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Autonomous Vehicles as an Essential Component of Industry 4.0 for Meeting Last-Mile Logistics Requirements

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Abstract: The most sensitive and vulnerable component of the supply chain is last-mile logistics, which is especially vulnerable to consequential challenges due to the current global crises. Customers expect prompt and dependable delivery of their orders, regardless of where they buy or order them. To meet the needs and requirements of customers, logistics companies are being forced to use innovative Industry 4.0 solutions. Last-mile logistics are under constant challenge due to high population density and growing urbanization, which concentrate the majority of user service requests in urban city areas. As a result of the increase in the number of online orders and the volume of e-commerce, longer delivery times, delivery errors, and customer dissatisfaction occur. Therefore, the implementation of modern Industry 4.0 solutions, such as new autonomous vehicles, is necessary to respond to numerous challenges that affect the efficiency of all entities in the supply chain, particularly the last mile. Autonomous vehicles are an essential component of Industry 4.0, primarily concerned with the autonomy of activities in last-mile logistics, and have filled the market with numerous innovations. This study aims to highlight the benefits of some of the most common autonomous vehicles for realizing user requests in the last mile and provide suitable guidelines for selecting the most suitable alternative for the logistics company. Additionally, the research identifies certain challenges in their implementation, pointing to some of the key motivations for future research.

Keywords: Industry 4.0; Autonomous vehicles; Supply chain; Last-mile logistics; Customer requirements

1 Introduction

Urbanization, an increase in online ordering volume, and the intensification of e-commerce are some of the critical elements of modern business that contribute to the rise in the complexity of logistics system operations and the increase in supply chain activities. The increasing complexity of logistics companies' operations is due to the current business conditions becoming more stringent, the market becoming more demanding, and user requirements becoming variable. As a result, logistics systems are becoming increasingly vulnerable to challenges and problems. Cutting-edge technological solutions based on Industry 4.0 are necessary to improve customer service resilience at all levels of the supply chain to address numerous risks.

Customer service in urban areas is particularly vulnerable to risks and challenges in supply chains. Last Mile Logistics (LML) is regarded as the most sensitive segment of any Supply Chain (SC) because urban users have high expectations regarding the fulfillment of their requirements in the shortest possible time, at the lowest possible cost, and without delays or errors [1]. The delivery of goods to users has the greatest impact on traffic congestion, delays, the load on city roads, and a high level of pollution, as LML is primarily realized through the use of road transport [1, 2]. LML faces massive difficulties due to increased traffic congestion, limited parking spaces, and the need to harmonize and comply with increasingly stringent environmental regulations, especially in densely populated urban areas, thus demanding the implementation of contemporary Industry 4.0 technologies. In the last decade, new solutions for the delivery of goods to customers have appeared within LML, including bicycles, electric scooters, and cargo vans. However, the increased driver workload, which includes not only driving these vehicles but also handling delivery, necessitates the use of autonomous vehicles. Predictions show that by 2025, autonomous cars will handle more than 80% of deliveries within LML as a result of growing customer demands in urban city areas [2, 3].

The aim of this study is to provide insight into the advantages of using autonomous vehicles for customer service in LML activities due to numerous challenges in SC. These challenges are significantly highlighted in customer service as a consequence of increasing e-commerce volume. The purpose of this study is to highlight some of the requirements for the gradual, yet faster and more effective, implementation of autonomous vehicles while respecting the constraints imposed by current urban plans and the vehicle fleets that logistics companies depend on (type and number of vehicles, load capacity, age structure, and so on). Autonomous electric-powered alternatives are in focus as answers to the ecological risks of conventional diesel or hybrid-powered modes of transportation for LML objectives. Drones are already a widely acknowledged and frequently used solution that shifts some transportation from "ground to airspace" [1, 3]. This study offers fundamental guidelines for the use of autonomous vehicles, with a focus on droids and robotic vans. As the electrification of transportation is a crucial reaction to reducing environmental pollution, this study also aims to explain the benefits of Industry 4.0 in the context of autonomous vehicles as an answer to customer requirements in urban city areas.

This study is organized into several chapters. After the introduction, the second chapter will deal with the basic issues and difficulties concerning LML activities that logistics companies in SC are usually exposed to. The third chapter of the research goes into significant detail about robotic vehicles and droids as promising and widely used alternatives for urban package delivery. The advantages and weaknesses of their application will also be discussed, providing insight into the quantitative indicators and qualitative characteristics of autonomous vehicles in the context of LML requirements. The fourth chapter is a discussion that provides insight into the benefits and limitations of applying the analyzed autonomous vehicles to LML requirements. The last chapter is the conclusion. It provides limitations in the use of autonomous vehicles under investigation, which will be explored with future academic research directions, as well as their potential for practical suitability. All the citations in the original text have been retained.

2 Key Challenges in the Activities of Last-Mile Logistics

The increase in urban development, digitization, and e-commerce has led to a rise in LML activity, resulting in traffic congestion and negative environmental impacts [3, 4]. To enhance urban sustainability, logistics companies, which frequently use city roads to reach customers, are under pressure to implement innovative LML solutions [4, 5]. These companies often adopt best practices from developed regions to improve their business and remain competitive. Consequently, smart solutions have been developed to increase driving autonomy, eliminate harmful emissions, and improve public freight traffic policies.

LML efficiency is heavily influenced by regional circumstances and infrastructure limitations, such as unloading zones or locations where customers pick up their orders or goods. Inadequate network transport infrastructure in developing countries can lead to long trips, inefficient routes, high delivery costs, delays, and other significant issues [3, 4]. Current trends, such as the rising demand for services and the complexity and inefficiency of implementing end-user requests, further impact LML efficiency. Personalized delivery options over frequently unpredictable routes to frequently uncertain destinations create inefficiency, making LML the most expensive, environmentally unfriendly, and socially vulnerable part of SC [3, 4].

The type of goods being delivered can also pose significant challenges for LML. Items such as hazardous, fragile, flammable, perishable, or massive commodities require special handling to prevent harm to the environment [4, 6]. LML for these goods requires complex planning that demands significant time, resources, and experience. As the least efficient part of the distribution of goods, increasing LML sustainability is challenging due to the dynamic nature of urban environments and the significance of economic activities [5]. To achieve more efficient LML in smart and sustainable cities, it is necessary to focus simultaneously on the economic, environmental, and social aspects of goods distribution in SC [5, 6].

Over the past 20 years, numerous approaches and strategies based on Industry 4.0 have been proposed to reduce and ultimately eliminate failures in the delivery of goods in LML. Modern technology adoption has led to customer satisfaction becoming one of the main issues, especially when a place is selected without consideration for when the goods will be delivered. Delivery at common locations like point-of-sale terminals also raises doubts regarding capacity or working hours at the time of delivery [5, 7]. Communication barriers during the pickup and/or delivery of goods pose a growing challenge for logistics companies, with the human factor in urban city areas being a significant barrier.

The deployment of driverless vehicles, or the autonomy of transportation within LML, is the focus of contemporary Industry 4.0 technology development. Urban regions in cities are constantly subject to detrimental environmental effects such as CO_2 emissions and noise, traffic jams on city streets, delays, and erroneous and unrealized deliveries, all of which reduce the efficiency of logistical activities within LPM [7, 8]. The development of Industry 4.0 has led to novel solutions in freight transportation that are primarily based on the usage of electric vehicles with a substantial level of autonomy.

Drones have been recognized for a long time as a solution for autonomous transportation and other logistics activities in LML. They are seen as socially and environmentally acceptable alternatives supported by Industry 4.0, and are already being used in developed and densely populated world metropolises. However, their high investment costs and constrained range are the biggest barriers to their full use in LML, and they can only be implemented in certain regions where appropriate legislation supports their use. Their load capacity, which is limited to only a few tens of kg, is also a significant limiting factor, making their use in logistics companies' LML activities still a vulnerable research area [8, 9].

As online ordering and urbanization continue to increase LML activities for many logistics companies, drone delivery of goods is expected to be a crucial component of the smart city environment's sustainability. However, the legal framework governing their use in many urban areas is still under development, which is a significant barrier to their full implementation [6, 9]. The limited range and capacity of drones, as well as their relatively high cost, further limit their complete implementation for LML activities.

As a result, environmentally friendly vehicles that can utilize the current transportation infrastructure are being examined as a way to address the challenges associated with drone introduction. Autonomous road electric vehicles are being considered as solutions to improve the efficiency of LML, which is the most vulnerable part of SC, due to significant pollution and human-caused accidents.

3 Autonomous Vehicles in Industry 4.0 for Last-Mile Logistics Challenges

Autonomous driving has been tested by Continental for over 50 years, and there are currently five levels of driving autonomy. For the distribution of goods, three levels are being used, with the fourth level expected to be implemented by 2025 and full autonomy to the fifth extent expected by 2027 [10]. By 2030, levels 4 and 5 are predicted to be fully employed for LML operations, with an expectation that 40% of commercial vehicles will be autonomous by 2050 [10, 11].

High automation (level 4) indicates user service, where the driver routinely operates the vehicle but does not participate in the planned route (starting and stopping). Full automation (level 5) does not require a driver, which is a challenge from the perspective of social sustainability. The implementation of high-level (level 4) and fully autonomous driving (level 5) will begin gradually but quickly, starting in 2040. The multiple highly interconnected components and their roles required for these levels of autonomy include sensors and cameras, vehicle communication, and the implementation of appropriate algorithms for prediction and decision-making [11, 12].

Autonomous vehicles offer many benefits for LML, including high degrees of autonomy, improvements to traffic safety in urban areas, faster delivery times, and less congestion [9, 11, 12]. These smart transportation systems are designed to assist in all aspects of sustainability while saving energy during exploitation [10, 11]. Electric vehicles are a conventional example since they can easily be integrated into fleets that currently consist predominantly of diesel vehicles.

Due to the increasing volume of customer requests, LML is considered the most vulnerable area of SC. Legal limitations and the high cost of implementing drones are major barriers to their full implementation in LML. As a result, companies are turning to autonomous vehicles that operate on the ground more frequently. The remainder of this chapter analyzes two increasingly popular options for carrying out LML activities: droids and robotic vehicles.

3.1 Droids for Last-Mile Logistics Challenges

Droids are small autonomous vehicles designed to deliver goods to customers in urban areas. As driverless vehicles, they are often referred to as "urban robots" and are slightly larger than ordinary packages. Droids are equipped with GPS and a camera for navigation, and are opened with a unique code known only to the customer to ensure safe delivery. These devices move at low speeds on sidewalks and footpaths, which are the most suitable transportation infrastructure.

Although their usage in last-mile logistics (LML) is still in its early phases, droids offer a promising solution for logistics companies seeking to address issues with urgent, relatively brief, and unpredictable deliveries [11]. However, droids currently require regular supervision and are unable to serve users independently. Like drones, droids have a limited payload and range, which prevents them from being fully integrated into LML activities [5, 11, 13].

The electrification of the road network presents a key implementation challenge that is common to other contemporary LML technologies with electric propulsion [8]. It is important to offer enough locations for battery charging as well as suitable service locations where the (scheduled) replacement of empty batteries with full batteries is carried out for these and other electric vehicles.

While droids offer an environmentally friendly option for low-quantity delivery, they are not currently regarded by users as socially sustainable [5, 11]. To enable communication between the user and the droid, a fully functioning internet connection, software that can detect difficulties and variations in delivery, and a shared network are necessary. The user can access up-to-date information on the status of their items through a licensed application on their mobile device.

Logistics companies in last-mile (LML) parts of the supply chain often receive a significant number of requests and frequently use courier assistance. However, droids are seen as vehicles for the future as they can communicate with customers and deliver goods to them [5, 13]. In this scenario, both the sender of the goods from the company and the recipient are considered users, and the droid handles physical distribution while both users send and receive information via mobile phones.

Efficient user service is only possible when the user application is used effectively, and this requires a high level of digitization among all supply chain participants. One of the biggest challenges in deploying droids, as with all current autonomous vehicles, is the need for digitization throughout the supply chain [11, 13].

3.2 Robotic Vans in Last-Mile Logistics

Robotic vans are one of the most common and efficient autonomous alternatives for addressing the many challenges in last-mile logistics (LML). These electric, driverless vehicles are designed to eliminate human error from road freight transportation and are particularly useful in urban areas where customers require a variety of delivery options and timeframes [14, 15]. By using robotic vans, the consolidation of freight at common delivery locations in LML is encouraged, and more contemporary models have improved stopping systems that help to lower operating costs, hazardous emissions, and traffic congestion [14].

In terms of carrying capacity, driving speed, and environmental sustainability, robotic vans are comparable to conventional commercial electric vehicles. They also decrease the occurrence of accidents caused by human error, reduce noise and pollutants, and provide flexibility in customer service [14]. However, a network of insufficiently built electric battery charges, inadequate public knowledge of driverless traffic flows, and undeveloped government policies for subsidies for cleaner driving are some of the main weaknesses during the deployment of these sophisticated smart vehicles [15].

Robotic autonomous vans are seen as the fastest-implemented ”vehicle of the future” in both the LML and comprehensive supply chain frameworks since they can be readily coupled with other autonomous vehicles [15]. However, their implementation for LML activities mainly considers their convenience in integrating with drones and droids for efficient customer service in urban environments, as they have a significant impact on traffic congestion when moving through city roads.

3.3 Comparing Autonomous Vehicle Options for Last-Mile Logistics

The adoption of autonomous vehicles for last-mile logistics (LML) has become a significant challenge for all supply chain entities due to the continued pressure of Industry 4.0 development. Logistics companies considering investing in autonomous technologies often base their decisions on price, implementation time, and integration with existing technologies [16] . However, social and environmental sustainability criteria related to sustainability regulations and the humanization of employment must also be considered alongside economic objectives. In addition, the quality of service, including accuracy, timeliness, velocity, and reliability of fulfillment, is crucial for meeting customer expectations. Therefore, the implementation of suitable autonomous vehicles based on the advantages of Industry 4.0 is necessary to meet the performance requirements of logistics firms and customer needs.

Table 1 compares the quantitative or measurable characteristics of drones, robotic vans, and droids for the requirements of LML activities, taking into account the benefits and weaknesses of each type of autonomous vehicle [3, 4, 11, 12, 14, 17]. Table 2 offers a comparative presentation of the non-measurable quality components for the three alternatives that were analyzed as necessary for the effectiveness of LML activities, which is the most vulnerable area of the supply chain. These tables provide a summary of the most often addressed issues in the reviewed literature while considering numerous aspects of diverse investigations [8, 10, 12, 14, 15].

Table 1. Quantitative characteristics of autonomous vehicles

	Drones	**Robotic vans**	**Droids**
Load capacity	over 50 kg	$2 - 5$t	to 50 kg
Range with one charged battery	to 20 km	$100 - 150$ km	to 5 km
Estimated operating time between (two) charges	30 min	45 min	20 min
Average speed	$100 - 120$ km/h	$70 - 100$ km/h	$5 - 10$ km/h

According to Tables 1 and 2, robotic vans are currently the most favorable autonomous vehicle option for last-mile logistics (LML) efficiency. They offer reliable, fast, accurate, and reasonably priced service, making them suitable for meeting most LML requirements for sustainable and effective customer service. In densely populated urban areas, historic districts, and pedestrian zones, drones and droids are suitable alternatives, especially for individual customer requirements. Drones are particularly useful for relieving congestion in smaller-weight deliveries moved ”from the ground to the air” [4]. However, to employ these smart devices, all supply chain entities must be given specific usage instructions and necessary legal regulations.

Table 2. Quality features of autonomous vehicles

	Drones	**Robotic vans**	**Droids**
Influence on city traffic	without	short	little
The expected time of fulfillment of the company's requirements for implementation	medium to long	considerable	medium
Convenience for LML	partialy	fully	limited
A key challenge for LML implementation	undeveloped legislation	poor electrification of traffic roads	low load capacity

The usage of droids is mostly concentrated in more developed countries, where the benefits of robotic solutions have long been acknowledged in all different business sectors, and social distance is seen as one of the pillars of contemporary life. From the perspective of sustainable logistics companies, the deployment of robotic vans has been identified as the most quickly applicable autonomous alternative. There are no infrastructure limitations in their implementation because these delivery and mobility vehicles use the city's road network even if they are driverless [13, 14, 18]. This makes them desirable for meeting the most LML requirements for sustainable and effective customer service.

In addition to many advantages, employing autonomous vehicles has certain risks and challenges. The user's perception of the delivery of goods by automated vehicles is one of the most important challenges in terms of social sustainability. However, there are also risks associated with applying Industry 4.0 technologies nowadays due to the requirement for dependable and rapid internet support while utilizing an expanding number of user applications [4, 12, 14, 19]. The kind, form, and amount of goods that a specific device must handle constitute another constant challenge. This issue can be addressed by incorporating suitable material handling devices, making LML activities in the supply chain more effective [14, 16–18]. Appropriate user applications enable the elimination of errors caused by the human factor. However, customers may have difficulties when using these applications that are often too inflexible for all users. Moreover, customers do not have the opportunity to communicate with a person when downloading goods, which is considered a key challenge in the implementation of autonomous vehicles [3, 4, 12, 14, 18].

Overall, while there are certain risks and challenges associated with the adoption of autonomous vehicles, the benefits in terms of efficiency, sustainability, and customer service make them a promising solution for last-mile logistics.

4 Autonomous Alternative Discussion

Table 3 provides the basis for selecting the fleet of autonomous vehicles to encourage a logistics company's capability to satisfy last-mile logistics (LML) requirements. Every analyzed alternative has advantages, disadvantages, and a varied level of implementation. According to the analyses, Table 3 suggests the main benefit of each autonomous vehicle but also the essential limitation during their implementation for LML activities [3, 4, 16, 18].

Based on Tables 1 and 2, the implementation of robotic vans is currently proposed for LML activities in a logistics company. Despite their high costs, robotic vans are flexible in many ways, especially due to the possibility of incorporating materials handling devices. They are highly suitable for combining with other autonomous vehicles like drones and droids. However, drones still face a barrier to implementation in many logistics companies due to undeveloped regulations, even if they are utilized in developed cities. In addition to being sophisticated autonomous aircraft of Industry 4.0, they require high investments and have a low payload and range. Therefore, they cannot fully and independently realize LML activities but are used as an aid to serve individual users in hard-to-reach locations.

Droids are self-driving vehicles that are being tested for delivery in pedestrian zones and historic sections of cities. Although they are inexpensive and environmentally friendly, they are still challenging to use due to their vulnerability to cybercrime and inability to handle goods. Overall, the selection of the appropriate fleet of autonomous vehicles for LML activities depends on the specific needs and challenges of the logistics company, as well as the benefits and limitations of each autonomous vehicle option.

Despite the many benefits of robotic vans, logistics companies are trying to address the challenges of employing small-sized vehicles to guarantee the completion of all last-mile logistics (LML) activities, enabling supply chains to become more resilient. Robotic vans can impact the city's infrastructure and are difficult to use in pedestrian areas and historic districts. Due to the necessity of legal regulations for the use of drones, logistics companies are trying to hire droids for deliveries that are made individually, over short distances, and with small deliveries. These advanced urban robots of Industry 4.0 are suitable for connecting to a transportation system and are recognized as quick-to-implement alternatives for the fulfillment of specific user requests [19].

The importance of employing droids for the success of LML activities in order to improve supply chain resilience is illustrated by examples of successful practice. Droids might completely replace vans and cars for short-distance

Table 3. Comparison of autonomous vehicles for LML activities

	Drones	Robotic vans	Droids
Benefits	relief of road traffic	the possibility of integration with materials handling devices	low investment costs
	environmentally acceptable suitability for deliveries to inaccessible locations high flexibility	high flexibility environmentally friendly suitable for fitting into the current fleet of vehicles	small noise environmentally friendly relieves the city traffic
Limitations	the necessity of regulation	impact on city traffic	high technological dependence
	high investment costs limited payload and range require monitoring	high investments require human supervision vulnerability to cyber crime	require human control without the possibility of handling the goods susceptible to cybercrime
Level of implementation	use in developed countries	widespread use in city centers	pilot in developing cities

travel, primarily for individual customer service, according to the results of deploying them at Amazon in Southern California's urban areas. FedEx also employs these autonomous devices to successfully deliver items to customers in urban locations [19]. Droids are a symbol of Industry 4.0 technology, and LML activities bring a variety of challenges, making them one of the weakest aspects of any supply chain.

Similar circumstances apply to drones, where a specific limitation is the current legal framework. In addition to the high price and significant requirements for the use of advanced technologies, even if they transfer cargo "from the ground to the air", drones are also very challenging for the complete realization of LML activities. Despite the traffic relief provided by droids and drones, logistics companies are currently favoring robotic vans for the autonomy of LML activities, with the aim of integrating these small-capacity smart devices for sustainable supply chains in the near future.

5 Concluding Remarks

The current processes of any logistics company today cannot be rationalized without the use of Industry 4.0 technologies, whose success is directly related to the level of autonomy applied in the realization of vulnerable last-mile logistics (LML) activities. Due to increased urbanization, expansive digitization, and the growth of e-commerce, logistics companies are trying to improve their operations by implementing new technologies, improving customer service, and extending their own distribution network [3, 4]. Customers prefer logistics companies that deliver goods faster and cheaper than competing companies while receiving all of the benefits of e-commerce [5, 8]. Consequently, home delivery becomes an essential characteristic of e-commerce, placing additional responsibility on LML activities as an essential segment of supply chain efficiency.

Implementing autonomous vehicles poses a reasonable answer to many environmental challenges in the logistics company's reduced emissions. Moreover, it can be considered an essential step toward smart and sustainable cities. However, there are several issues with the widespread adoption of emerging autonomous LML solutions based on advanced Industry 4.0 technologies [10, 17, 19]. The lack of appropriate infrastructure, city hubs, and legislation are considered the main barriers to full transportation autonomy in customer service at LML activities. Concerning operating costs, maintenance, job losses, and the absence of people in material handling, full automation can be critical for supply chain efficiency [9, 10, 12]. The social pillar of sustainable supply chains is also exposed to challenges due to risks associated with the user's communication "with the device" during the delivery of goods. It requires additional user training and the adaptation of the fleet of autonomous vehicles to the customer's individual needs. For this purpose, there are a significant number of Industry 4.0 innovations and applications on the market that are used to track goods, couriers, drivers, and vehicles to implement modern technologies as rapidly as possible that are equally effective for both logistics businesses and their customers.

Logistics companies can realize effective cost benefits by eliminating driver salaries as a significant cost in the fleet of conventional diesel trucks, despite the significant financial expenditures for the introduction of autonomous vehicles. The foundation for future investigation is figuring out ways to overcome societal constraints linked to user perception when goods are delivered by self-driving vehicles because these vehicles minimize errors brought on by human factors and are environmentally acceptable [5, 20]. Robotic vans are the most extensively used and quickly implemented autonomous vehicles appropriate for the full implementation of LML assignments. The integration of smaller payload and capacity vehicles, such as drones and droids, ought to be additionally investigated in order to realize the maximum benefits of autonomous vehicles for the logistics company's LML activities. Future research should focus on methods for overcoming societal barriers related to user perception when goods are delivered by self-driving vehicles because these cutting-edge solutions reduce errors caused by human factors and are environmentally friendly. To completely realize the benefits of autonomous vehicles for the logistics company's LML activities, it is necessary to further examine the integration of smaller payload and capacity vehicles, such as drones and droids.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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