge, hindering the adoption of innovative solutions by companies as well as their acceptance by the public. The novel character of the technologies establishing an *autonomous/semi-autonomous delivery transport* might explain the absence of such standards. Hence, even though further regulation is needed in order to address deriving complexities such as traffic requirements or liability issues in the event of accidents, the situation is likely to improve in the future. Likewise, adequate regulation is also needed in relation to big data applications. Given the likely involvement of 3rd parties, legislators must ascertain individual rights regarding access requirements, as well as sound usage and manipulation.

In order to overcome the aforementioned societal challenges, increasing legitimacy is indispensable, given that inadequate industry standards and regulation lead to a more hesitant implementation of automation, robotization and intelligent systems in last-mile delivery. Leading companies are stepping in the new field of automation, robotization and intelligent systems with various innovative logistics solutions, however, the companies who are following the top group are still in the attitude of watching and waiting. Based on the experience of existing innovation solutions, principles or standards by which behaviours and operations would be judged or decided are strongly demanded.

Research and evaluation of the social impact, especially from labour market and efficiency development perspectives, are considered equally important. Academic knowledge should be considered in conjunction with practical insights in order to achieve the best possible outcomes. Lacking the research and evaluation of social impact of labour marketing, is likely to reinforce panic feelings from public, when it comes to automation, robotization and intelligent systems in last-mile delivery. Releasing human capital is the opportunity that technology provides, but should not be the problem that efficiency improvement brings. Consequently, how to balance the transformation of a structural change in labour market is a crucial question, because of automation, robotization and information technology, needs to take under consideration each individual's welfare as well.

6. Conclusions

This research achieved the main purpose of propose a roadmap regarding viable automation, robotization and intelligent solutions to the last-mile delivery. By identifying and assessing each solution's properties and characteristics, we were able to assess their value for market implementation. Among the various innovative solutions found, we discerned 3 main clusters based on the functional characteristics of each solution, namely an *Autonomous/semi-autonomous delivery transport*, solutions relevant to the *autonomous/semi-autonomous final delivery destination location*, and *automation prior to dispatch* based on big data processing systems; an insightful categorization that enabled further evaluation. The reasoning of Assumption 1 (*automation*, *robotization and intelligent solutions are viable in last-mile logistics*) and Assumption 2 (*making automation*, *robotization and intelligent systems viable in last-mile logistics is influenced by opportunities and challenges related to the implementation*) could them be framed with answers.

Assumption 1: Are automation, robotization and intelligent solutions are viable in last-mile logistics? The collaborative endeavour between representatives from the logistics provider sector and members of academia substantiates the validity of Assumption 1. By pooling insights and expertise, a comprehensive panorama emerges, illuminating the feasibility of integrating automation, robotization, and intelligent solutions within the intricate landscape of last-mile logistics. This synthesis of viewpoints underscores the potential of these innovative technologies to reshape the delivery landscape, enhancing efficiency, speed, and overall performance. The findings emanating from this collaborative synthesis convincingly establish the viability of implementing automation, robotization, and intelligent systems in the context of last-mile logistics. The amalgamation of real-world operational experiences and scholarly insights fortifies the notion that these solutions are not just theoretical constructs, but practical tools that can significantly elevate the final leg of the supply chain.

Assumption 2: Is viability of automation, robotization, and intelligent systems in last-mile logistics influenced by opportunities and challenges related to the implementation? The collaborative discourse, as encapsulated by the dialogue between logistics provider representatives and academia, articulates the nuanced interplay of opportunities and challenges inherent in Assumption 2. The collective exploration discerns that the journey toward rendering automation, robotization, and intelligent systems practicable within last-mile logistics is characterized by a dynamic interplay between promising prospects and complex hindrances. The synthesis of perspectives brings to the fore a multifaceted landscape where innovative solutions bear the potential to revolutionize last-mile delivery. Simultaneously, the endeavour shines a spotlight on the intricate network of challenges that must be negotiated for successful implementation. The collaborative endeavour reveals that these challenges vary significantly across different solutions, manifesting in technical, operational, and even societal dimensions.

Hence, the joint inquiry underscores the imperative for in-depth research that delves into the specific challenges that each innovative solution within the realm of automation, robotization, and intelligent systems presents. This dual focus on technical feasibility and societal implications serves as the bedrock for a holistic comprehension of the path forward. The collaborative dialogue paves the way for an informed pursuit of these transformative technologies, weaving together the opportunities and challenges into a cohesive narrative that shapes the future of last-mile logistics.

By means of a collaborative process among logistics provider representatives and members of the academia, we provide a comprehensive synopsis of the relevant opportunities and challenges associated to the application of the innovative solutions. We thus were able to answer the main research question of "how to propose a roadmap of automation, robotization and intelligent systems associated to viable implementation in the last-mile delivery?" (demonstrated and analysed in Section 5). The results demonstrate that although the beneficial impact of automation, robotization and intelligent systems in the last-mile delivery appears well-established, each particular solution identified is tied to a different number of straining factors. Hence, further research focusing on associated challenges is indispensable, both regarding technical requirements of application as well as regarding emanating societal concerns.

From a managerial perspective, this study presents not only a comprehensive overview of viable innovative solutions that may be implemented, but also insights on key aspects likely to increase the effectiveness of their application. Specifically, practitioners should focus on increasing customers' willingness to accept and use automation, robotization and intelligent solutions, especially in cases that involve direct human-robot interaction. Equally important, companies should put an emphasis in securing and ensuring customer safety expectations, in relation not only to the selected autonomous and semi-autonomous robots, but also in relation to big data applications.

It is vital to recognize that numerous aspects of the aforementioned contributions extend beyond the confines of last-mile delivery. They can be applicable to various stages within the logistics chain that are undergoing different degrees of automation, robotization, and intelligent systems integration. Nevertheless, in the context of this research, our methodological approach was intentionally concentrated on the realm of last-mile delivery. Although the specific focus could be seen as a limitation, the insights gained from our contribution hold the potential to be advantageous for forthcoming studies not only within the last-mile niche but also across 1st-mile logistics, SCM, and broader logistic chain domains.

The results provide an overview of what has to be considered in the decision-making process by developers, logistic service providers and other companies interested in implementing innovative solutions for automation, robotization and intelligent systems in the last-mile logistics. Investing in R&D, establishing industry standards and regulation as well as additional scientific insights on the identified challenges are considered as a prerequisite in order to increase the societal acceptance of automation, robotization and intelligent solutions and mitigate unforeseen complexities of their use.

Acknowledgements

The authors would like to thank the OP-Zuid program awarded funding.

The project is made possible in part by financial support from the European Union (European Fund for Regional Development), OP-Zuid, the Province of North Brabant, the Province of Limburg and the Ministry of Economic Affairs and Climate (The Netherlands).

Disclosure statement

All authors have read and approved the final manuscript and agree with its submission to the TRANSPORT.

The authors have no conflicts of interest to declare.

References

Aurambout, J.-P.; Gkoumas, K.; Ciuffo, B. 2019. Last mile delivery by drones: an estimation of viable market potential and access to citizens across European cities, *European Transport Research Review* 11: 30. https://doi.org/10.1186/s12544-019-0368-2

Badue, C.; Guidolini, R.; Carneiro, R. V.; Azevedo, P.; Cardoso, V. B.; Forechi, A.; Jesus, L.; Berriel, R.; Paixão, T. M.; Mutz, F.; De Paula Veronese, L. P.; Oliveira-Santos, T.; De Souza, A. F. 2021. Self-driving cars: a survey, *Expert Systems with Applications* 165: 113816. https://doi.org/10.1016/j.eswa.2020.113816

Barratt, M.; Choi, T. Y.; Li, M. 2011. Qualitative case studies in operations management: trends, research outcomes, and future research implications, *Journal of Operations Management* 29(4): 329–342. https://doi.org/10.1016/j.jom.2010.06.002

Bjørgen, A.; Bjerkan, K. Y.; Hjelkrem, O. A. 2021. E-groceries: sustainable last mile distribution in city planning, *Research in Transportation Economics* 87: 100805. https://doi.org/10.1016/j.retrec.2019.100805

Bosona, T. 2020. Urban freight last mile logistics – challenges and opportunities to improve sustainability: a literature review, *Sustainability* 12(21): 8769. https://doi.org/10.3390/su12218769

Chen, Y.; Yu, J.; Yang, S.; Wei, J. 2018. Consumer's intention to use self-service parcel delivery service in online retailing: An empirical study. *Internet Research* 28(2): 500–519. https://doi.org/10.1108/IntR-11-2016-0334

Chiang, W.-C.; Li, Y.; Shang, J.; Urban, T. L. 2019. Impact of drone delivery on sustainability and cost: realizing the UAV potential through vehicle routing optimization, *Applied Energy* 242: 1164–1175. https://doi.org/10.1016/j.apenergy.2019.03.117

Chui, M.; Manyika, J.; Bughin, J. 2011. *Big Data's Potential for Businesses*. McKinsey & Company. Available from Internet: https://www.mckinsey.com/mgi/media-center/big-data-potential-for-businesses

Corentin, P.; Saraceni, A. V. 2022. Automated delivery robots: a vehicle routing problem on last mile delivery cost per unit based on range and carrying capacity, *IFAC-PapersOnLine* 55(10): 121–126, https://doi.org/10.1016/j.ifacol.2022.09.378

Comi, A. 2020. A modelling framework to forecast urban goods flows, *Research in Transportation Economics* 80: 100827. https://doi.org/10.1016/j.retrec.2020.100827

Comi, A.; Savchenko, L. 2021. Last-mile delivering: analysis of environment-friendly transport, *Sustainable Cities and Society* 74: 103213. https://doi.org/10.1016/j.scs.2021.103213

Davis, F. D. 1989. Perceived usefulness, perceived ease of use, and user acceptance of information technology, *MIS Quarterly* 13(3): 319–340. https://doi.org/10.2307/249008

Di Puglia Pugliese, L.; Macrina, G.; Guerriero, F. 2021. Trucks and drones cooperation in the last-mile delivery process, *Networks* 78(4): 371–399. https://doi.org/10.1002/net.22015

Dorling, K.; Heinrichs, J.; Messier, G. G.; Magierowski, S. 2016. Vehicle routing problems for drone delivery, *IEEE Transactions on Systems, Man, and Cybernetics: Systems* 47(1): 70–85. https://doi.org/10.1109/TSMC.2016.2582745

Dubey, R.; Gunasekaran, A.; Childe, S. J.; Roubaud, D.; Fosso Wamba, S.; Giannakis, M.; Foropon, C. 2019. Big data analytics and organizational culture as complements to swift trust and collaborative performance in the humanitarian supply chain, *International Journal of Production Economics* 210: 120–136. https://doi.org/10.1016/j.ijpe.2019.01.023

Elsayed, M.; Mohamed, M. 2020. The impact of airspace regulations on unmanned aerial vehicles in last-mile operation, *Transportation Research Part D: Transport and Environment* 87: 102480. https://doi.org/10.1016/j.trd.2020.102480

Emmens, T.; Amrit, C.; Abdi, A.; Ghosh, M. 2021. The promises and perils of automatic identification system data, *Expert Systems with Applications* 178: 114975. https://doi.org/10.1016/j.eswa.2021.114975

Ewedairo, K. S. 2019. *The Future of Last-Mile Delivery: a Scenario Thinking Approach*. PhD Dissertation. School of Business IT and Logistics, College of Business, RMIT University, Australia. 265 p. https://doi.org/10.25439/rmt.27598776

Fehling, C.; Saraceni, A. 2023. Technical and legal critical success factors: Feasibility of drones & AGV in the last-mile-delivery, *Research in Transportation Business & Management* 50: 101029. https://doi.org/10.1016/j.rtbm.2023.101029

Feng, Y.; Zhu, Q.; Lai, K.-H. 2017. Corporate social responsibility for supply chain management: a literature review and bibliometric analysis, *Journal of Cleaner Production* 158: 296–307. https://doi.org/10.1016/j.jclepro.2017.05.018

Florio, A. M.; Feillet, D.; Hartl, R. E. 2018. The delivery problem: Optimizing hit rates in e-commerce deliveries, *Transportation Research Part B: Methodological* 117: 455–472. https://doi.org/10.1016/j.trb.2018.09.011

Fosso Wamba, S. 2022. Humanitarian supply chain: a bibliometric analysis and future research directions, *Annals of Operations Research* 319(1): 937–963. https://doi.org/10.1007/s10479-020-03594-9

Geetha, S.; Poonthalir, G.; Vanathi, P. T. 2013. Nested particle swarm optimisation for multi-depot vehicle routing problem, *International Journal of Operational Research* 16(3): 329–348. https://doi.org/10.1504/IJOR.2013.052336

Ghaderi, H.; Tsai, P.-W.; Zhang, L.; Moayedikia, A. 2022. An integrated crowdshipping framework for green last mile delivery, *Sustainable Cities and Society* 78: 103552. https://doi.org/10.1016/j.scs.2021.103552

Hahn, G. J. 2020. Industry 4.0: a supply chain innovation perspective, *International Journal of Production Research* 58(5): 1425–1441. https://doi.org/10.1080/00207543.2019.1641642

Heimerl, F.; Lohmann, S.; Lange, S.; Ertl, T. 2014. Word cloud explorer: text analytics based on word clouds, in *2014 47th Hawaii International Conference on System Sciences*, 6–9 January 2014, Waikoloa, HI, US, 1833–1842. https://doi.org/10.1109/HICSS.2014.231

Hoffmann, T.; Prause, G. 2018. On the regulatory framework for last-mile delivery robots, *Machines* 6(3): 33. https://doi.org/10.3390/machines6030033

Jackson, A.; Srinivas, S. 2021. A simulation-based evaluation of drone integrated delivery strategies for improving pharmaceutical service, *International Series in Operations Research & Management Science* 304: 185–204. https://doi.org/10.1007/978-3-030-69265-0_7

Kapser, S.; Abdelrahman, M. 2020. Acceptance of autonomous delivery vehicles for last-mile delivery in Germany – Extending UTAUT2 with risk perceptions, *Transportation Research Part C: Emerging Technologies* 111: 210–225. https://doi.org/10.1016/j.trc.2019.12.016

Kiba-Janiak, M.; Marcinkowski, J.; Jagoda, A.; Skowrońska, A. 2021. Sustainable last mile delivery on e-commerce market in cities from the perspective of various stakeholders. Literature review, *Sustainable Cities and Society* 71: 102984. https://doi.org/10.1016/j.scs.2021.102984

Lazarević, D.; Dobrodolac, M. 2020. Sustainability trends in the postal systems of last-mile delivery, *Perner's Contacts* 15(1): 1–12. https://doi.org/10.46585/pc.2020.1.1547

Letnik, T.; Peruš, I.; Božičnik, S.; Mencinger, M. 2019. On fundamental principles of the optimal number and location of loading bays in urban areas, *Transport* 34(6): 722–740. https://doi.org/10.3846/transport.2019.11779

Leung, K. H.; Choy, K. L.; Siu, P. K. Y.; Ho, G. T. S.; Lam, H. Y.; Lee, C. K. M. 2018. A B2C e-commerce intelligent system for re-engineering the e-order fulfilment process, *Expert Systems with Applications* 91: 386–401. https://doi.org/10.1016/j.eswa.2017.09.026

Lim, S. F. W. T.; Jin, X.; Srai, J. S. 2018. Consumer-driven e-commerce: a literature review, design framework, and research agenda on last-mile logistics models, *International Journal of Physical Distribution & Logistics Management* 48(3): 308–332. https://doi.org/10.1108/IJPDLM-02-2017-0081

Lukinskiy, Va.; Lukinskiy, Vl.; Merkuryev, Y. 2018. Modelling of transport operations in supply chains in obedience to "just-in-time" conception, *Transport* 33(5): 1162–1172. https://doi.org/10.3846/transport.2018.7112

Macioszek, E. 2018. First and last mile delivery – problems and issues, *Advances in Intelligent Systems and Computing* 631: 147–154. https://doi.org/10.1007/978-3-319-62316-0_12

Maditati, D. R.; Munim, Z. H.; Schramm, H.-J.; Kummer, S. 2018. A review of green supply chain management: from bibliometric analysis to a conceptual framework and future research directions, *Resources, Conservation and Recycling* 139: 150–162. https://doi.org/10.1016/j.resconrec.2018.08.004

Maghazei, O.; Netland, T. 2020. Drones in manufacturing: exploring opportunities for research and practice, *Journal of Manufacturing Technology Management* 31(6): 1237–1259. https://doi.org/10.1108/jmtm-03-2019-0099

Mangiaracina, R.; Perego, A.; Seghezzi, A.; Tumino, A. 2019. Innovative solutions to increase last-mile delivery efficiency in B2C e-commerce: a literature review, *International Journal of Physical Distribution & Logistics Management* 49(9): 901–920. https://doi.org/10.1108/ijpdlm-02-2019-0048

Moshref-Javadi, M.; Winkenbach, M. 2021. Applications and Research avenues for drone-based models in logistics: A classification and review, *Expert Systems with Applications* 177: 114854. https://doi.org/10.1016/j.eswa.2021.114854

Mucowska, M. 2021. Trends of environmentally sustainable solutions of urban last-mile deliveries on the e-commerce market – a literature review, *Sustainability* 13(11): 5894. https://doi.org/10.3390/su13115894

Paddeu, D.; Parkhurst, G.; Fancello, G.; Fadda, P.; Ricci, M. 2018. Multi-stakeholder collaboration in urban freight consolidation schemes: drivers and barriers to implementation, *Transport* 33(4): 913–929. https://doi.org/10.3846/transport.2018.6593

Ranieri, L.; Digiesi, S.; Silvestri, B.; Roccotelli, M. 2018. A review of last mile logistics innovations in an externalities cost reduction vision, *Sustainability* 10(3): 782. https://doi.org/10.3390/su10030782

Rossolov, A.; Rossolova, H.; Holguín-Veras, J. 2021. Online and in-store purchase behavior: shopping channel choice in a developing economy, *Transportation* 48(6): 3143–3179. https://doi.org/10.1007/s11116-020-10163-3

Saetta, S.; Caldarelli, V. 2020. How to increase the sustainability of the agri-food supply chain through innovations in 4.0 perspective: a first case study analysis, *Procedia Manufacturing* 42: 333–336. https://doi.org/10.1016/j.promfg.2020.02.083

Saraceni, A.; Oleko, R.; Guan, L.; Bagaria, A.; Quintens, L. 2022. Autonomization and digitalization: index of last mile 4.0 inclusive transition, *IFIP Advances in Information and Communication Technology* 663: 173–182. https://doi.org/10.1007/978-3-031-16407-1_21

Sarma, D.; Das, A.; Kumar Bera, U. K. 2020. Uncertain demand estimation with optimization of time and cost using Facebook disaster map in emergency relief operation, *Applied Soft Computing* 87: 105992. https://doi.org/10.1016/j.asoc.2019.105992

Seghezzi, A.; Mangiaracina, R.; Tumino, A.; Perego, A. 2021. "Pony express" crowdsourcing logistics for last-mile delivery in B2C e-commerce: an economic analysis, *International Journal of Logistics Research and Applications: a Leading Journal of Supply Chain Management* 24(5): 1–17. https://doi.org/10.1080/13675567.2020.1766428

Shan, S.; Zhao, F.; Wei, Y.; Liu, M. 2019. Disaster management 2.0: a real-time disaster damage assessment model based on mobile social media data – a case study of Weibo (Chinese Twitter), *Safety Science* 115: 393–413. https://doi.org/10.1016/j.ssci.2019.02.029

Shani, A. B. R.; Tenkasi, R. R. V.; Alexander, B. N. 2017. Knowledge and practice: a historical perspective on collaborative management research, in J. Bartunek, J. McKenzie (Eds.). *Academic–Practitioner Relationships: Developments, Complexities and Opportunities*, 17–34. https://doi.org/10.4324/9781315657530-3

Shi, K.; De Vos, J.; Yang, Y.; Witlox, F. 2019. Does e-shopping replace shopping trips? Empirical evidence from Chengdu, China, *Transportation Research Part A: Policy and Practice* 122: 21–33. https://doi.org/10.1016/j.tra.2019.01.027

Silvestri, P.; Zoppi, M.; Molfino, R. 2019. Dynamic investigation on a new robotized vehicle for urban freight transport, *Simulation Modelling Practice and Theory* 96: 101938. https://doi.org/10.1016/j.simpat.2019.101938

Simoni, M. D.; Marcucci, E.; Gatta, V.; Claudel, C. G. 2020. Potential last-mile impacts of crowdshipping services: a simulation-based evaluation, *Transportation* 47(4): 1933–1954. https://doi.org/10.1007/s11116-019-10028-4

US Chamber of Commerce. 2025. *Supply Chain Security Working Group*. Available from Internet: https://www.uschamber.com/security/supply-chain

Tsai, Y.-T.; Tiwasing, P. 2021. Customers' intention to adopt smart lockers in last-mile delivery service: A multi-theory perspective, *Journal of Retailing and Consumer Services* 61: 102514. https://doi.org/10.1016/j.jretconser.2021.102514

Vakulenko, Y.; Shams, P.; Hellström, D.; Hjort, K. 2019. Service innovation in e-commerce last mile delivery: mapping the e-customer journey, *Journal of Business Research* 101: 461–468. https://doi.org/10.1016/j.jbusres.2019.01.016

Vanelslander, T.; Deketele, L.; Van Hove, D. 2013. Commonly used e-commerce supply chains for fast moving consumer goods: comparison and suggestions for improvement, *International Journal of Logistics Research and Applications: a Leading Journal of Supply Chain Management* 16(3): 243–256. https://doi.org/10.1080/13675567.2013.813444

Viu-Roig, M.; Alvarez-Palau, E. J. 2020. The impact of e-commerce-related last-mile logistics on cities: a systematic literature review, *Sustainability* 12(16): 6492.
https://doi.org/10.3390/su12166492

Willcocks, L. 2020. Robo-Apocalypse cancelled? Reframing the automation and future of work debate, *Journal of Information Technology* 35(4): 286–302.
https://doi.org/10.1177/0268396220925830

Winkelhaus, S.; Grosse, E. H. 2020. Logistics 4.0: a systematic review towards a new logistics system, *International Journal of Production Research* 58(1): 18–43.
https://doi.org/10.1080/00207543.2019.1612964

Xu, S.; Zhang, X.; Feng, L.; Yang, W. 2020. Disruption risks in supply chain management: a literature review based on bibliometric analysis, *International Journal of Production Research* 58(11): 3508–3526. https://doi.org/10.1080/00207543.2020.1717011

Zhang, Y.; Sun, L.; Hu, X.; Zhao, C. 2019. Order consolidation for the last-mile split delivery in online retailing, *Transportation Research Part E*: *Logistics and Transportation Review* 122: 309–327.
https://doi.org/10.1016/j.tre.2018.12.011

Zhou, M.; Zhao, L.; Kong, N.; Campy, K. S.; Xu, G.; Zhu, G.; Cao, X.; Wang, S. 2020. Understanding consumers' behavior to adopt self-service parcel services for last-mile delivery, *Journal of Retailing and Consumer Services* 52: 101911.
https://doi.org/10.1016/j.jretconser.2019.101911

Zhu, Y. 2019. The status & future trend of the last mile distribution mode in Chinese cities, in *Proceedings of the 2019 2nd International Conference on Education*, *Economics and Social Science* (*ICEESS 2019*), 30–31 October 2019, Singapore, 261–264.
https://doi.org/10.2991/iceess-19.2019.67