SOME SOLUTIONS TO OVERCOME CHALLENGES FACED BY LAST-MILE DELIVERY IN SMART CITIES

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Abstract

The growth of online retail is creating critical logistical challenges in the last part of the distribution chain. Traditional home delivery by truck reaches its limits in big cities and ceases to be efficient. Alternative and innovative logistics solutions are needed. This article discusses how smart cities can overcome the challenges caused by last-mile delivery, like CO_2 emissions, noise pollution, and congestion increases. After a brief introduction to smart cities and last-mile delivery essentials, the authors discussed last-mile delivery challenges and proposals for several problem solutions. For the purpose of the analysis, the authors created a table where for each of the mentioned challenges are proposed solutions to overcome them. In Chapter 3, the authors discussed some innovative models in delivery. Here are discussed cargo bikes, parcel lockers, delivery drones, and the organization of last-mile delivery. The fourth chapter discusses future trends in last-mile delivery. The authors believe that in the near future, transporters will continue to try to reduce delivery costs by optimizing existing ways of delivering goods and by almost imperceptibly transferring part of the transport activities and costs to clients. Here, above all, they mean the popularization of parcel lockers. Based on the analysis presented in this article and their experience, the authors in Chapter 5 gave their conclusions about last-mile delivery in smart cities.

INTRODUCTION

In 1950, 30% of the population lived in cities (751 million). Since then, the urban population has increased rapidly. In 2018, 54.8% (4.2 billion) lived in cities. [1] If the predictions come true, by 2050, the urban population's share will increase to 68%. About 54% of the world's urban population lives in Asia. Europe and Africa are the next with 13% each. People gradually shift from rural to urban areas and from small to larger cities. Given the overall growth of the world's population, an additional 2.5 billion people could inhabit urban areas by 2050. According to the UN report, the largest share, close to 90% would be realized in Asia and Africa [2].

What is a Smart City?

There are many definitions of "smart city" formulated by different authors. That leads to an expanded interpretation of the smart-city concept. [3] However, diversity of opinion favors the development of an effective smart-city concept. [4] The phrase “smart cities“ includes different meanings that overlap with each other. The idea is based on an environmentally friendly city, which introduces innovative technical solutions to meet the needs of its citizens. Even Aristotle defended the idea that the city and its inhabitants are in partnership for common well-being. Hippocrates dealt with the quality of climate, water, and soil and their influence on life quality and people’s health. [5] From this, we can conclude that the idea of a smart city, despite the current popularity of this phrase, is not new. What is new is the technology that makes the city more livable. [3]

When it talks about smart cities, the United Nations Development Program (UNDP) is about using new technologies to achieve inclusive and sustainable urban development that considers people, the economy, and the environment. [6].

Smart cities developed different technologies to make citizens’ lives easier. They can be grouped, and the most expectable groups are [7]:

- Smart IoT devices,
- Smart energy,
- Smart mobility and transportation,
- Smart-waste management, and
- Smart buildings.

To be 'smart', a city needs investments in technology improvement. It must search for more suitable alternative solutions, the provision of relevant data and their processing, decision-making, training, and preparation of residents for the new way of life. From the aspect of logistics, some crucial components of the smart-city system are [8]:

- Organization of transportation,
- Roadways,
- Logistics centers,
- Global positioning systems receivers,
- High-speed communications networks, and
- Computerized systems with sensors, actuators, microcontrollers, microcomputers, computers, databases, and end-user terminals.

Given the article topic, we will focus on last-mile logistics challenges and models and technology solutions.

What is Last-Mile Delivery?

Last-mile delivery is the final stage of delivering goods to the customer. Because customers mostly live in urban areas, this service has many specificities related to cities. Specialized carriers, courier companies, independent drivers, and couriers provide last-mile delivery. Delivery of goods can be to the home address but also in stores that offer this type of service, self-service parcel lockers, and at destination hubs of postal services. Last-mile delivery vehicles are typically smaller due to better passability and more efficient utilization. They can be trucks, vans, passenger cars, motorcycles, bicycles, drones, and autonomous uncrewed road vehicles. Due to the constant growth of cities and e-commerce, the need for last-mile delivery has also increased. As a result, the volume of deliveries, the number of delivery vehicles, and the locations to which goods are delivered have increased. Due to increased needs, independent drivers and new service providers and models have appeared on the market to compete with traditional courier companies.

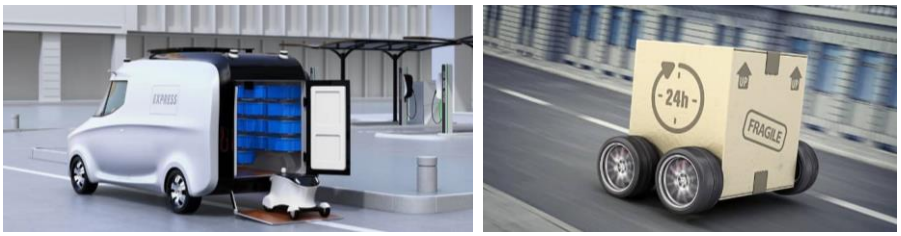


Fig. 1 A visualization of uncrewed road vehicles.

Source: [9]

LAST-MILE CHALLENGES AND SOLUTIONS

Last-mile deliveries are part of the urban ecosystem. That last part of the supply chain is fraught with numerous challenges resulting in street congestion, environmental pollution, and public safety impacts. More than 50 percent of road transport fuel is burned in urban areas in Europe [9]. Last-mile delivery is the most expensive and time-consuming part of the goods transportation process. It accounts for 53 percent of total delivery costs.

In narrow streets of urban centers, only a narrow passage remains for pedestrians, cyclists, wheelchairs, and baby carriages. In addition to the dissatisfaction of passers-by, stress also occurs among drivers of delivery vehicles who must navigate a narrow street and look for free space to stop legally when delivering goods.

Improving the quality of last-mile delivery can be done in many ways that can be both compatible and mutually opposed. What is indisputable is that we should strive to group shipments in specialized city centers and load as many packages as possible into each truck used. It is necessary to develop freight corridors and carefully locate distribution centers.

That can contradict the current organization of life in cities, so it is often necessary to look for compromise solutions. They might be a consequence of political decisions. For example, one of the main tasks of the city governments is to reconcile the conflicting interests of companies and citizens in regulating how motor cargo vehicles are allowed to operate in cities. Local governments can limit the types of fuel used, the vehicle sizes, and the time of use in certain zones and streets. Some cities impose a delivery fee to discourage deliveries at other times.

Smart cities identified the necessity for a sustainable last-mile delivery system combined with innovative solutions, for example, a smart-locker logistics system. The system consists of delivery lockers combined with sustainable transportation of shipments to pick-up points. [10] Several cities like Madrid, Belgrade, and Moscow have already implemented the pilot programs. An assessment of the economic, social, and environmental impacts and urban mobility challenges in long-term integration in smart cities must follow the idea implementation. Table 1 presents, listed, some challenges and potential solutions for last-mile delivery systems.

Table 1 Last-mile delivery - Challenges and solutions

The Challenge	The Solution
The rise of e-commerce increases the number of delivery vans in cities and consequently causes more *$C0_2$ emissions and noise pollution*. These issues directly affect citizens' quality of life.	New methods for last-mile delivery, including a smart-locker logistics system that allows cities to reduce the negative impact by aggregating deliveries at lockers.
The cities suffer the effects of the *increase in deliveries* and the last-mile delivery system was identified as one of the city's urban mobility challenges.	Smart lockers can be used combined with any courier and retailer. They allow users to pick up their orders and to order goods and services directly from the locker.
Cities are getting bigger and the problem of *organizing last-mile delivery* is becoming more and more complex.	A selection of the optimal organization of last-mile delivery, hubs' location, and types of means of transport.

Last-mile delivery is followed by the *economic, social, and environmental consequences*.	These issues must be the subject of comprehensive analyses and optimizations.
Congestion of city centers. City centers usually have narrow streets, numerous shops, rare parking spaces, and a large flow of pedestrians.	- Loading more goods and parcels into each truck. - Developing freight corridors to concentrate shipments. - Consolidating loads in specialized urban distribution centers. - Locating shared distribution centers near business districts.
Sustainability	Incentivizing the courier service to electrify its delivery fleet by, among other things, allowing such vehicles to use lanes reserved for buses and taxis.
Late delivery or failure to deliver can result from a lack of control over inventory, inefficiency in fulfilling orders, lack of human and material resources, tracking of shipments in real-time, and unforeseen situations.	On-time delivery, among different solutions, can be improved by increasing the visibility of shipments, automation, optimizing all elements of the distribution process, constant connection with customers, and planning backup solutions.
Costs of vehicles' depreciation, operating materials, park places, and personnel	The optimization of routes, time of delivery, and vehicle utilization.

Source: Authors based on [11] *and the authors' experience*

Delivery is expensive. Based on our research of large retail chains, the delivery of smaller packages to a home address companies charge on average 3 to 7€ (unless the delivery is free, i.e., included in the price of the product). The transportation price depends on many factors, but companies usually do not research the actual costs for a specific case but set the price based on previous experiences and expected total costs. It is not rare that the same price is given for one country, regardless of the recipient's location. That should not be surprising when we know that last-mile delivery costs are the highest and similar in most of the territory.

LAST-MILE DELIVERY INNOVATIVE MODELS

Last-mile delivery requires innovative solutions as they can significantly contribute to the success of sustainable urban economies, reducing traffic congestion and improving public health through reducing emissions. The innovative solutions can also make cities safer for pedestrians, cyclists, and public transport passengers. From an economic point of view, such solutions can contribute to improved service quality, lower costs, and increased efficiency of delivery service providers.

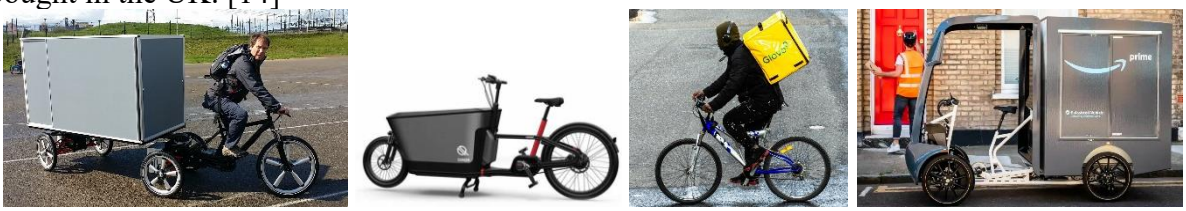
In addition to innovations in delivery vehicles, the design of advanced algorithms and analytics can improve last-mile delivery. Improvements can be achieved primarily through integrated inventory management, dynamic routing, courier collaboration, and delivery proofing tools. Also, innovative approaches include new logistics models, flexible delivery offers, social delivery services, and parcel lockers.

In Europe, in addition to the C-LIEGE initiative, which deals with examples of good practice in urban freight transport (UFT), there are several EU-sponsored programs to support last-mile delivery practices, e.g., CIVITAS, BESTFACT, ENCLOSE, and FREVUE [9]. There are similar programs in the USA, e.g., the PierPASS OffPeak program released in 2005 to reduce cargo-related congestion on streets and highways around the Los Angeles and Long Beach ports [12].

Innovations in short-distance delivery represent a significant opportunity for smart cities. Many deliveries are at distances of less than five kilometers from the hub. According to research by Tecnico Lisboa, even in 2013, at least 25 percent of those deliveries were suitable for delivery by non-motorized vehicles [13]. Human-powered, robotic, and semi-autonomous vehicles can play a significant role in transporting small shipments. That would also reduce the number of vans and trucks on the streets.

Cargo bikes

One of the alternative solutions suitable in city centers is the cargo bike. Cargo bikes, manual or electrical, are more environmentally friendly than motor vans. They are common in pizza delivery but also can be good for small parcel delivery. Amazon announced its intention to use bikes to replace deliveries by vans in London. In 2020, close to 2000 cargo bikes were bought in the UK. [14]



a) *b)* *c)* *d)*

Fig. 2 Some examples of cargo bikes

Source: [15], [16], [17], [18]

Bikes can reach places inaccessible by cars without worrying about parking spaces. They can be classic, adapted for more demanding operating conditions, but also specially constructed for transporting some cargo. Figure 2 shows different versions of the bikes.

The Amazon vehicle shown in Figure 2.d can also transport larger packages. And other carriers, such as DHL and the United States Postal Service (USPS), are experimenting with the same idea and similar solutions. These are (mostly) tricycles powered by Bosch's Cargo Line e-bike drive systems, which can provide 85Nm of torque [18]. The cargo boxes can have a volume of $2m^3$ and require a reinforced braking system to stop the vehicle safely. These are well-known, slightly modernized rickshaws that transport cargo instead of people. UPS is testing Fernhay's quadricycle, eQuad. The eQuad is supposed to take over deliveries when the large vehicles cannot approach the delivery location and when large vehicles can be inefficient. The eQuad is a modernized, urban version of an electric vehicle used in work at airports, railway stations, or internal transport.

Their commonality is that they run at speeds up to 25 km/h, which can be considered satisfactory in city conditions. In the case of two-wheelers, the main bike limitations are a limited carrying capacity, the necessity for drivers' good fitness (even in the case of electric bikes), and the safety of drivers who drive regardless of weather conditions. Cyclists are a very vulnerable category of road users. In Serbia alone, in the first half of 2023, 23 cyclists were killed, and more than 400 were injured. In the EU, almost 2000 cyclists yearly have died on average, in the last ten years [19].

Cargo bikes need replenishment with parcels several times a day. Bike drivers can adapt to current needs and pick up shipments from different depots, including mobile trailers. In that case, motor vans can replenish mobile depots, and bikes will deliver shipments to clients. That can significantly contribute to the optimization of the delivery.

Parcel lockers

Last-mile delivery is demanding in every way. Plenty of small shipments and frequent stops by the delivery person affect the efficiency of delivery, the time spent, and the delivery cost. The possible failure of delivery on the first attempt aggravated the situation. In such cases, the delivery price, on average, reaches $17.20 per order. [20] Considering that such cases occur in about 8% of deliveries, costs are significant. Parcel lockers have appeared as a solution to such problems. They can be placed in convenient places, e.g., in shopping centers or stores. The delivery person leaves the parcels in the locker compartments, and the recipient collects them at a time convenient for him in the same way as he does with letters from the postal box. The crucial difference is in the way the box opens. Now, he does not use a mechanical key but a mobile application. Research has shown that this delivery method is significantly cheaper for the transporter than home delivery. The bottom line is that part of the cost, time, and distance

traveled was passed on to the client by the carrier. Research by Schnieder, Hinde, and West [21] showed that with parcel lockers, carbon emissions are at 5% of the emissions that would occur with home delivery. Once more, the fact is that most of the activities now involve clients. Their influence is not in this calculation. Also, instead of one delivery person who would deliver parcels to 20 addresses, now 20 people come to one place to pick up their parcels. Due to a possible failure of the mechanism of one mailbox, the delivery may fail in all remaining mailboxes. Here, the benefit of such solutions is for the deliverers, although sometimes it can be favorable for the recipient of the shipment as well.

Delivery drones

Unmanned aerial vehicles (UAV), drones, originally developed for military purposes, have shown their potential and become a topic in logistics as well. They develop continuously and take different forms. Figure 3 presents some of the drone models. Given their limitations in range and capacity, drones can be, almost exclusively, used in last-mile delivery. Their main advantage is that they do not use roads and do not create congestion in road traffic. When we analyze the possibilities of using drones for nonmilitary purposes, we can see that the applications are related to the transportation of:

- food (Wing, Flytrex, and Zing),
- medical preparations (Zipline, United Parcel Service, Matternet, and Elroy Air), and
- packages (Amazon, Wingcopter, and Elroy Air). [22]

Although there are attempts to use drones in cities, for now, it is more realistic to apply them in rural and sparsely populated areas, primarily for security reasons. For the same reasons, the weight of the transported cargo is small. Cargo drones must not transport larger sizes and masses in cities.

Fig. 3 Some examples of UAVs

Sources: [23], [24], [25], & [26]

One of the real risks in the use of drones is the electronic interference of their movement. The current military conflict in Ukraine has shown that it is possible to influence the deviation of a drone from its intended path. If something like that were to happen in cities, the consequences could be extremely unacceptable. In addition, drones are sensitive to strong winds and rain.

Last-mile delivery organization

The problem of organizing last-mile delivery can be said to be more complex than the organization of other phases of the logistics chain. The reasons are the number of shipments and the number of addresses to which they should be delivered. The shipment distribution should be coordinated with available means of transport and available human potential, acceptably and sustainably. The problem becomes more complex with the increase of cities and traffic density. Transporters can achieve Improvements primarily through integrated inventory management, dynamic routing, courier collaboration, delivery proofing tools, and new logistics models. The problem is that all the mentioned factors are variable in time, so it is necessary to apply multi-criteria decision-making (MCDM) methods in conditions of uncertainty. There is no universal recipe for all cities, but each should be considered separately, with its specificities. Simić, Lazarevic, and Dobrodolac made one such analysis for Belgrade and published it in the work [27]. To solve the last-mile delivery mode selection problem, the authors used an

extension of the Weighted Aggregated Sum Product Assessment (WASPAS) method under the picture fuzzy environment. They claim it is highly beneficial to managers who deal with LMD since it can consider neutral/refusal information and efficiently deal with high levels of imprecise, vague, and uncertain information. It is suitable for LMD improvement in urban areas worldwide. Besides, it is applicable to other emerging MCDM problems in an uncertain environment. [27] In the case of Belgrade, the authors found parcel lockers to be the best mode for LMD. The next are cargo bicycles, drones, traditional delivery, autonomous vehicles, and tube transport.

In last-mile delivery, it has been observed that drivers often deviate from planned routes because they think that they know better the road infrastructure, customer availability, and other elements essential to the service they perform. Often, they can be right, and in real-world conditions, the stop sequence chosen by the driver may be more advantageous than the shortest-distance route. In a paper that addressed this problem [28], the authors proposed an attention-based pointing neural network for this prediction task using historical driver delivery path data. They presented an attention mechanism based on an alternative specific neural network to capture pairwise local information for each pair of stops and a new algorithm to generate an iterative sequence that is used after training the model to identify the first route stop that yields the lowest operating cost. They checked the model effectiveness on operational data from Amazon's last-mile delivery operations in the US. The authors claim their method can significantly outperform traditional optimization-based approaches and concurrent machine-learning methods. Compared with the reference models, the proposed model can increase the average prediction accuracy of the first four stations from about 0.229 to 0.312 and reduce the disparity between the predicted and actual routes by about 15%. [28]

In the last-mile delivery, there appeared also new participants, robots. They bring great novelty to the process, new possibilities, and many unknowns. Robots will be diverse and will differ in appearance and capabilities. Many new elements will need to be considered. Therefore, scientists need to develop new process optimization procedures. An article by Simoni, Kutanoglu, & Claudel [29] presents one approach to integrated truck-robot system optimization. The authors applied an adaptive search procedure and dynamic programming for the optimization. They found a similarity between integrated truck-robot systems and truck-drone problems. Robots are much slower than drones but can perform consecutive deliveries. Based on these features, using a specific version of the "Weighted Interval Scheduling Problem," the authors presented a heuristic that identifies solutions based on initial truck tours and corresponding joint robot operations. According to the results, robot-assisted last-mile delivery systems can be efficient if robots work in heavily congested areas and aim to deliver several packages consecutively.

THE LAST-MILE DELIVERY FUTURE

In the future, last-mile delivery will constantly adapt to current needs and provide innovative solutions for new conditions and customer requirements. We expect the integration of new delivery services with disruptive technologies such as drones and autonomous vehicles. Based on the McKinsey study, mobile parcel lockers placed on autonomous ground vehicles (AGVs) will replace the current parcel lockers located in specific locations. The authors also expect to see drones, and small robots (droids). However, the legislation that (maybe) will not allow this form of delivery can slow it down. It is most likely that soon, there will not be a mass of drones flying around the cities and delivering parcels. It is more likely that autonomous vehicles will transport drones to a selected location from where they will carry out their tasks. After the shipment delivery, the drones will return to their carriers, which will return them by road to the hubs. This scenario is, however, more likely in the suburbs of cities and less populated areas than in the inner-city centers. Neuhaus predicts that package delivery could be

to one central place where our robots will pick up shipments and bring them into our homes because we will all have personal robot assistants. However, if that happens, the crowds on the streets will be even bigger than now. Hausmann states that people in China are already talking about tunnels in which shipments will be "shot" to the basements of large apartment buildings, like pneumatic mail. In this way, the last-mile delivery will not be visible on the surface and will not burden the roads. However, here we should consider the necessary investments in the construction of such an alternative network. [30]

We can also expect delivery based on personalized user experience. Retailers and startups have high expectations for this type of service. They believe this approach will provide greater customer satisfaction than a free or same-day delivery service. To achieve this, service providers must have sophisticated data management tools and a wealth of data about each customer. It is quite likely that customers will not be thrilled with this approach when it comes to collecting personal data.

We should not lose sight of the local shops either. The advantage of small shops is that they cover small localities, and traders can know the needs of their customers and their habits. That way, the chance of a delivery attempt being unsuccessful is minimal. Also, small shops can be active participants in last-mile delivery. They have goods in their warehouses and can be a local hub for that commodity. The last-mile carrier would be engaged only when the local store does not have the ordered goods. This principle is already represented in trade chains when traders can check the database to determine which of their stores has the desired product and pick it up or refer the customer to that store.

CONCLUSIONS

Based on the previous analyses, we can conclude that recent years have seen significant changes in the needs and behavior of the urban population and the conditions in which citizens live. Cities are exposed to high pressures regarding the influx of new residents and the need to reorganize the lives of their residents. The solution lies in the technological and organizational modernization toward realizing smart cities. One significant factor that needs modernization is last-mile delivery. Existing means of transport will evolve towards sustainability. We expect new, alternative solutions to increase the economy and better use of resources, including robotization. It is not enough to create new technical solutions. It is necessary to find new organizational models, methods, and programs that will include many factors and enable calculations and the selection of the optimal variant efficiently and in real time.

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