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A Guide to Parcel Lockers in Last Mile Distribution - Highlighting Challenges and Opportunities from an OR Perspective

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Abstract. Current growth in e-commerce and online sales has confronted companies with major logistical challenges arising in the area of last mile distribution. Small order quantities, the urban environment and changing consumer behaviour require companies to adapt logistical processes and to invest in more resilient concepts that are able to cope with these new developments. In this context, parcel locker stations provide opportunities for companies to ensure smooth and more efficient delivery to the final customer. As such, locker stations may further contribute to the creation of more sustainable and customer-friendly last mile solutions. In this research, we give an overview of the different concepts for alternative delivery and parcel locker stations that can be found in practice. Based on these concepts, we investigate current challenges and possible decision problems that arise in the context of parcel locker stations, review the related literature and identify potential gaps and future research directions from an OR perspective. With this contribution, we hope to shape a new research agenda of practical relevance and stimulate future research within this promising area.

Keywords: Parcel lockers, alternative delivery, city logistics, last-mile distribution.

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1 Introduction

Composing the final leg in the supply chain, last mile distribution builds an integral link to connect upstream supply chain activities with the final customers. Defined by many and dispersed customer locations, small customer demands and limited customer availability, it is, however, often described as one of the most costly, challenging and inefficient stages in the chain (Gevaers et al., 2009; Zhou et al., 2018). The continuous growth of e-commerce and internet sales has, moreover, led to a significant increase in last mile deliveries, and requires more resilient logistic concepts that are able to overcome the current challenges and mitigate the negative effects. In particular, the rise in traffic congestion and air pollution associated with current last mile distribution, impacting the quality of people's life, is a growing concern in this regard and requires more sustainable and efficient solutions for the future (Savelsbergh and Van Woensel, 2016). Urbanisation, changing consumer behaviour and the continuous transformation of today's cities put further pressure on the last mile and continue to pose new challenges in the future. However, this constant change combined with innovative ideas and technological advances also provides new opportunities to improve existing logistic solutions.

Automated parcel lockers and pick-up stations, where customers can pick up their orders, present an attractive alternative to standard home delivery and provide a more flexible way of organising the last mile, that allows to overcome some of its inherent challenges (Savelsbergh and Van Woensel, 2016). By bundling customer demands and decreasing the number of failed deliveries, pick-up stations are able to increase delivery efficiency and reduce the associated operating costs as well as potential carbon emissions. While pick-up point networks are not uncommon in practice, with many different concepts being adopted in countries all over the world, research on pick-up point networks is still rather limited. This article is therefore meant as an attempt to stimulate more research on the topic and provide a guide to automated pick-up stations that may help to formulate an adequate research agenda. In this context, we intend to review the specific challenges associated with pick-up station networks and discuss opportunities to improve the practical decision making through optimisation approaches. To better understand the existing trends, we start in Section 2 by giving an overview of the general concept and its variations that can be found in practice. In Section 3, we explore possible decision problems and optimisation challenges that occur in the context of automated pick-up networks and highlight potential research directions. Section 4 finalises the paper by providing some concluding remarks on the topic and the proposed research streams.

2 General concept and typology

This section describes the general idea behind customer pick up stations and presents the main concepts, before giving a more detailed overview of the ways in which automated parcel lockers have been implemented in practice.

2.1 General concept: pick up points vs. automated lockers

Acting as an alternative to standard home delivery, the general idea behind customer pick up stations is to provide customers with an alternative location, where orders can be delivered and picked up at the customer's convenience. To provide the customers with the necessary real time information regarding the status of their order, modern pick up station networks rely heavily on integrated IT solutions and web applications, facilitating parcel tracking and customer interaction. The physical setup of pick up stations varies, but can roughly be categorised into the following two concepts: i) customer pick up points and ii) automated lockers. Customer pick up points can be described as staffed collection points, often integrated in local shops and operated during their normal business hours. Automated lockers, in contrast, refer to parcel lockers, from which customers are able to retrieve their orders without staff assistance. These locker boxes are often located in public transport stations, shopping centers and other public areas, but also in busy apartment buildings and office spaces, and may be accessible to customers 24 hours a day.

Table 1 provides a comparison of the different home delivery concepts with regards to a number of distinctive characteristics. The table shows that the indirect delivery concepts provide more flexibility in terms of delivery times, better use of vehicle capacity and almost no failed deliveries in comparison to standard last mile delivery, resulting in low delivery costs. However, at the same time, indirect delivery concepts pose new challenges in terms of the types of deliveries permitted and the limited capacities at the delivery locations. In addition, initial investment costs are often high in order to provide the alternative delivery facilities. Making the comparison between the two indirect delivery concepts, automated lockers provide longer and more flexible operating times, yet are often more restrictive in terms of their capacity and require a higher initial investment.

While the concept of customer pick up points has already been widely adopted in practice, the following focuses mostly on the still emerging concept of automated locker boxes and the different ways in which they have been implemented in practice. Due to the many similarities and overlaps between the two concepts, many of the inherent planning decisions and optimisation problems

Table 1: Comparison of last mile delivery concepts

	Attended delivery	**Pick up points**	**Automated lockers**
Delivery:	Direct	Indirect	Indirect
Customer attendance:	Yes	No	No
Delivery times:	Tight time windows	During opening hours	Any time
Types of deliveries:	All kinds of deliveries	Depending on equipment at the storage facility	Depending on the design of the lockers
Capacity at delivery location:	Unlimited	Limited (Station)	Limited (Station & Locker)
Customer pickup:	-	During opening hours	Any time
Collection time window:	-	Short-Long	Short-Long
Use of vehicle capacity:	Poor	High	High
Number of failed deliveries:	High	Close to none	Close to none
Delivery Cost:	High	Low	Low
Initial investment cost:	Low	Medium-High	High
Uncertainties	Travel times, customer attendance	Travel times, storage times and available capacity	Travel times, storage times and available capacity

described below do, however, also apply to pick up point networks and their logistics operations.

2.2 Automated Lockers: Typology

With parcel lockers providing a new level of flexibility for the distribution of products, more and more players enter the market, resulting in a variety of different business models being implemented in practice. The type of player involved often impacts the design choices and planning behind the locker networks, due to the different needs, resources and objectives of the individual players. In general, one can differentiate between the following two business models: carrier owned parcel locker networks and non-carrier owned parcel locker networks.

Carrier owned parcel lockers

Carrier owned parcel lockers are lockers that belong to the delivery network of postal services and third party logistics providers. Often located close to post offices, train stations and supermarkets, these pick up stations are meant to complement the traditional distribution network of the carriers. Belonging to the network of a specific carrier, these parcel lockers are generally planned, serviced and managed by a single carrier, thus restricting other carriers from using the lockers. Maintenance and IT services on the other hand are often outsourced and not covered by the carrier itself. With many postal services around the world implementing their own parcel locker stations to offer more flexible services to their customers, examples of carrier owned parcel lockers can be found in a variety of countries and include for instance the parcel locker networks of Australia Post (AusPost, 2019), Hong Kong Post (HongkongPost, 2019), CTT in Portugal (CTT, 2019) and Correos in Spain (Citypaq, 2019). Moreover, international logistic providers such as DHL (DHL, 2019), the DPD group (Pickup, 2019) and Hermes (Hermes, 2019) also have their own locker networks operating in a multitude of countries all over the world. The design of the stations, as well as the service conditions for using the locker boxes, may, however, vary depending on the carrier and the country. DHL for example requires their customers in Germany to pick up a parcel from the locker within 9 days, while Australia Post has a pick up policy of 48 hours after notification. In addition, some carriers allow for both pick up and drop off at the locker stations, while others restrict their customers to only the picking up of orders.

Non-carrier owned parcel lockers

Apart from the traditional carriers, there is an increasing variety of other companies that use automated locker solutions for their business model.

E-commerce businesses

To smooth operations and improve their delivery concepts, major e-commerce players, such as Amazon, are investing in their own parcel locker networks, providing their customers with more convenient and flexible services (Amazon, 2019a). The locker stations are, however, often still serviced by the preferred carrier of the e-commerce player, as many e-commerce companies outsource their logistics operations. Amazon, as the main player, already operates parcel locker networks in a variety of countries, such as the UK, Canada, the US, and France. Within these countries, Amazon often places the lockers at libraries and universities or partners with major retail chains (e.g. 7eleven in the US or Morissons in the UK) to host its lockers at their store locations. At these locations, the lockers are then accessible to all Amazon customers for the pick up and return of their Amazon orders, as long as there is enough capacity available at the locker.

Retailers

With more and more retailers also engaging in e-business activities, automated locker stations provide a useful tool for retailers to extend their traditional brick-and mortar store network and allow customers to gain flexible access to their online orders. Given the retailers' existing store network, delivery of orders can in this case occur from both a centralised depot and the existing brick-and-mortar store locations. Examples of retailers using automated lockers to extend their sales network include the supermarket chains of EDEKA in Germany, with among others a locker station at the Audi headquarters in Ingolstadt (Edeka, 2017), and INTERSPAR in Austria with lockers at, for instance, Vienna airport and several train stations (Interspar, 2019). Grocery retailers are often more likely to operate their own lockers in comparison to other retailers, due to the special handling requirements of products, preventing them from relying on the existing logistic solutions of standard carriers. For this reason, the locker stations of grocery retailers are generally serviced by the retailers own fleet and feature different temperature compartments using cold chain technology to comply with the specific product requirements.

Locker system companies

In addition to e-commerce businesses and retailers, the companies behind the locker systems also often establish their own locker networks. These locker networks are then available to a variety of carriers and other companies that have entered a partnership agreement in order to use the lockers. As a result, the locker stations may be serviced by several companies, reserving lockers for a certain period of time. Common locations for the locker stations, in this case, are usually shopping malls and petrol stations, as well as public transport stations, that are easily accessible to all partners. Examples of such locker networks are provided by InPost in the UK and several other countries (InPost, 2019), PalmBox in Taiwan (Palmbox, 2019) as well as ParcelLock in Germany (Parcel, 2019).

Public transport providers

In addition to providing locations for parcel locker networks of other players, public transport providers are also starting to introduce their own parcel locker stations. A first example of such stations can be found in Germany operated by MVG, the Munich transport corporation (Quartiersbox, 2019). With different temperature compartments, the MVG lockers are available for deliveries by the current project partner Getnow (an online grocer operating in the Munich area), or can be reserved by individual customers to be used for deposits, as well as for the exchange of goods. As such, these lockers present a hybrid between automated parcel lockers and locker systems for security deposits often used at public transport stations.

Property management

Besides the companies providing parcel lockers in public locations, the property management of large office and apartment buildings also often invests in automated parcel lockers to facilitate parcel delivery to the building complex. The lockers are then generally owned by the building and restricted to the use of the residents or employees working in the building, while the delivery to the lockers, in contrast, is open to all carriers and (online) retailers. Amazon recently ventured into this market with its concept of Amazon Hub, providing locker stations for apartment buildings within the US (Amazon, 2019b).

3 Decision problems and research opportunities

Despite the many examples and different business models of parcel locker networks in practice, research from an OR perspective, aimed at optimising the inherent planning and design decisions, is still rather limited. The complex nature of last mile logistics, however, necessitates high levels of efficiency and thus requires sound coordination and effective planning. Parcel locker stations pose particular challenges that affect decision making and should be taken into account in this context. This, in turn, provides opportunities for the OR community to investigate these logistical challenges and contribute to finding better solutions to these practical decision problems. In the following, we present an overview of relevant decision problems in the context of automated parcel lockers and highlight possible future research opportunities from an OR perspective.

3.1 Network design and facility location

Designing parcel locker networks is a challenging optimisation problem at the strategic level that largely depends on the business model at hand. Crucial considerations in this context are the users of the lockers, the existing available infrastructure, and the predicted demand for the lockers in terms of the amount and type of expected deliveries. For an overview of some of the main variables and constraints in this context, we refer the interested reader to the research of Morganti et al. (2014), focusing the analysis on the deployment of pick up point networks in France. Taking these considerations into account, the resulting optimisation problem may then involve decisions regarding the following:

- **Number of locker stations:** Given a certain objective, the provider aims to choose the optimal number of stations based on the potential future demand for the locker network. Depending on the business model, the demand can either be covered fully or partially by the locker network. The main challenge in this context is often the willingness of customers to travel to the locker stations and the resulting variations in demand for the lockers.

- **Configuration of the locker stations:** The configuration of the lockers includes decisions on the size of the station and the mix of lockers used. Given that locker stations are often setup in a modular way, this means the provider needs to choose the number of modules per station, as well as the type of modules used (Faugere and Montreuil, 2017). Depending on the purpose of the locker, modules can be designed in different ways, varying for example in locker sizes or temperature settings. Depending on the locker type, there may be, furthermore, certain constraints that have to be taken into account when deciding on the general setup of a station, such as a maximum number of modules per operating terminal.

- **Locations of the locker stations:** The choice of location is crucial for the efficiency of the network, affecting the willingness of customers to use the stations. The set of possible locations is therefore generally based on places that are easily accessible and most likely to be visited on a regular basis by the potential future users (Iwan et al., 2016). This may include for example public spaces, as well as already established sites in the existing network of the locker provider (e.g., retail and public transport setting). Due to space and other requirements of the station, the location decision links furthermore closely to the configuration of the locker.

Note that these decisions are often highly interrelated and dependent on one another. As such, they should be addressed in an integrated framework. Deciding on the optimal network design, the objective of a locker provider is generally to either minimise the overall costs for a given demand or to maximise the total profit taking into account the pricing and different cost components, as well as, for example, the loss of potential customers. Focusing on the latter, Deutsch and Golany (2018) are the first to propose a quantitative approach determining the optimal number, location and size of locker facilities for a parcel locker network within the last mile context. The authors show that the problem can be formulated as the well-known uncapacitated facility location problem and illustrate it using an example based on data of Toronto's metropolitan area.

While network design and facility location problems in the general context have been studied quite intensively, a number of interesting challenges remain in the context of parcel locker networks. This concerns in particular the possible modifications in the configuration of a locker station as a result of its modular structure and the associated variations in setup cost. In this context, it is also important to consider the planning horizon of the facility location decisions. While planning decisions in traditional facility location problems are generally made under consideration of a rather long planning horizon (often concerning several decades), the modular nature of parcel locker stations may provide more flexibility in terms of movable locations, thus shorting the planning horizon to a few years or less. Depending on the length of the planning horizon, the planning problem shifts from more strategic decisions with fixed locations towards more tactical decisions in the context of movable locations. Aside from this modular and more flexible nature of the facility location decisions, the willingness of customers to use the service and the effect of location decisions on the demand for the locker stations present interesting directions for future research streams in this field.

3.2 Vehicle Routing

Generally aimed at optimising logistics operations and improving efficiency, vehicle routing decisions are highly relevant in the context of last mile distribution. Within the field of OR, the optimal routing of vehicles presents an important set of problems that has been extensively studied for decades (Cordeau et al., 2007, Laporte, 2009). Over time, this has resulted in a number of interesting variants of the basic vehicle routing problem (VRP) that have incorporated other aspects and are therefore more applicable to a certain practical setting. In the setting of the last mile, the routing of vehicles often includes for example customer delivery time-windows, time-dependent travel times or a two-echelon distribution structure with intermediary depots. Routing problems in the context of parcel locker stations often incorporate some of these aspects, while adding location decisions to the routing setting. Two types of location decisions can be considered in this context, 1) the choice of alternative delivery locations and 2) decisions related to the facility location of parcel locker stations. The latter relates to the field of location-routing problems, where tactical location decisions are embedded within the operational setting of a vehicle routing problem. A general overview of location-routing problems can be found in Nagy and Salhi (2007), as well as Prodhon and Prins (2014).

Vehicle routing with alternative delivery locations

Focusing on the choice of alternative delivery locations, parcel locker networks provide different location options where customers can pick up their orders. The delivery location may therefore no longer be fixed for certain customers but instead becomes a decision variable. The alternative locations, in the form of parcel locker stations, have then, furthermore, different characteristics in comparison to the traditional home delivery at the customer locations. Parcel locker stations provide, for example, more flexibility with respect to the delivery time of orders, relaxing the tight time windows associated with direct home delivery. At the same time, parcel locker stations are restricted in terms of their capacity and may thus not be able to cover all deliveries at all times. Capacity restrictions can occur both in terms of the overall number of deliveries to the locker stations as well as in terms of a limited available number of a certain locker type (e.g. temperature controlled lockers or different sized lockers). Depending on the business model, delivery companies may also incur an additional cost for renting a specific locker from a locker provider over a certain period of time. In other cases, where the delivery company owns the locker stations, the company may not be charged for using the lockers, but may, for example, have to provide customers with a discount for choosing an alternative delivery location within their locker network.

Within the scientific literature, vehicle routing problems with alternative delivery locations have received growing attention over recent years. In this context, Zhou et al. (2018) propose a problem with multiple depots and customer pickup facilities, assuming a two-echelon structure, where two different logistics providers consolidate orders through a number of satellite facilities. The problem is solved using a hybrid multi-population genetic algorithm. Considering both vehicle pickup and delivery, Sitek and Wikarek (2019) introduce alternative delivery points in a capacitated vehicle routing problem. Minimising the travel distance of the couriers taking into account a penalty cost for delivery to the alternative locations, the proposed model also considers the alternative delivery locations, in the form of parcel locker stations, to be limited in capacity with respect to the number of items that can be delivered. The authors solve the problem for different instances with a hybrid approach using constraint linear programming to presolve the model. Assigning parcels to specific lockers based on size and availability of the locker, Orenstein et al. (2019) propose a model to optimise the delivery of customer orders to a number of parcel locker stations. Minimising the total travel cost, vehicle cost and penalty cost for undelivered items, the model decides on the optimal routes and assignment of orders to the locker stations. The authors present two matheuristics, based on a savings heuristic and a petal method, in combination with a tabu search algorithm to solve the problem. Studying a travelling salesman problem with time windows, Jiang et al. (2019) introduce the option of delivering to shared customer facilities with a specific opening cost and service radius. Minimising total cost, consisting of delivery cost, a cost for customer pickup and the cost for opening the facilities, the problem is solved using an adaptive large neighbourhood approach. Taking into account uncertainty, Zhou et al. (2019b) address the concept of dual service delivery, considering home delivery or delivery to collection points, in a vehicle routing problem with time dependent travel times. The problem is formulated as a two-stage stochastic optimisation model with recourse strategy and solved by applying a two-stage heuristic algorithm. Focusing on the optimisation of bike routes under consideration of total profit, route distance and the safety of the biker, Osaba et al. (2018) study a multi-objective optimisation problem allowing for delivery at third-party drop-off points instead of direct delivery at the customer locations. Solving the problem, the authors apply a number of different evolutionary multi-objective heuristics and test their performance on a set of instances based on real geographical information of Madrid.

Location-routing with alternative delivery locations

Adding the more tactical decisions of placing the alternative delivery locations, Zhou et al. (2016) are amongst the first to incorporate the concept of alternative delivery locations in the form of customer pickup facilities into a location-routing problem. Deciding on both the location of pickup points and the service option for each customer, the authors propose a multi-depot location-routing problem in which each customer can be delivered either directly or through a pickup point. Minimising the total operating cost, the problem is solved using a hybrid approach based on a genetic algorithm and a local search heuristic. Employing two different fleets for delivery to customer homes and customer collection terminals, Zhou et al. (2019a) propose a bi-level multi-sized terminal location-routing problem under consideration of different customer groups and customer delivery preferences. To fit the problem more closely to practice, the authors consider the likelihood of collection point customers switching to home delivery with increasing distance, as well as a certain probability of failed delivery in case home delivery service is selected. The problem is solved using a genetic algorithm in combination with simulated annealing. Also assuming distant dependant demand for the customer pickup points, Janjevic et al. (2019) present a location-routing problem under consideration of a two-echelon structure. Applied to a real-world case study of a Brazilian e-commerce player, the problem is formulated as a non-linear optimisation model and solved using a heuristic approach.

While there has been a clear trend over recent years within the routing literature on the topic of alternative delivery locations and customer pickup points, a number of interesting challenges and opportunities remain in the context of parcel locker stations. Possible future research directions in this area include more dynamic approaches (Voccia et al., 2019), as well as more intricate models with regards to the demand for deliveries at a locker station in relation to the customers' travel distance. Moreover, the current research does not allow for multiple collection time windows at the parcel locker stations or takes into account uncertainties in the collection of orders from a locker station. Future studies could thus explore these topics and propose more stochastic approaches to deal with the inherent uncertainties in the problem. In general, to focus more specifically on parcel locker stations within the routing setting, studies should consider more detailed capacity constraints that take into account the available lockers and their specifications.

3.3 Locker assignment and scheduling

Relating to the available capacity and locker characteristics at the parcel stations, one of the main operational decisions is the assignment of parcels to specific lockers and collection time windows. The challenge, in this context, is to accept individual requests for delivery at the locker stations and match these customer orders, in the form of parcel deliveries, with the right lockers that fit both the size and any other storage requirements of the order. From a spatial perspective, matching customer orders with the locker boxes at the station may in some cases require to split the customer order into smaller units or according to product characteristics. An area where this assignment of lockers to customer orders has particular importance lies within the context of cold chain deliveries, such as fresh food or flowers, where products have different temperature requirements that have to be met during storage, in order to ensure specific quality and safety standards.

From a temporal perspective, customer orders have to be assigned to a number of pickup time windows that need to be scheduled in advance. Shorter pickup time windows may in this context increase capacity at the locker stations, yet, in turn, be less robust with respect to uncertainties related to the pick up of customer orders. Uncertainties play an important role for the operational planning associated with parcel locker stations, as uncollected orders may impact capacity and, thus, decisions in subsequent planning periods. More recently, the implementation of same day or next day delivery concepts has been more popular with many companies (Voccia et al., 2019). As a result, additional challenges emerge for the assignment and scheduling of lockers, in the form of an increasingly dynamic delivery environment and shorter planning periods between order placement and delivery of the item. Focusing on the more general level of assigning customer orders to pick up stations, Ulmer and Streng (2019) present in this context a dynamic dispatching problem for the case of same-day delivery, taking into account customer preferences, as well as different travel and pick up times for the customer.

Despite the many challenges and opportunities to improve planning decisions, research on delivery assignment and scheduling for parcel locker stations is still scarce. Due to the close interlinkages between these decisions and the planning of delivery routes, aspects of assignment and scheduling decisions at the locker facilities may also sometimes be incorporated into the framework of a vehicle routing problem. At this point, assignment decisions in routing problems are, however, limited to the decision of either delivering an order directly to the customer or via a locker station. More research is therefore needed, focusing on the capacity management of the locker stations at the operational level, while taking into account uncertainties and the dynamic operating environment.

3.4 Collaborative approaches

Depending on the business model, parcel lockers may bring together several actors, involved in the servicing, maintenance and usage of the locker. While collaboration brings challenges with regards to planning and information sharing between actors, it also provides opportunities for the different actors to divide tasks, share available facilities, save costs and streamline their operations (Cleophas et al., 2019). Focusing on the challenges of collaboration within the context of parcel locker stations, the following provides an overview of different decision making aspects, in which decision support tools can help to improve the success rate of collaborative approaches.

Aligning incentives

One of the most important factors for successful collaborations between different actors, is the alignment of incentives between actors. This is in particular true in the case of horizontal collaboration, where actors operate in the same tier of the supply chain, due to possible competition between actors (Cruijssen et al., 2007). In general, the alignment of incentives is largely dependent on the business model, as well as the contracts and relationships between actors.

Pricing of lockers and cost sharing

A crucial component of incentive alignment, within the context of parcel locker stations, is the pricing of lockers and the sharing of costs between partners. Dependent on the level of collaboration, actors may choose to either charge prices for the use of individual lockers without a fixed contract or share costs and access rights for the locker facilities on the basis of a long term partnership agreement. Important things to consider in this context are the demand for the lockers by the different actors, with regards to time and space, as well as potential priority access rights. Setting the price an actor has to pay in order to use the locker facilities, therefore, closely links to the benefit a particular actor obtains from using it. Dynamic pricing schemes can, moreover, be a useful tool to balance demand patterns, by incentivising actors to use the locker facility during off-peak hours and thus ensure better usage of capacity.

Examples of studies on cost sharing can be found in the area of collaborative urban transport settings, using concepts based on cooperative game theory (Lozano et al., 2013; Hezarkhani et al., 2016) as well as the Shapley value (Dai and Chen, 2012). Despite the relevance for capacity sharing of parcel locker stations, no research has been conducted in this area so far.

Partner selection

Closely related to the tactical alignment of incentives, concerning decision making about how to share the costs and benefits between partners, is the strategic decision of selecting partners for a potential collaboration. As such, aspects of these problems are often integrated in a common framework (Krajewska et al., 2008; Lozano et al., 2013). Within the framework of parcel locker networks, partner selection may concern the selection of carriers and businesses, servicing the locker facilities, as well as the selection of parcel locker providers, locker system companies and other organisations, providing facilities for the locker network. A crucial consideration for the selection of partners, is therefore the role of the partner within the framework of the collaboration, determining the most important characteristics based on which the evaluation takes place. Standard characteristics, that can play a role in this regard, are the amount, locations and sizes of the order requests or the lockers a partner contributes.

Incentivising and modelling customer behaviour

In addition to aligning incentives between organisations, it is crucial to study customer willingness to make use of the parcel locker facilities and, based on this, motivate potential customers to participate. A number of studies can be found in this context, investigating customer perception of parcel locker stations, as well as the potential value gain and benefits associated with using the locker facilities (Chen et al, 2020; Vakulenko et al., 2018a; Vakulenko et al, 2018b; Verlinde et al., 2018; Yuen et al., 2018; Lemke et al., 2016). Most of this research is, however, still based on empirical observations, while research on analytical models incorporating these aspects is still very limited. Given the importance of modelling and incentivising customer behaviour, more research is necessary in this area to better understand, steer and model customer demand for parcel locker stations. This also holds for the modelling of customer collection behaviour and the use of penalties in order to prevent late collection of orders. With regards to customer collection behaviour, Liu et al. (2019) present a study analysing customer travel patterns related to the pick up of orders at collection points using a panel cross-nested logit model.

Order and task sharing

The sharing of customer order requests between different logistics providers in urban settings is a promising concept in the context of logistics collaboration and has received more attention in the scientific literature of recent years. Examples of such studies can be found amongst others in Krajewska et al. (2008), Vanovermeire and Sörensen (2014), Wang et al. (2014), Defryn et al. (2016), Gansterer and Hartl (2016), Fernández et al. (2018) and Zhou et al. (2018). With parcel locker stations aggregating orders from different customers, the potential for collaboration of carriers with regards to sharing their customer order requests is even more pronounced. Moreover, while most of the existing literature focuses on collaborative transportation and thus the sharing of requests for the routing and shipment of orders, parcel locker stations also allow for capacity sharing at the locker facilities themselves, relating to the assignment and scheduling of orders at the facilities. Opportunities also exist, in this context, to utilise unused capacity at the locker facilities as intermediary depots/consolidation points from where orders are subsequently collected for direct delivery to customer locations. Related to the sharing of order requests, actors may also share responsibilities for other aspects, such as the performance of small maintenance tasks. This is of particular importance in the case of parcel locker networks for grocery deliveries, where disruptions may occur due to dirty or unclosed refrigerated lockers. Important considerations for order or task sharing are possible differences in the priority of orders/tasks, as well as the level of information and capacity sharing between actors. Depending on the level of information and capacity sharing, the collaboration between actors may apply to all resources and orders/tasks or be limited in its extent. In addition, information about orders/tasks and available capacity can be exchanged before the start of the planning horizon or dynamically as they appear in real time.

Despite the potential of order/task sharing in parcel locker networks, studies on this topic are still very limited, with Zhou et al. (2018) being the only example incorporating customer pick up points into their study. Building on this gap, more research is needed, in particular with a view on the potential of the shared use of the available capacity at the locker facilities.

Integration in public transport networks

Another interesting research direction related to collaboration in parcel locker networks, is the integration of locker facilities in public transport networks and its potential of using public transport infrastructure for last mile delivery. The utilisation of public transport networks for city logistics has recently received growing attention in the scientific literature and holds potential for more sustainable urban transportation, encouraging better utilisation of publicly funded infrastructure (Cleophas et al., 2019). Examples of research in this area can be found in the review paper of Mourad et al. (2019), as well as the works of Motraghi and Marinov (2012), Dampier and Marinov (2012), Ghilas et al. (2016a), Ghilas et al. (2016b) and Behiri et al. (2018).
Within the framework of public transport networks, locker facilities can function as both customer collection and consolidation points, where products are collected for later shipment. The latter also provides opportunities to connect different modes of transport, by requiring lower levels of synchronisation between the different modes. However, despite its potential, the integration of parcel locker networks has not yet been addressed in the scientific literature studying the use of public transport networks for urban deliveries.

4 Concluding remarks

In this contribution, we have provided an overview of parcel locker stations presenting the underlying concepts and applications in practice. In addition, we outlined and discussed the related planning and decision making problems with reference to the recent advances and remaining gaps within the scientific literature. The overview shows that, from an OR perspective, most research in the context of parcel locker stations focuses on routing problems with alternative delivery options. However, the proposed research in this area often still lacks more specific locker station characteristics, as well as dynamic approaches and the consideration of uncertainty within the modelling framework. Outside of the routing literature, the concept of parcel locker station has not yet received much attention. In particular, the aspects of scheduling and assignment of lockers, related to the operational decisions concerning the capacity management at the locker stations, require more attention within the scientific literature. Promising research directions in this area also include the consideration of a dynamic operating environment and the modelling of uncertainties. In addition to these research directions at the operational level, more research needs to be carried out with respect to the tactical and strategic decisions concerning the partnerships and collaboration between actors in the parcel locker network.

Overall, we identified several avenues for future research of high practical relevance on parcel locker networks, from an OR perspective. As such, we hope to have contributed to the rise of a promising research agenda, focusing on modelling and methodological contributions.

References

[1] Amazon. (2019a). Available at: https://www.amazon.com/b?ie=UTF8&node=6442600011 (Accessed: 4 October 2019)

Amazon. (2019b). Available at: https://www.amazon.com/b?ie=UTF8&node=17337379011 (Accessed: 4 October 2019)

[2] AusPost. (2019). Available at: https://auspost.com.au/receiving/alternative-delivery-addresses/use-a-247-parcel-locker (Accessed: 7 October 2019)

[3] Behiri, W., Belmokhtar-Berraf, S., & Chu, C. (2018). Urban freight transport using passenger rail network: Scientific issues and quantitative analysis. Transportation Research Part E: Logistics and Transportation Review, 115, 227–245.

[4] Chen, C. F., White, C., & Hsieh, Y. E. (2020). The role of consumer participation readiness in automated parcel station usage intentions. Journal of Retailing and Consumer Services, 54, 102063.

[5] Citypaq. (2019). Available at: https://www.citypaq.es/index.html (Accessed: 7 October 2019)

[6] Cleophas, C., Cottrill, C., Ehmke, J. F., & Tierney, K. (2019). Collaborative urban transportation: Recent advances in theory and practice. European Journal of Operational Research, 273(3), 801–816.

[7] Cordeau, J.-F., Laporte, G., Savelsbergh, M. W. P., & Vigo, D. (2007). Vehicle Routing. C. Barnhart, G. Laporte, eds. Transportation, Handbooks in Operations Research and Management Science, 14 Elsevier, Amsterdam, 367–428.

[8] Cruijssen, F., Cools, M., & Dullaert, W. (2007). Horizontal cooperation in logistics: opportunities and impediments. Transportation Research Part E: Logistics and Transportation Review, 43(2), 129–142.

[9] CTT. (2019). Available at: https://www.ctt24h.pt/ (Accessed: 4 October 2019)

[10] Dai, B., & Chen, H. (2012). Profit allocation mechanisms for carrier collaboration in pickup and delivery service. Computers & Industrial Engineering, 62(2), 633–643.

[11] Dampier, A., & Marinov, M. (2015). A study of the feasibility and potential implementation of metro-based freight transportation in Newcastle upon Tyne. Urban Rail Transit, 1(3), 164–182.

[12] Defryn, C., Sörensen, K., & Cornelissens, T. (2016). The selective vehicle routing problem in a collaborative environment. European Journal of Operational Research, 250(2), 400–411.

[13] Deutsch, Y., & Golany, B. (2018). A parcel locker network as a solution to the logistics last mile problem. International Journal of Production Research, 56(1-2), 251–261.

[14] DHL. (2019). Available at: https://www.dhlparcel.nl/en/consumer/dhl-locker (Accessed: 4 October 2019)

[15] DPD. (2019). Available at: https://www.pickup.fr/about/activity.sls (Accessed: 4 October 2019)

[16] Edeka. (2017). Available at: https://verbund.edeka/presse/pressemeldungen/kooperation-mit-audi-edeka-s%C3%BCdbayern-baut-online-service-aus.html (Accessed: 7 October 2019)

[17] Faugere, L., & Montreuil, B. (2017). Hyperconnected pickup & delivery locker networks. In Proceedings of the 4th International Physical Internet Conference.

[18] Fernández, E., Roca-Riu, M., & Speranza, M. G. (2018). The shared customer collaboration vehicle routing problem. European Journal of Operational Research, 265(3), 1078–1093.

[19] Gansterer, M., & Hartl, R. F. (2016). Request evaluation strategies for carriers in auction-based collaborations. OR Spectrum, 38(1), 3–23.

[20] Ghilas, V., Demir, E., & Van Woensel, T. (2016a). An adaptive large neighborhood search heuristic for the pickup and delivery problem with time windows and scheduled lines. Computers & Operations Research, 72, 12–30.

[21] Ghilas, V., Demir, E., & Van Woensel, T. (2016). A scenario-based planning for the pickup and delivery problem with time windows, scheduled lines and stochastic demands. Transportation Research Part B: Methodological, 91, 34–51.

[22] Gevaers, R., Van de Voorde, E., & Vanelslander, T. (2009). Characteristics of innovations in last-mile logistics-using best practices, case studies and making the link with green and sustainable logistics. Association for European Transport and Contributors.

[23] Hermes. (2019). Available at: https://www.hermesparcelreturn.co.uk/our-services/lockers.html (Accessed: 4 October 2019)

[24] Hezarkhani, B., Slikker, M., & Van Woensel, T. (2016). A competitive solution for cooperative truckload delivery. OR Spectrum, 38(1), 51–80.

[25] HongkongPost. (2019). Available at: https://www.hongkongpost.hk/en/receiving˙mail/ipostal /index.html (Accessed: 7 October 2019)

[26] InPost. (2019). Available at: https://inpost.co.uk/en/about-us (Accessed: 7 October 2019)

[27] Interspar. (2019) Available at: https://www.interspar.at/shop/lebensmittel/Abholbox/ (Accessed: 7 October 2019)

[28] Iwan, S., Kijewska, K., & Lemke, J. (2016). Analysis of parcel lockers' efficiency as the last mile delivery solution–the results of the research in Poland. Transportation Research Procedia, 12, 644–655.

[29] Janjevic, M., Winkenbach, M., & Merchán, D. (2019). Integrating collection-and-delivery points in the strategic design of urban last-mile e-commerce distribution networks. Transportation Research Part E: Logistics and Transportation Review, 131, 37–67.

[30] Jiang, L., Dhiaf, M., Dong, J., Liang, C., & Zhao, S. (2019). A traveling salesman problem with time windows for the last mile delivery in online shopping. International Journal of Production Research, 1–12.

[31] Krajewska, M. A., Kopfer, H., Laporte, G., Ropke, S., & Zaccour, G. (2008). Horizontal cooperation among freight carriers: request allocation and profit sharing. Journal of the Operational Research Society, 59(11), 1483–1491.

[32] Laporte, G. (2009). Fifty years of vehicle routing. Transportation Science, 43(4), 408–416.

[33] Lemke, J., Iwan, S., & Korczak, J. (2016). Usability of the parcel lockers from the customer perspective -– the research in Polish Cities. Transportation Research Procedia, 16, 272–287.

[34] Liu, C., Wang, Q., & Susilo, Y. O. (2019). Assessing the impacts of collection-delivery points to individual's activity-travel patterns: A greener last mile alternative?. Transportation Research Part E: Logistics and Transportation Review, 121, 84–99.

[35] Lozano, S., Moreno, P., Adenso-Díaz, B., & Algaba, E. (2013). Cooperative game theory approach to allocating benefits of horizontal cooperation. European Journal of Operational Research, 229(2), 444–452.

[36] Morganti, E., Dablanc, L., & Fortin, F. (2014). Final deliveries for online shopping: The deployment of pickup point networks in urban and suburban areas. Research in Transportation Business & Management, 11, 23–31.

[37] Motraghi, A., & Marinov, M. V. (2012). Analysis of urban freight by rail using event based simulation. Simulation Modelling Practice and Theory, 25, 73–89.

[38] Mourad, A., Puchinger, J., & Chu, C. (2019). A survey of models and algorithms for optimizing shared mobility. Transportation Research Part B: Methodological.

[39] Nagy, G., & Salhi, S. (2007). Location-routing: Issues, models and methods. European Journal of Operational Research, 177(2), 649–672.

[40] Orenstein, I., Raviv, T., & Sadan, E. (2019). Flexible parcel delivery to automated parcel lockers: models, solution methods and analysis. EURO Journal on Transportation and Logistics, 1–29.

[41] Osaba, E., Del Ser, J., Nebro, A. J., Laña, I., Bilbao, M. N., & Sanchez-Medina, J. J. (2018). Multi-Objective Optimization of Bike Routes for Last-Mile Package Delivery with Drop-Offs. In 2018 21st International Conference on Intelligent Transportation Systems (ITSC) (pp. 865–870). IEEE.

[42] Palmbox. (2019). Available at: https://www.palmbox.com.tw/ (Accessed: 7 October 2019)

[43] ParcelLock. (2019). Available at: https://www.parcellock.de/ (Accessed: 7 October 2019)

[44] Prodhon, C., & Prins, C. (2014). A survey of recent research on location-routing problems. European Journal of Operational Research, 238(1), 1–17.

[45] Quartiersbox. (2019). Available at: https://www.muenchen.de/leben/orte/quartiersbox.html (Accessed: 7 October 2019)

[46] Savelsbergh, M., & Van Woensel, T. (2016). 50th anniversary invited article—city logistics: Challenges and opportunities. Transportation Science, 50(2), 579–590.

[47] Sitek, P., & Wikarek, J. (2019). Capacitated vehicle routing problem with pick-up and alternative delivery (CVRPPAD): model and implementation using hybrid approach. Annals of Operations Research, 273(1–2), 257–277.

[48] Ulmer, M. W., & Streng, S. (2019). Same-day delivery with pickup stations and autonomous vehicles. Computers & Operations Research, 108, 1–19.

[49] Vakulenko, Y., Hellström, D., & Oghazi, P. (2018a). Customer value in self-service kiosks: A systematic literature review. International Journal of Retail & Distribution Management.

[50] Vakulenko, Y., Hellström, D., & Hjort, K. (2018b). What's in the parcel locker? Exploring customer value in e-commerce last mile delivery. Journal of Business Research, 88, 421–427.

[51] Vanovermeire, C., & Sörensen, K. (2014). Integration of the cost allocation in the optimization of collaborative bundling. Transportation Research Part E: Logistics and Transportation Review, 72, 125–143.

[52] Verlinde, S., Rojas, C., Buldeo Rai, H., Kin, B., & Macharis, C. (2018). E-Consumers and their perception of automated parcel stations. City Logistics 3: Towards sustainable and livable cities, 147–160.

[53] Voccia, S. A., Campbell, A. M., & Thomas, B. W. (2019). The same-day delivery problem for online purchases. Transportation Science, 53(1), 167–184.

[54] Wang, X., Kopfer, H., & Gendreau, M. (2014). Operational transportation planning of freight forwarding companies in horizontal coalitions. European Journal of Operational Research, 237(3), 1133–1141.

[55] Yuen, K. F., Wang, X., Ng, L. T. W., & Wong, Y. D. (2018). An investigation of customers' intention to use self-collection services for last-mile delivery. Transport Policy, 66, 1–8.

[56] Zhou, L., Wang, X., Ni, L., & Lin, Y. (2016). Location-routing problem with simultaneous home delivery and customer's pickup for city distribution of online shopping purchases. Sustainability, 8(8), 828.

[57] Zhou, L., Baldacci, R., Vigo, D., & Wang, X. (2018). A multi-depot two-echelon vehicle routing problem with delivery options arising in the last mile distribution. European Journal of Operational Research, 265(2), 765–778.

[58] Zhou, L., Lin, Y., Wang, X., & Zhou, F. (2019a). Model and algorithm for bilevel multi-sized terminal location-routing problem for the last mile delivery. International Transactions in Operational Research, 26(1), 131–156.

[59] Zhou, F., He, Y., & Zhou, L. (2019b). Last mile delivery with stochastic travel times considering dual services. IEEE Access, 7, 159013–159021.