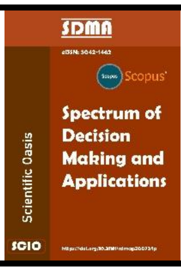
Spectrum of Decision Making and Applications Volume 3, Issue 1 (2026) 412-427

Spectrum of Decision Making and Applications

Journal homepage: www.dmap-journal.org
ISSN: 3042-1462



Intelligent Out-of-Home Delivery Planning in Urban Logistics: A Case Study of Prague

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ARTICLE INFO

Article history:
Received 3 February 2026
Received in revised form 13 June 2026
Accepted 7 September 2026
Available online 12 September 2026

Keywords:
City Logistics; Last-mile Delivery; Internet of Things; E-Commerce; Local Depo; Self-service Machines; Postal Items; Postal Process

ABSTRACT

The rapid growth of e-commerce has increased the demand for efficient and sustainable last-mile delivery solutions, creating challenges related to traffic congestion, delivery costs, and environmental impacts in urban areas. This paper presents an intelligent last-mile delivery model that integrates Internet of Things (IoT) technology with collaboration among delivery companies to improve urban logistics. The proposed concept enables multiple companies to share local urban depots as consolidation and distribution points for final deliveries, while real-time information on depot occupancy and available capacity is collected through sensor networks and cloud-based communication systems to support coordinated resource allocation. The model is further extended to out-of-home delivery through stationary and mobile parcel lockers equipped with IoT sensors for monitoring available capacity and facilitating reservation management. To evaluate current last-mile delivery practices, a survey was conducted among 38 postal and logistics companies operating in Prague and other regions of Czechia. The survey examined the use of local depots, delivery infrastructure, fleet characteristics, smart technologies, and collaboration practices. The findings indicate limited adoption of collaborative delivery concepts and IoT-enabled infrastructure despite considerable opportunities for improvement. The proposed model provides a practical framework for better resource utilization through shared infrastructure and real-time information exchange. Its implementation can reduce redundant vehicle movements, improve delivery coordination, lower operational costs, mitigate traffic congestion, and decrease transport-related emissions, supporting the development of more efficient and sustainable urban logistics systems.

1. Introduction

Urban logistics is becoming increasingly important as cities continue to grow, populations expand, and e-commerce activities rise [1]. As a result, many urban areas are struggling to manage freight

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https://doi.org/10.31181/sdmap41202784

movements efficiently while also dealing with traffic congestion, emissions, and competing land-use demands [2]. In particular, the rapid growth of last-mile deliveries has added significant pressure on existing transport systems and urban infrastructure [3]. Because of these challenges, urban logistics is now widely seen as a crucial part of sustainable city development. This has led to growing interest in more integrated planning approaches and innovative solutions such as consolidation centres, alternative delivery methods, and digital tools for optimisation [4].

Cities all around the globe are facing the increasingly frequent problem of traffic congestion, the lack of parking spaces, and elevated air pollution generated by increased transportation flows [5]. All these issues make life in cities more stressful and difficult while endangering the well-being of citizens. The application of technologies linked to online services brings many advantages. People are buying goods online more frequently, and the volumes of e-commerce have been on the rise [6, 7]. The availability of personal computers, smartphones, and other electronic devices makes online buying and selling products easier and faster. However, there is a big challenge for postal and logistics companies to deliver physically all the products ordered online. This paper deals with the procedures in the last-mile delivery.

Last-mile delivery of goods (parcels) is considered the final phase in the delivery process. This phase connects the e-retailers with the consumers through the postal and logistics service providers. Most consumers who order items online demand professional, fast, and reliable delivery to their addresses [8]. Due to the increasing number of delivery vehicles in operation within cities, and therefore significantly contributing to traffic congestion and air pollution, cities are searching for sustainable city logistics strategies while implementing sustainable urban logistics plans (SULPs). This development leads to the pressure under which city authorities and delivery companies try to optimize the last-mile delivery process in compliance with the social, environmental, and economic domains of sustainability. A specific challenge of successful functioning is related to the designated postal operator that must cover the complete country-level territory with a designated scope of postal services, fulfilling the so-called universal service obligation [9]. One option to cover urban ares in terms of the delivery is using parcel lockers since the parcel lockers eliminate the risk of a return trip when customers are not at home [10].

As a solution, in this paper, we propose a last-mile delivery concept based on collaboration between the delivery companies. A need for collaboration is evident.

This research is driven by the need to make urban last-mile delivery more efficient, affordable, and environmentally friendly. It explores how IoT technologies and collaboration among delivery companies can help reduce congestion, lower costs, improve resource use, and cut transport emissions. It is common for the vehicles of different delivery companies to meet at the same place or street at the same time, resulting in inefficient last-mile delivery in terms of parking and vehicle capacity usage. Our concept implies the existence of local depots that would serve as the preparation points for last-mile deliveries located close to the customers. Coming from previous experiences in practice, these depots offer numerous advantages, such as the possibility of using small zero-emission vehicles and machines, such as cargo bikes, scooters, droids, drones, etc. [11]. However, to optimize the use of depots, a regulatory body such as a relevant city or municipal authority shall engage in the concept of collaboration. Further, its management should be based on collected data on last-mile delivery infrastructure and available capacities in real-time. This should be achieved by using a network of sensors and by implementing the current technologies with emphasis on the Internet of Things (IoT) concept. According to Qian *et al.,* [12], the IoT technology connects everything together on the Internet by using appropriate protocols for information exchange, achieving intelligent recognition, location, tracking, monitoring, and management. We explain the proposed concept further in the paper.

To examine the current state in one of the European cities, we designed a questionnaire aimed mainly at postal and logistics companies (and e-retailers) in Czechia, and we subsequently interviewed 38 companies that were willing to participate in the survey and operate in Prague. The results indicate that there is a space for improving the concept of out-of-home delivery in the city, first by introducing the proposed new concept.

Based on the above mentioned, the main research question of this study is: How can IoT-enabled collaboration among logistics companies, supported by shared urban depots and real-time data, improve the efficiency and sustainability of last-mile delivery in urban areas? The next sections will give the answer to the question.

This paper is organized as follows. In the second section, a review of state-of-the-art literature on the use of IoT in the context of last-mile delivery and on interviews and questionnaires in transport and logistics is offered. In Section 3, we explain the newly proposed last-mile delivery concept based on collaboration and IoT technology in detail. A case of the City of Prague is explained in Section 4, including the results of the conducted survey. Finally, in Section 5, we discuss possible improvements in the concrete case. In the Conclusion, there are some final comments, limitations, and potential directions for future research.

2. Literature Review

The literature review is organized into two subsections. Subsection 2.1 presents the literature review based on the IoT in the context of last-mile delivery. Subsection 2.2 deals with the literature based on the interviews and questionnaires in the research fields of transport and logistics.

2.1 Literature review based on the Internet of Things in the context of Last-Mile Delivery

The last-mile delivery process represents one of the vital issues in city logistics. Due to the rapid expansion of e-commerce and the internet connection that is becoming widely affordable, there are a lot of new opportunities in organizing the last-mile delivery process. Therefore, IoT development has considerably affected the final phase of the delivery process. Rey *et al.,* [13] emphasized that the IoT consists exclusively of smart sensors and other devices. There are many research studies considering the IoT and its connection with the last-mile delivery process. For instance, Ding *et al.,* [14] proposed an overview of the literature regarding smart logistics based on IoT technology. The overview was conducted between 2008 and 2019 and considered smart freight transportation, warehousing, and delivery. Chen *et al.,* [15] considered the IoT drone system for last-mile delivery. Wang *et al.,* [16] analyzed the parcel delivery solutions in cities, using autonomous vehicles managed through the IoT. Markovic *et al.,* [17] coupled the IoT, provenance, and blockchain to monitor the last-mile delivery of food to enhance security. Tang *et al.,* [18] examined customer satisfaction with the IoT-based smart parcel lockers to enhance the quality of service in China. De Araujo and Etemad [19] predicted the last-mile parcel delivery time in the Toronto area using the IoT. Hou *et al.,* [20] proposed a library material delivery system based on the IoT. Khosravi *et al.,* [21] considered a multi-purpose drone for delivery. Rey *et al.,* [13] evaluated the factors affecting a company's adoption of the IoT in the transport and logistics industry. Levina *et al.,* [22] discussed the role of IoT services in intelligent transport systems (ITS) in St. Petersburg. Hiari *et al.,* [23] proposed the IoT-based virtual addressing framework for efficient tracking, monitoring, and managing of package deliveries. A summarized review of literature on the Internet of Things in last-mile delivery is offered in Table 1.

Table 1
Summarized review on the Internet of Things in last-mile delivery

Research	Focus
Hiari *et al.,* [23]	Internet of Things-based virtual addressing framework for tracking, monitoring, and managing package deliveries
Levina *et al.,* [22]	Internet of Things services in intelligent transport systems in Petersburg
Khosravi *et al.,* [21]	Multi-purpose drone for package delivery
Hou *et al.,* [20]	Material delivery system based on the Internet of Things and the role of libraries
De Araujo and Etemad [19]	Internet of Things-based prediction of last-mile delivery time in the Toronto Area
Tang *et al.,* [18]	Customer satisfaction with the Internet of Things-based smart parcel lockers in China
Markovic *et al.,* [17]	Monitoring the last-mile delivery of food to enhance security
Wang *et al.,* [16]	Parcel delivery solutions in cities using smart vehicles based on the Internet of Things
Chen *et al.,* [15]	Drone system for last-mile delivery based on the Internet of Things
Ding *et al.,* [14]	Smart logistics based on the Internet of Things technology - review
Rey *et al.,* [13]	Company's adoption of the Internet of Things (IoT) in the transport and logistics industry

2.2 Literature review based on interviews and questionnaires in transport and logistics

Numerous studies refer to using interviews and questionnaires in logistics and transport. For instance, Gorman and Kanet [24] conducted a survey-based evaluation of logistics and transportation research journal quality. They addressed two of the key questions in their survey: familiarity with the exact journal and the perceived journal's quality. Boysen *et al.,* [25] surveyed various last-mile delivery concepts through the lens of operational research. Eryuruk *et al.,* [26] compared the logistics and clothing sectors for a logistics center site selection in Turkey. They utilized the Analytic Hierarchy Process (AHP) method to evaluate the questionnaire results. Simões *et al.,* [27] surveyed the reverse logistics practices in Portugal. The results show that the companies mostly adopt the reverse logistics approach to improve customer satisfaction and reduce logistics costs. Chang *et al.,* [28] designed a fuzzy DEMATEL questionnaire to develop criteria for supplier selection. The seventeen professional purchasing personnel in the electronics industry participated in the survey. Combes and Laurent [29] collaborated on improving roadside surveys for a better knowledge of road freight transport. They emphasized that roadside freight surveys were one of the major types of service used for the monitoring of road freight transport. Mathong *et al.,* [30] used the questionnaire to assess the quality of service (QoS) for third-party logistics (3PL) providers in the beverage industry. Six experts participated in the QoS evaluation process. Revindran *et al.,* [31] assessed the logistics service quality amongst online shoppers in Kuala Lumpur. Davidavičienė and Majzoub [32] utilized the questionnaire to evaluate the performance of reverse logistics in e-commerce in Lebanon and Syria. Zhang and Li [33] applied the questionnaire to investigate the customer preferences for logistics services within the online retailing of fresh products in Sweden. Rajendran *et al.,* [34] investigated how logistics services shape e-shoppers' satisfaction. They applied the structured questionnaire to obtain the data. A summarized review of the literature on the interviews and questionnaires in transport and logistics is shown in Table 2.

The literature shows that Internet of Things (IoT) technologies are playing an increasingly important role in improving last-mile delivery, especially by enhancing tracking, efficiency, and overall service quality through solutions such as smart logistics systems, drones, and connected delivery platforms. At the same time, research based on interviews and questionnaires continues to provide valuable insights into real-world logistics and transport issues, particularly in areas such as service quality, customer satisfaction, and operational decision-making. Taken together, these studies offer a balanced view of the field, combining technological developments with practical, data-driven perspectives from industry and users.

Table 2
Review based on interviews and questionnaires in logistics

Research	Focus
Rajendran *et al.,* [34]	Logistics services and their impact on e-shoppers' satisfaction
Zhang and Li [33]	Customer preferences assessment for logistics services within online retailing of fresh products
Davidavičienė and Majzoub [32]	Reverse logistics performance evaluation of e-commerce in Lebanon
Revindran *et al.,* [31]	Logistics service quality assessment of online shoppers
Mathong *et al.,* [30]	QoS assessment in 3PL
Combes and Laurent [29]	Roadside survey improvement
Chang *et al.,* [28]	Criteria development for supplier selection
Simões *et al.,* [27]	Reverse Logistics (RL) Practices in Portugal
Eryuruk *et al.,* [26]	Logistics center site selection in Turkey
Boysen *et al.,* [25]	The application of operational research methods in the last-mile delivery
Gorman and Kanet [24]	Evaluation of logistics and transportation research journal quality

3. Methods

The main topic of this paper relates to the improvement of the postal and logistics process, considering, first of all, the final phase – last-mile delivery. This can be achieved in various segments, such as the transportation management system (TMS), human resource management, market adjustments, service management, business policy, and physical and IT resource management [35]. We propose an improvement that incorporates service management, business policy, and physical and IT resource management. This solution is based on intelligent last-mile delivery planning and infrastructure monitoring. The issue of planning relates to two segments:

- Implementation of smart technologies, such as IoT, and
- Choosing the corresponding concept of last-mile delivery.

The main applications of IoT technology in the field of postal services can be structured as follows [36]:

- Transportation and logistics applications,
- Smarter postal buildings,
- Enhanced mail and parcel services,
- Neighborhood services.

Transportation and logistics applications imply the use of sensors and connectivity on vehicles to track vehicle movements and their condition. Examples of these applications relate to the monitoring of fuel levels, brake condition, tire pressure, engine performance, and maintenance requirements.

In smarter postal buildings, a network of sensors should be installed to assess the temperature, the condition of heating and ventilation systems, and the movement of employees through the building. This would bring lower maintenance costs, optimized energy usage, and increased security and safety. Considering the mail processing centers, IoT technology can be used to track postal items or processing equipment, in this way providing better visibility of asset utilization.

Smart technologies are used to improve the core business of postal and logistics operators. Sensors can add value to the postal service for senders and make a better delivery experience for the recipient. The main benefits imply enhanced postal item tracking experience, adjusting to last-mile delivery preferences, and enabling the creation of new value-added services.

Neighborhood services are based on the fact that postal vehicles and employees are present in the same neighborhoods every day. By using IoT technology, a platform can be provided to support the collection of data and the provision of both postal and government services to local communities.

In this paper, we propose the last-mile delivery concept that would imply the two previously mentioned categories of IoT implementation: Transportation and logistics applications, and Enhanced mail and parcel services. Our concept is centered on collaboration in last-mile activities.

Such a center is placed on the borders of cities in suburban areas. It is common that the vehicles of different carriers use the same routes at the same time. These dynamics contribute to the inefficient utilization of vehicles, increased traffic congestion, and air pollution [37].

A last-mile delivery concept that would bring improvements to many fields is based on the collaboration of various carriers working in a certain area and the coordination of last-mile activities. Sensor-based data on vehicles' location, space availabilities, and traffic conditions must be analyzed in real-time to examine for each postal item which vehicle would perform last-mile delivery most efficiently [38]. In addition, our concept implies the introduction of lower-capacity hubs all over a city, which we titled local depots. Different postal and logistics companies could use such a depot. The function of the local depot would be the preparation of postal items for final delivery to the destinations [39]. This type of processing center is closer to customers. Consequently, in comparison with the traditional concept, transport means of lower capacity and environmentally friendly could be employed, such as cargo bikes or droids [40], which is particularly convenient in the case of plain terrain.

Since more companies would utilize the same infrastructure, a local depot, an appropriate technology should be introduced to support successful cooperation. We propose a solution based on the IoT technology in this paper with its visualization in Figure 1. A starting point for all deliveries in a city or certain area would be the Sorting Center (SC) owned or managed by a postal or logistics company. From the SC, the postal items should be transferred to the local depot (LD). According to the proposed concept, a city authority should own the LD and would rent it to all interested delivery companies. However, the capacity of LD is limited, and the resources used need to be carefully planned and monitored. For this purpose, the sensors should be installed to monitor the presence of vehicles and shipments in real time. This approach would provide information about the available capacity of a specific LD. When a delivery company demands space in the LD through the cloud server, it should be approved and reserved.

Another concept of collaboration implies the use of Parcel Lockers (PL) for the final delivery of postal items to customers. The PL is also known as a self-service machine, postomate, or self-pickup cabinet. It is composed of storage terminals and an intelligent system, providing remote monitoring of functioning. The company delivers the postal item, and the recipient self-picks it with an appropriate code, usually received by a mobile phone. The mobile application can also be used for opening the lockers via Bluetooth or bar-code scanning [18]. The smart parcel lockers are usually equipped with a touch screen, QR code scanner, camera monitoring, GPS, 3D connectivity, weight capture, face detection approach, and a module for multiple ways of payment [36, 41, 42]. Besides the mentioned possibilities offered by PL, the recipient can track the locations of the shipment and pick it up whenever best suits their needs. Accordingly, this out-of-home delivery concept is often well accepted by customers [18, 43].

In this paper, we propose a collaboration concept in using PL supported by IoT technology. We show the concept in Figure 2. It follows technologically the previously explained concept in Figure 1. The postal items prepared for last-mile delivery in local depo should be partially delivered at the recipients' home or business addresses and partially to the PL, according to customers' preferences and choice. As in the case of LD occupation, the resources in PL should be also reserved via a cloud server. Since the couriers engaged in LD are often in the street performing other delivery tasks, it is very convenient to include the possibility of mobile applications and their usage in the process of demand or approvals of PL use.

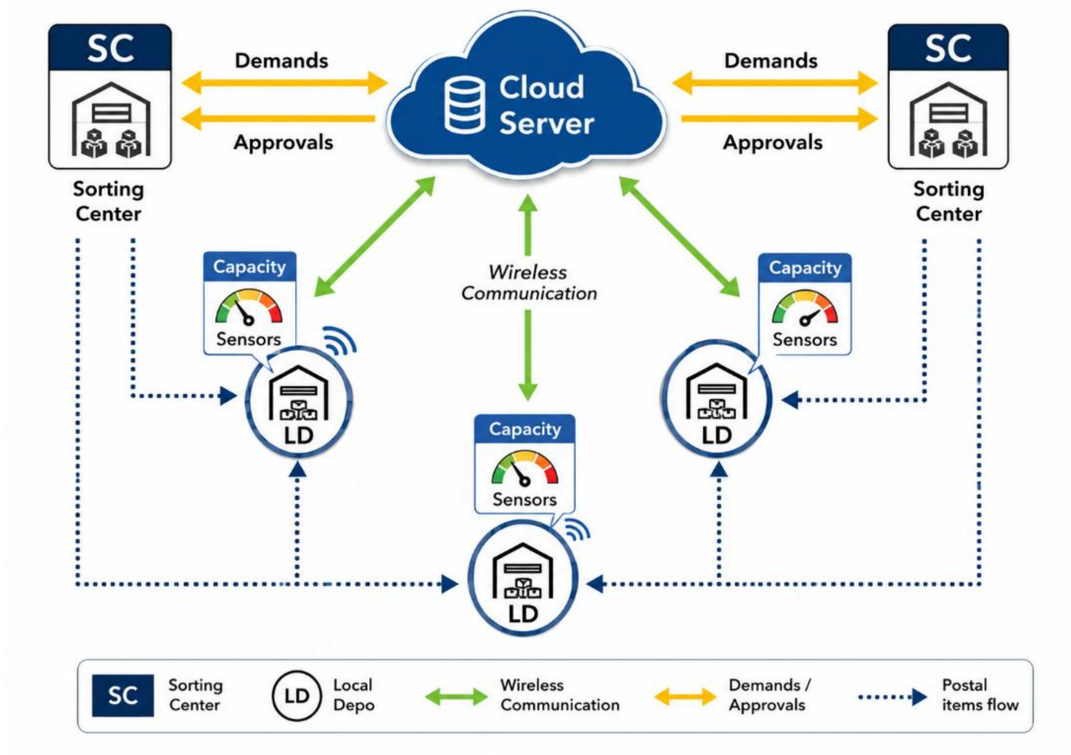

Fig. 1. A collaboration concept in out-of-home delivery supported by IoT technology

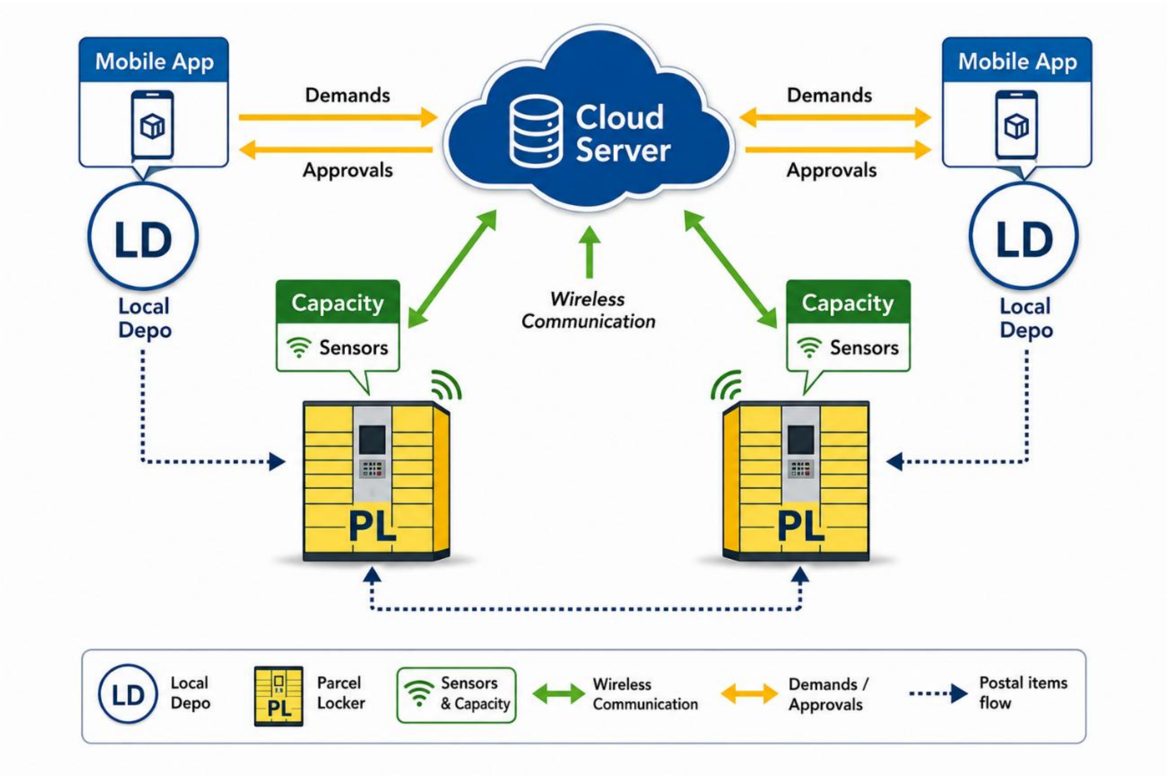

Fig. 2. A collaboration concept in using parcel lockers supported by IoT technology

In this methodology section, we should note that we use the questionnaire designed by the authors to make conclusions about the current state of the last-mile delivery process and to provide guidelines for possible improvements. The questionnaire is structured to interview the delivery companies. We explain it in the next section.

4. Case of Prague

Prague is the capital of the Czech Republic. It is the largest city in the country with a population of around 1.3 million people. The city is characterized by a continental climate, with significant annual variations in temperature, i.e., relatively hot summers and cold winters.

Prague is one of the most significant political, cultural, and economic centers in Central and Eastern Europe. The city has a very rich history. It was a residence of several Emperors of the Romans, the most famous Charles IV in the 14th century. The city center has been included in the UNESCO list of World Heritage Sites since 1992. The City of Prague is also well known for its education system, and Charles University is the oldest university in Central Europe.

Transportation volumes in Prague are on the rise, as well as in the whole Czech Republic. Considering the courier, express, and parcel market volumes in the country, the increase from 88.2 million postal items in the year 2012 to 226.6 million in 2020 can be noticed [44]. This is exactly an indicator that appropriate strategic issues in city logistics should be designed to reduce the negative effects of freight transportation.

To collect more detailed data on this topic, we carried out a survey interviewing 38 postal and logistics providers operating in Prague, and broader on the national or international level. One of the most important questions relates to the existence of local depots in the functioning of the companies. The results presented in Figure 3 illustrate that the interviewed companies do not use mostly IoT technologies in their business process. Even 25 companies did not use the local depot for their last-mile deliveries, while the number of depots of other delivery companies is relatively small.

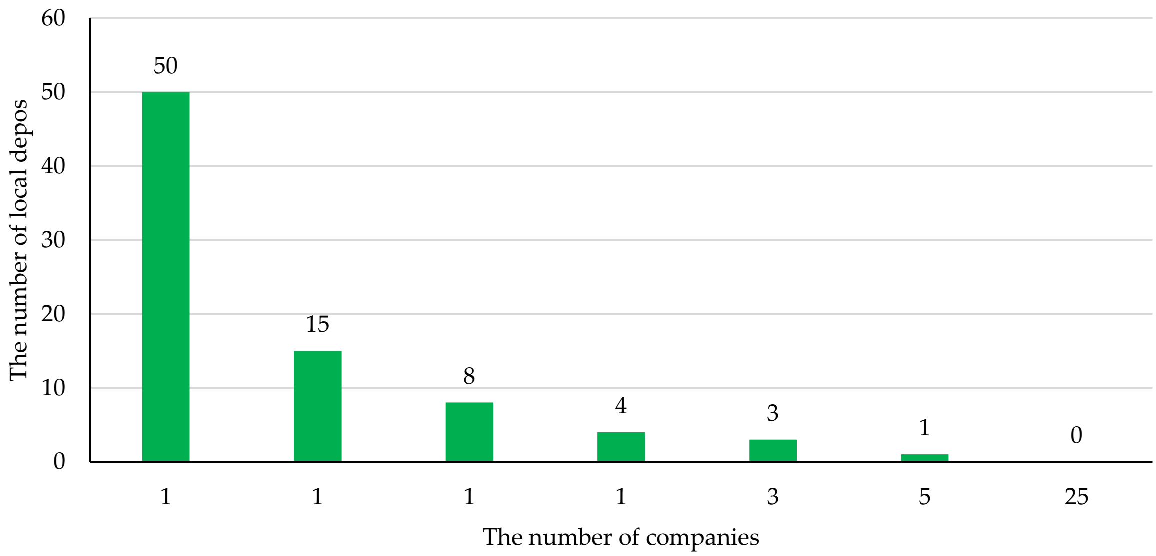

Fig. 3. An answer to the question “How many local depots do you operate?”

We asked all companies about their motives to select existing or potential locations for their depot. The results are shown in Table 3. We provided the option of multiple answers. Therefore, the sum of percentages is higher than 100%.

Table 3
A motivation for companies regarding local depot location

A motive	Percentage of positive answers
Tax cuts	8.33%
Labor force availability	58.33%
Distances to final customers	75.00%
Road network and other infrastructure	100.00%
Future flexibility	66.67%
Want to be inside a low-emission zone	16.67%
Want to be outside a low-emission zone	16.67%
Storage capacity of the depot	58.33%
Public image and brand development	8.33%
Real estate prices	50.00%

The road network and other infrastructure are the crucial factors for local depot introduction and location planning. The second most popular motive is the distance to final customers. Further, other important factors relate to future flexibility, labor force availability, the storage capacity of the depot, and real estate prices.

To examine the presence of new technologies in the city logistics in Prague, we asked the companies about the planning process of last-mile delivery when considering the factor of actual traffic in the city. Just 27.27% of companies always take care of this issue, while 33.33% never consider it (Figure 4). This is an indicator that there is a space for significant improvements in the use of sensors, IoT technology, and other new technologies for monitoring the real-time conditions in traffic. This would lead to savings on delivery deadlines, as well as in the costs of transportation.

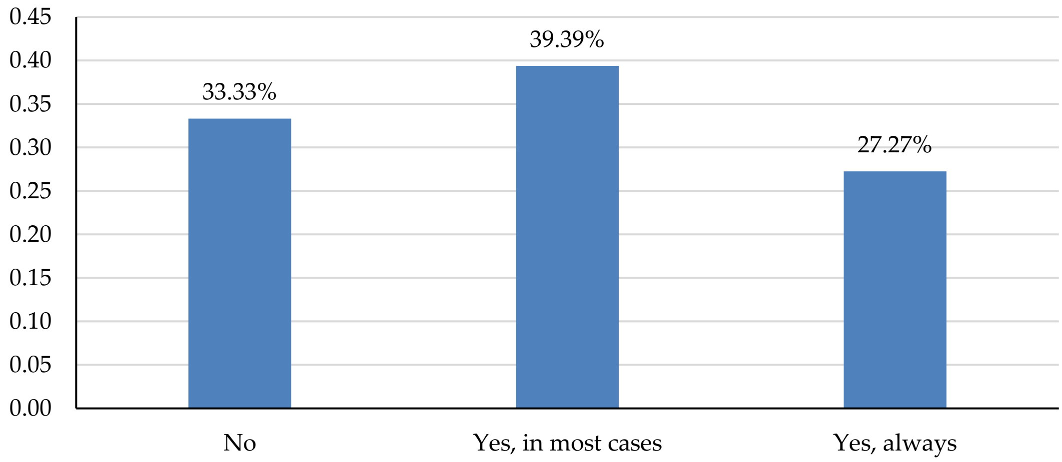

Fig. 4. An answer to the question “When you plan out your last-mile delivery, do you take into account the factor of actual traffic?”

Since the new concept of last-mile delivery proposed in this paper implies the collaboration of different logistics companies and city authorities' ownership of certain logistics infrastructure, we asked the companies about their current preferences regarding infrastructure ownership. In our analysis, we divided the companies into four groups: micro-enterprise, small business, medium enterprise, and large enterprise. The distribution of answers considering preference for depot and pick-up-point ownership is shown in Table 4. We can see that the majority of responses related to depot ownership are in the category of rather rental (26.32%) or always rental (36.84%), which represents a good basis for the introduction of the newly proposed concept. It is interesting that even for large companies, for whom it is supposed that it is easier to invest in the infrastructure, it is most acceptable to rent the depots.

Table 4
Preferences regarding logistics infrastructure ownership

Preference for depot ownership	Size of the delivery company				Total
	Micro enterprise	Small business	Medium enterprise	Large enterprise	
Always rental	13.16%	5.26%	2.63%	15.79%	36.84%
Rather rental	0.00%	13.16%	5.26%	7.89%	26.32%
Both options in the same proportion	0.00%	0.00%	7.89%	15.79%	23.69%
Rather ownership	0.00%	0.00%	0.00%	7.89%	7.89%
Always ownership	2.63%	0.00%	0.00%	2.63%	5.26%
Pick-up-points or click-and-collect points					
Yes, our own network	5.26%	2.63%	5.26%	10.53%	23.68%
Yes, externally operated	0.00%	2.63%	0.00%	10.53%	13.16%
Yes, both externally operated and our own network	0.00%	0.00%	2.63%	18.42%	21.05%
No	10.53%	13.16%	7.89%	10.53%	42.11%

The pick-up or click-and-collect points refer to the service that allows recipients to collect their packages at a parcel collection point close to their home. It is a hybrid e-commerce model in which people purchase items online and pick them up in-store or at a centralized collection point. This concept is known in the postal and logistics industry as out-of-home delivery and includes the use of self-service machines, such as parcel lockers. From Table 4, it can be seen that the externally operated concept of this infrastructure is also significantly present; however, more than 42% of companies do not use it yet.

Further, the companies commented on the most common places of last-mile delivery (Table 5). With the possibility of multiple answers, the companies confirmed that delivery to the home or business address is still a dominant way of last-mile delivery. However, alternative modes of last-mile delivery are also more and more popular (Figure 5).

Table 5
Usual places of last-mile delivery

Usual place	Percentage of positive answers
Home	81.25%
Workplace	87.50%
Concierge (or doorman)	43.75%
Neighbours	6.25%
Pick-up point	50.00%
Depot (or warehouse)	21.88%
Parcel locker (or automatic deposit box)	25.00%
Post office	15.63%

To assess the environmental impact of last-mile delivery activities, it is useful to consider the structure of the operating company's fleet. Based on Figure 6, we can identify that large capacity vans are mostly used in Prague, which may be considered as badly for environmental sustainability. The reason is that these vans mostly use diesel engines. This is further confirmed in Table 6, where the diesel type of engine is dominantly used by postal and logistics companies.

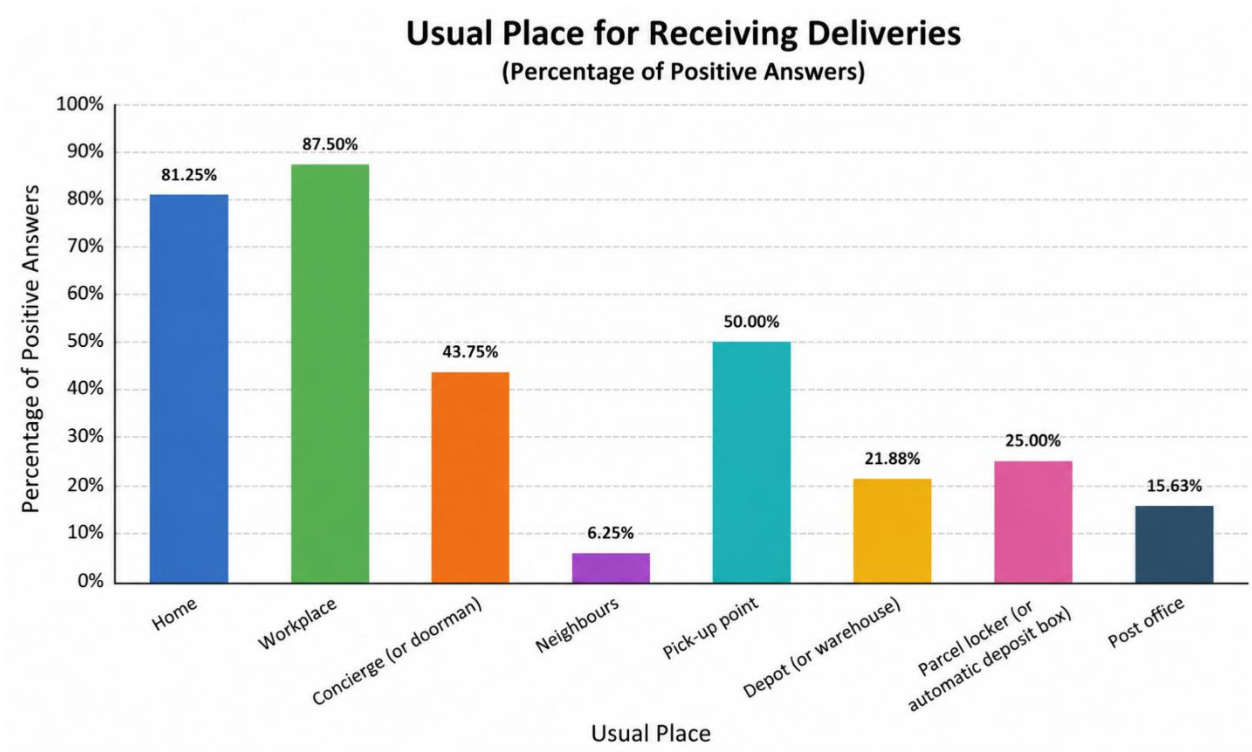

Fig. 5. Usual places for receiving deliveries

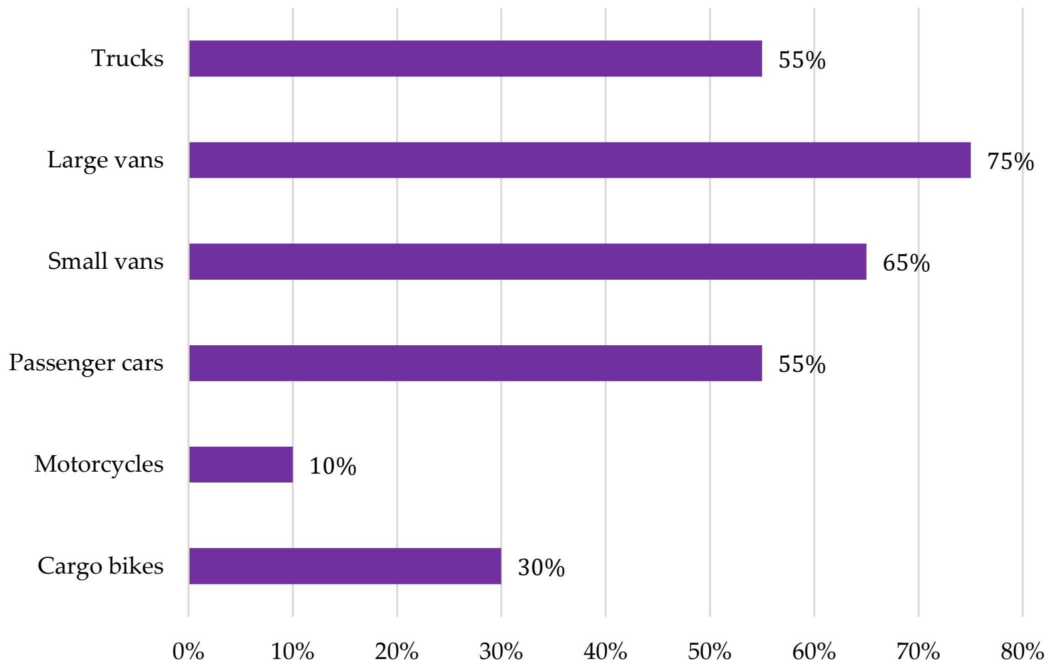

Fig. 6. An answer to the question "What is the structure of the company fleet?"

In the competitive logistics market, companies intend to provide added-value services. Some types of these services are related to preferred-time delivery. The current situation in Prague is shown in Figure 7. Most operators offer the possibility of delivery in a one-hour time slot. However, since the implementation of a parcel locker provides 24-hour a day service availability, this is certainly a very convenient option for customers.

Table 6
Types of engines used for last-mile delivery

Types of engines	Types of engines used in the fleet	Approximate share of the engine types
Diesel/Petrol engines	90%	69.67%
Hybrid engines	15%	6.97%
Electric engines	20%	3.69%
Autogas, CNG	20%	19.67%

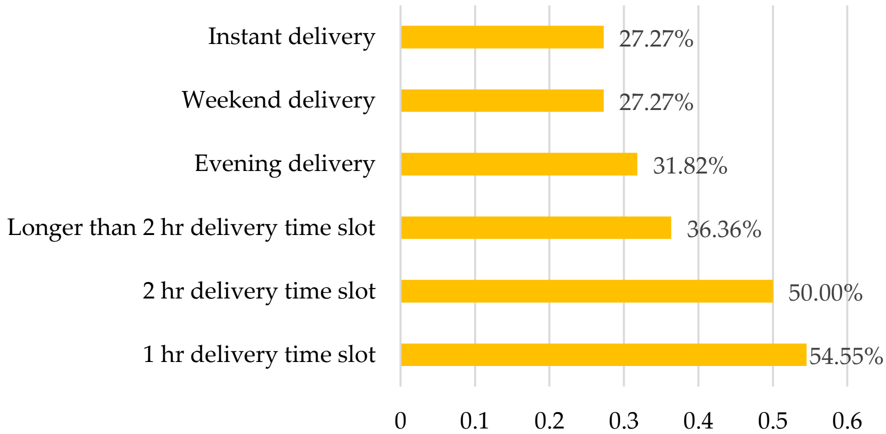

Fig. 7. An answer to the question "Do you provide your customers with an option of preferred time delivery?"

Finally, the issue of collaboration in city logistics is crucial for the sustainable last-mile delivery process. By analyzing the results we can conclude that the companies do not rely on collaboration even though it can bring benefits to all stakeholders. Accordingly, this should serve as a warning to the city authorities. They shall motivate the companies to participate in the collaboration activities, such as the collaboration model that we proposed in the paper.

5. Discussion

The results of our survey indicate a very low use of depots that are close to the final destinations of delivery in Prague. In addition, these depots are used independently, without any collaboration between the delivery companies. Furthermore, the use of communication technologies based on sensors, IoT, etc., is still at a relatively low level. The proposed new concept of last-mile delivery would improve the current situation significantly within the environmental, social, and economic dimensions of sustainable development.

Considering the topographic characteristics of the city, one additional option would bring even more benefits. It relates to the use of the river Vltava for the transportation of postal items and for supplying the parcel lockers, as illustrated in Figure 8. The parcel lockers would be installed close to the river banks, easily filled with shipments. The customers would pick up their items whenever it is most convenient for them. Such a concept would bring significant managerial implications in this industry. As a benefit, it would probably reduce the traffic congestion in the city even more than the original proposal, as well as the air and noise pollution.

The applicability of the proposed model is illustrated in the case of Prague. However, this concept is general and can be implemented in many other cases. Those city authorities aiming to implement SULPs would certainly be interested in the implementation of such a concept.

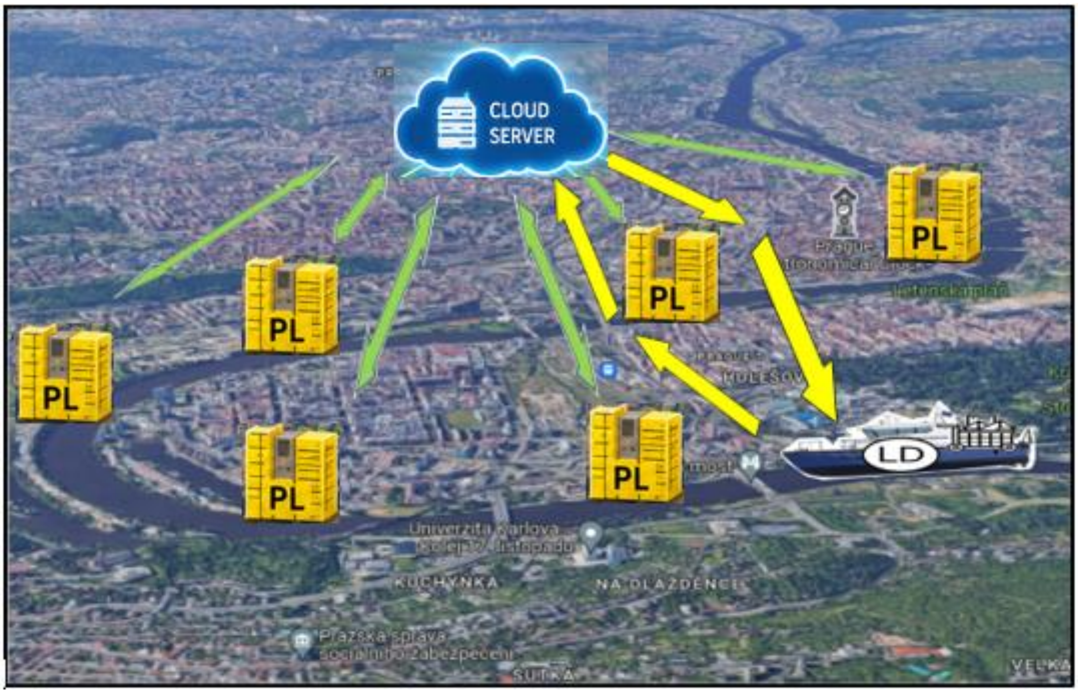

Fig. 8. A collaboration concept supported by IoT technology in the case of Prague

Further, the delivery companies would benefit from the proposed concept as well. The companies would outsource the last-mile delivery activities, and they should expect lower costs for individual delivery of the postal item. The companies, which would participate in the last-mile delivery, can do the job through the city authority's management. In this way, the capacity of last-mile delivery vehicles would be utilized better and their routing more efficiently optimized, reducing costs for all stakeholders. Since the number of delivery vehicles in the streets would be lower, it would bring environmental and social benefits to the whole society.

6. Conclusions

In this paper, we propose an intelligent last-mile delivery concept that implies collaboration between delivery companies and infrastructure monitoring, using sensors together with well-established as well as emerging information and communication technologies. The key drivers of collaboration are in the use of local depots and parcel lockers. To implement such a concept into the project, it is necessary to install a network of sensors on the mentioned infrastructure to monitor the capacity in real-time. This would help optimize the coordination of pickups, postal items consolidation, and deliveries. The companies should develop collaborative platforms, including mobile applications, to manage last-mile deliveries. One of the key questions, and a major limitation of the proposed concept, would be to determine who the owner of the platform and installed infrastructure should be. We proposed that this subject would be determined by the relevant city authorities. The subject would be responsible for ensuring fairness and business transparency among the collaborative companies. Since the logistics process should be organized and managed from a centralized point, another limitation is related to the privacy and security of the data. Concrete rules should be set to fulfill these criteria.

Considering the future research directions, they could be related to the examination of the transportation modes most suitable for use from local depots to the final destinations. As collaborative technologies, human–machine systems, robots, and self-service technologies continue to develop, greater emphasis should be placed on evaluating the interactions between humans and these technologies within the proposed framework. Another option for further research that we identified is an examination of platforms for organizing and integrating various sensor data. These data can be used to optimize internal processes, but also to further extend existing customer services.

Funding
This work was supported by "Multi-Sector and Interdisciplinary Cooperation in Research and Development of Communication, Information, and Detection Technologies for Control and Signaling Systems (CIDET)" (No.CZ.02.01.01/00/23_021/0008402) and Western Balkans–Visegrad Fellowship No. 62570170.

Acknowledgement
This research was not funded by any grant.

Conflicts of Interest
The authors declare no conflicts of interest.

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