Directions for future research on urban mobility and city logistics

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Abstract
This survey article provides an overview on future directions for research in urban mobility and city logistics. It sets a focus on three particularly serious changes in the business models: vehicle autonomy, crowdsourced logistics, and urban micro-consolidation centers. In the future, service fleets might fully or partially be autonomous which brings new operational opportunities and challenges. In many business models, crowdsourcing jobs are already common. While this might save costs, it also leads to uncertainty in the available workforce and their behavior. Finally, micro-consolidation centers enable the use of smaller, cheaper, and emission-friendlier vehicles, but lead to more complex planning and operations. For each topic, the article presents an overview on the relevant literature as well as important and open research challenges.

KEYWORDS
autonomous vehicles, city logistics, crowdsourced logistics, survey, urban micro-consolidation centers, urban mobility

1 | INTRODUCTION

City logistics and urban mobility are going through rapid changes in technology and customer expectations. At the same time, constantly increasing amounts of passengers and goods need to be transported in the limited urban network [3, 11]. These settings have given rise to many new business models and services, each representing multiple design and operational challenges. As a natural outcome, this is leading to increased attention and efforts by the research community. In particular, the focus is set on defining new models and algorithms fitted to the characteristics of these services, to facilitate better decision making.

The transportation and logistics fields have been effected by several technological advancements that have occurred in recent years. Particularly, advancements in information technology, vehicle autonomy and connectivity, vehicle electrification, payment methodologies, and clearing solutions have enabled creating new types of services and reshaping existing ones. Notable trending topics include: drones and autonomous ground vehicles [1, 29, 52, 57, 70, 74, 75], physical internet for parcel and cargo delivery [14, 19, 80], electric vehicles and micromobility [43, 71], ride-sharing and ride hailing [44, 68], crowd shipping and the gig economy [7, 82, 93], same-day delivery of goods and meals [32, 86], collaborated transportation and brokering [30, 40].

This article is a product of editing a special issue in Networks on the future of city logistics and urban mobility. It serves as a means of sharing the insights derived while handling the submissions and reviews. While we saw a broad area of topics in the submissions, three areas were particularly prominent, namely, vehicle autonomy, crowd-shipping, and micro-hubs. In the following sections, we focus on these three main areas which we believe pose substantial paradigm shifts in the logistical business concepts. We also present a broader outlook of the upcoming opportunities and challenges. Our aim is to highlight...
promising directions for future research and promote further work on these topics by the transportation and logistics research community.

The remainder of this article is structured as follows: In Section 2, the opportunities and challenges brought by vehicle autonomy capabilities are discussed along with research directions for the transition period toward an era of autonomous mobility. Crowdsourced transportation is the focus of Section 3. The contrasts with conventional logistics services are highlighted and new optimization problems are introduced. In Section 4, the developments in urban logistics prompted by urban micro-consolidation centers (UMCs) are described. In particular, the literature on micro-hubs location, micro-hubs operations, and physical Internet are reviewed. The section ends with current and future research directions. Lastly, Section 5 provides a broader outlook for the future research on urban transportation and logistics.

2 | VEHICLE AUTONOMY

Vehicle autonomy is one of the expected technological breakthroughs of the current century. The capability of cars, trucks, busses, drones, and delivery robots to travel fully autonomously within the urban environment promises to transform the way people and goods are moving in cities and beyond. Fully autonomous vehicles introduce opportunities to revolutionize current transit and logistics services. In this section, we summarize these opportunities, discuss the main challenges, and propose directions for research in the coming years.

Regarding passenger transit, autonomous vehicles can expedite the shift toward consumption of mobility-as-a-service. In particular, a widespread availability of shared autonomous vehicle services [70] may decrease private vehicle ownership, and increase vehicle utilization, through car sharing (the sequential use of the same vehicle by different passengers) and through ridesharing (the simultaneous use of the same vehicle by different passengers). This, in turn, may decrease the need for parking spaces, which is particularly important in city centers, where land is scarce. Moreover, vehicle-to-vehicle and vehicle-to-infrastructure communication will allow better synchronization between system elements and improve traffic flow [89]. Eventually, better synchronization and saving the need to find parking space, will make multimodal trips more convenient. In particular, by solving the first and last mile problems, shared autonomous vehicles will make mass transit services more accessible and convenient [2].

Despite the above and the impressively rapid development of autonomy related technologies, large scale implementations of transportation services that are based on fully autonomous vehicles are still far away. Some optimistic observers believe that the deployment of such services in the urban environment will be technologically and economically viable in ten to fifteen years. More conservative forecasts see them in three to four decades [20, 55]. Reasons for the slow penetration of the technology include: price and accuracy, certification and regulations, data privacy, psychological and sociological barriers, road safety, and cybersecurity concerns [36].

Autonomous travel presents several cost saving opportunities for logistics planning. First, autonomous trucks can conduct long-haul intercity trips [16], speeding up inland freight delivery by avoiding regulations requiring truck operators to rest and sleep at specific intervals. Human-driven hours can be dedicated to downtown trips, which might be more complex. Second, fleets of small vehicles, drones, and robots can be efficiently distributed inside the city to provide last-mile logistics. These fleets offer reduced energy consumption and improved maneuverability (compared to large trucks) and can lower logistics’ traffic footprint inside cities [84].

Fleets of automated delivery robots (ADR) [51, 87] and drones [61] already provide delivery services in several cities around the world on a small scale. Battery range and flight regulations keep the service radius to only 2–3 km. While delivery drones can fly at nearly 50 km/h, heavier packages require robots that travel at pedestrian speed (6 km/h). Thus, in the near future, autonomous urban logistics planning will not likely expand to consider larger service radiuses. Large scale implementations will require the use of support layers such as stationary or mobile micro-hubs, see Section 4.

Several scholars recently surveyed the scientific literature on vehicle autonomy in the transportation and logistics fields, see [26, 58, 70]. Most studies consider design and operational requirements for widespread, fully autonomous vehicle deployments, such as traffic flow management [69, 89], intersection control [52, 95], shared vehicle services [25, 56], and autonomous logistics [38]. While such studies provide insights into the future potential benefits of vehicle autonomy, they remain (far) ahead of the actual state of the industry.

The gradual and relatively slow penetration of autonomous vehicle technology poses a substantial challenge. Namely, how to design and operate innovative transportation and logistics services during the long transition period from human driven to autonomous mobility. We next identify several aspects of transportation planning inherent to this transition period and offer directions for further research.

During the transition period, vehicle autonomy technology will improve continuously and a growing number of autonomous vehicles will be deployed-but most vehicles on the road will be human driven. Moreover, regulations regarding vehicle autonomy
will be in a state of flux and vary between- and even within-countries. We consider three main operational scenarios that may allow operating autonomous transportation and logistics services at large scale under these conditions: (1) operation over separated infrastructures, (2) operation in restricted areas, and (3) operation in mixed traffic.

**Operation over separated infrastructures:** Operating autonomous vehicles on separate infrastructures such as rails, guideways, or elevated lanes, reduces interactions with pedestrians, human-driven vehicles, and other obstacles. Separation is more easily achieved in controlled environments such as airports, campuses, factories, and resorts as well as in purposely built infrastructures. The transportation network in such deployments often has a special structure, such as circuits [64, 77, 90]. The design and operation of logistics and flexible transit services over such structures is a potential area for future research. The goal would be to develop models and algorithms tailored to these structures that outperform their general purpose variants.

**Operation in restricted areas:** Fully autonomous travel may be limited to specific areas within the urban environment due to range limitations as well as traffic and safety regulations. Under such conditions, large scale services can be provided using semi-autonomous modes. Namely, some parts of a service would be provided by human driven vehicles while other parts of the service would be provided by autonomous vehicles. For example, a transit system based on high-capacity high-speed human-driven buses that serve the main corridors of the city accompanied by many short feeder lines, based on small low speed autonomous shuttles for the first and last mile legs of the journeys. Such configurations introduce various potential multi-layered planning problems for transportation services [79] and logistics services [4, 18, 27, 74]. The need to optimize the entire system and consider its dynamics while simultaneously synchronizing between the layers—presents multiple challenging directions for future research.

**Operation in mixed traffic:** Vehicle autonomy and connectivity may permit travelling at higher speeds with shorter headways, thus increasing the capacity of the transportation network. However, several recent studies have demonstrated that while the portion of autonomous vehicles remain low, the potential impact is negligible [72, 96]. Several mechanisms could be used to extract benefits from autonomous vehicles in mixed traffic, including dedicated lanes for autonomous vehicles and tolls for human driven vehicles [94]. Under mixed traffic, multiple planning aspects should be reexamined while taking into consideration not only the characteristics of the autonomous vehicles but also the interactions with human driven vehicles. Such aspects include network design, lane management, regulations, and incentives design. When the penetration of autonomous vehicles reaches a significant level, many services will be entirely based on them. The modeling emphasis may then shift toward higher resolution representations of the special characteristics of autonomous vehicles. For example, range limitations and battery management (recharging or swapping), tele-operation management as well as malfunctions handling and cybersecurity. In addition, the communication of autonomous vehicles with central service planners would become seamless, allowing more rapid and frequent plan changes in response to online demand, supply, and traffic updates. Indeed, the flexibility of autonomous fleets may eventually shift research focus to the development of highly dynamic models. Lastly, from a central planning perspective, the integration of different vehicle fleets and services will become feasible, causing multi-model planning and integration to attract more research attention.

## 3 CROWDSOURCED TRANSPORTATION

In the last decade, service providers already experienced an increase in uncertainty on the demand side as customers used their mobile devices to order goods or transportation online [86]. Consequently, planning and control had to be adapted in reaction and anticipation of new demand [44]. With this already being challenging enough, recently an additional dimension of uncertainty emerged, on the supply side. Several new transportation platforms such as GrubHub, Gorillas, or Roadie do not rely (entirely) on their own fleet and workforce but outsource transportation tasks to the crowd. These tasks are then fulfilled either by occasional drivers extending their trip slightly or by freelance drivers conducting several tasks over a longer time horizon, sometimes even for multiple platforms at the same time. Utilizing crowdsourced transportation resources has several advantages for the platforms as they avoid social and employer-liabilities (and responsibilities) and can flexibly adjust to demand changes. While these business models receive mixed feedback due to issues such as ethics, responsibility, and reliability, they also come with new challenges in planning and control of operations. In the following, we briefly illustrate the differences between crowdsourced transportation and conventional logistics services provided exclusively using a company fleet. We will then summarize the new, “untapped” planning and control problems resulting from these differences. For an in-depth discussion, we refer the reader to reviews of [6, 82].

### 3.1 The differences between crowdsourced and conventional logistics services

The nature of crowdsourced logistics is that the service is not conducted by company-employed drivers, but by independent individuals. Thus, the service providers cannot (fully) control the availability and acceptance of jobs by drivers:
Availability. Crowdsourced drivers are usually not available the entire service period, but may decide about the times they want to work. For example, for occasional drivers, they may only be available when driving home from work. In cases, where crowdsourced drivers work longer hours, they may only start working when the demand is high enough and may stop working in case they are dissatisfied with the earning opportunities, for example, when they did not get assigned a job for a longer time. Further, the spatial availability of drivers may differ. Occasional drivers may only be available for jobs along the way, that is, from a work location to residential areas if they drive home. In case crowdsourced drivers are willing to work longer, they may still focus on areas where most of the jobs arise and prefer areas of the city they are familiar with. As a consequence, the service providers may experience times and areas in the city where transportation resources are scarce and demand cannot be satisfied sufficiently. This leads to customer dissatisfaction and in cases like restaurant meal delivery where the service providers are intermediaries between restaurants and diners, also to dissatisfied restaurant owners.

Acceptances. While in conventional transportation planning, assignment decisions are always implemented, crowdsourced drivers may reject assigned jobs for several reasons. For example, in restaurant meal delivery, the reliability of the restaurant plays an important role as drivers do not want to spend longer times waiting until the food is ready. Also, the tip amount varies substantially from restaurant to restaurant and drivers may wait for jobs with potentially higher tips. Another important reason for rejections is the driving time required for a job and the location a driver ends up afterwards. In many cases, the compensation per job is fixed and longer driving does not lead to additional earnings. Furthermore, jobs are more likely to be rejected if they leave a driver “stranded” in an area where new jobs are unlikely to appear or far from home. Drivers rejecting offered jobs leads to several problems. First, the service of the job is delayed and the corresponding customer experiences poor service. Second, due to the often simultaneous matching of several drivers and jobs, individual rejections may render the entire offering decision ineffective. Third, the satisfaction of the drivers may be impacted if they are frequently offered unacceptable tasks to perform. Consequently they may quit working for the service provider.

3.2 New optimization problems

Interestingly, the majority of research on crowdsourced transportation does not directly address the new challenges of uncertain availability and acceptances in optimization, but rather focuses on evaluating crowdsourced resources, either by assuming perfect information [12, 13, 22, 23, 33, 93, 98] or via simulation studies [5, 15, 50]. The challenges of crowdsourced drivers lead to a variety of new and nearly untapped optimization problems. In the following, we discuss the most prominent problems and, if available, we mention the early literature addressing them.

Availability. Platforms need to ensure that sufficient driver resources are available to serve the customer demand at every time and every region of the service area. Thus, uncertain driver availability should be anticipated. There is already a growing research stream on how to incorporate the potential of future arrivals and departures of crowdsourced drivers into matching and routing optimization. For example, [28] optimizes matching decisions in anticipation of potential future driver availability, while [35, 78, 85, 97] sample future arrivals and incorporate them into current assignment and routing optimization. In contrast to matching and routing in anticipation of uncertain availability, studies on ensuring availability at the tactical and operational levels are very scarce. In tactical planning, platforms can schedule additional company drivers or set different compensation schemes over time and regions in the city, as for example, done in crowdsourced mobility systems. On the operational level, platforms can dynamically call additional drivers, let drivers commit for a longer time horizon for some additional compensation, or make sure that the drivers currently in the system are kept satisfied.

Tactical planning: Instead of solely relying on crowdsourcing, logistics service providers can schedule their employed drivers to complement the crowdsourced drivers. For example, company drivers can be scheduled for times of days and assigned to city zones when and where the usual crowdsourced resources are insufficient. Scheduling company drivers comes with several challenges: besides their additional costs, they impact earning opportunities for crowdsourced drivers. Thus, they may adversely affect the availability of crowdsourced drivers. Until now, the literature on scheduling company drivers to account for crowdsourced ones is sparse. [34, 35] schedule full time company drivers either for the perfect information case or in a simulation via enumeration. Neither paper accounts for temporal and spatial heterogeneity in the need for company resources. [24, 91] determine schedules for drivers based on expected demand and crowdsourced resources via machine learning, thus, they schedule different numbers of drivers for different times of the day. However, to the best of our knowledge, the spatial aspect has not been considered in the literature yet. Furthermore, the impact of scheduled company drivers to the crowdsourced drivers’ availability is also still unexplored.

Besides adding their own drivers to the system, a company may also change the available crowdsourced resources via heterogeneous compensation in time and space. For example, in areas or at times with less demand, earning opportunities may be too small and no crowdsourced driver may be willing to work. For such times and areas, the company could make the tactical decision to increase the compensation per job in general. Such a decision may motivate additional drivers to work and, therefore, mitigate the insufficient resources. Until now, there is no research on determining heterogeneous compensation
schemes over time and space on the tactical level. Closest is the work in [99], determining the optimal daily compensation analytically when knowing the relationship between compensation and crowdsourced driver availability. Extending the work to different compensation in time and space is challenging because it is not certain how compensation changes the behaviour of crowdsourced drivers. For example, an increase in compensation in one area of the city may attract (too) many drivers from adjacent areas, reducing the earning opportunities in the high-compensation area even further and leaving the other areas empty. A similar problem could occur when offering different compensation over time as crowdsourced drivers may only have a limited amount of time per day to work. Also, occasional drivers may be relatively insensitive to compensation changes, as they only work when they are traveling anyway, for example, on their way home from work.

**Operational planning:** While both scheduling company drivers and varying compensation on the tactical level can be important tools for a company to ensure sufficient driver availability, the same is true on the operational level, that is, during the day. Platforms may dynamically add company drivers in cases where demand is higher or crowdsourced driver participation is lower than expected. Such drivers may be willing to be on call for a small fee and then start working if they are needed. Notably, how many drivers to have on call and when is another interesting tactical planning problem. Operationally, the question is when to “activate” how many on call-drivers as they may take some time to start and, again, may change the behavior of crowdsourced drivers. Until now, there is no research investigating this question. As an alternative to having drivers on call, a platform can just call the known but currently not working crowdsourced drivers and ask them to join. However, the platform cannot be sure how many drivers will actually start working. The first paper to address this question [53] assumes a certain percentage of drivers joining the system when asked.

The alternative to adding new drivers to the system is to retain the drivers currently working. For example, a platform may offer a driver additional payment in case they are willing to stay longer in the system [67]. This may increase resources in the future and also reduces uncertainty in their availability. Deciding which drivers to offer such additional compensation is challenging, not only because, again, it may change the earning opportunities for other crowdsourced drivers, but also, because the platform does not fully know which driver would have stayed in the system anyway. Furthermore, such a strategy may leave a platform vulnerable to drivers “gaming” the system, for example, by organizing and artificially decreasing resources. To the best of our knowledge, this phenomenon has not been studied in the operations research literature yet. A more subtle way of retaining drivers is to keep them happy via enough earnings. For example, drivers may decide to leave if they have not earned enough in the last hour. Thus, it may be valuable for a platform to consider previous earnings in their assignment decisions. First work on this optimization problem has been presented in [34]. Finally, another option for a company is dynamically controlling the compensation, for example, by increasing the compensation in cases where not enough drivers are available. Interestingly, even though such “surge pricing” is well-established in crowdsourced mobility systems, it is not yet that common in crowdsourced transportation.

**Acceptances.** In contrast to conventional delivery routing by a company fleet, crowdsourced drivers do not necessarily need to accept all assigned jobs. In practice, drivers regularly reject offers for a variety of reasons not necessarily known to the platform. The rejections can easily render well-planned assignments ineffective. Thus, understanding, modeling, and anticipating such rejections becomes an important and novel challenge for the operations research community.

**Understanding and modeling:** First, the reasons for rejections need to be understood and modeled. Such reasons can be manifold and depend on a larger number of factors. These factors can be either job- or driver-related. Job-related factors are similar for all drivers and are amongst others, earning-related, for example, the compensation for the job and the expected tipping amount; effort-related, for example, the time required for pickup and delivery operations and the travel from pickup to delivery; reliability-related, for example, the variation in waiting times for pickup and delivery or the likelihood of traffic congestion in pickup and delivery area; or flexibility-related, for example, the probability for bundling the job with future jobs and for follow-up jobs at the destination. Driver-related factors of a job differ for each driver, for example, the travel time required from the driver’s position to the pickup location, the familiarity of the driver with pickup and delivery locations, the time the driver is without an assignment, or the time a driver is planning to work and their final destination (both unknown to the company). Future research should focus on understanding the factors, how they interact, and how they contribute to a driver’s decisions. Future research should further model the driver’s choices mathematically to allow an integration in the assignment optimization.

**Optimization:** There are two main streams of research on assignment with potential job-reactions, anticipation of and hedging against rejections. Anticipation should lead to assignments that are “robust” against potential rejections. Assignments should be made, that even in case of some rejections, the fleet stays flexible for future assignments. For example, “stranded” jobs and drivers, far away from potential future assignments should be avoided. Early work has been proposed by [41] sampling job-rejections and determining corresponding assignments via two-stage stochastic programming. As an alternative, new means should be introduced to hedge against potential rejections. For example, the crowdsourced drivers could be complemented by a (backup) fleet of company drivers that serve the jobs rejected by the crowdsourced drivers. This leads to a challenging optimization problem considering the interplay between assignments to crowdsourced drivers and routing and repositioning of
the company fleet. Another way to hedge against driver rejections was recently introduced by [63]. The authors suggest offering drivers *menus* of jobs to select from. This increases the likelihood of drivers accepting a job from the menu, however, selecting the right menus per driver leads to additional challenges [17]. First, menus should increase the probability of a driver selecting a job, that is, menus should be relatively large and may overlap among drivers. Second, duplicate selections should be avoided, that is, the number of overlaps should be limited. Third, the company should still aim for effective, centralized assignment decisions, that is, the menu size should not be too large. An extension of menus is offering (menus of) bundles of jobs to drivers [59]. For example, a driver is offered a combination of more and less lucrative jobs. Creating bundles for all crowdsourced drivers in the system simultaneously leads to a challenging combinatorial optimization problem. Finally, it could be very valuable to *learn* the specific driver preferences based on their previous decisions over the course of the optimization horizon.

### 4 URBAN MICRO-CONSOLIDATION CENTERS

UMCs, also known as micro-hubs, are small facilities, typically located in densely populated and congested areas, see [8, 31, 47]. The UMCs reside at the lowest tier of the logistics network and are replenished from larger sorting facilities, and fulfillment centers outside the city by relatively heavy vehicles or by businesses that are located inside the city [39]. From the UMCs, goods are either picked up directly by the customers [60, 92] or transported to the end customers [48, 54, 62], for example, by using light vehicles such as e-cargo bicycles [83], ADRs [37], and possibly delivery drones in the future. While UMCs can be used for the replenishment of bricks and mortar retail business, the main driver of their development is the explosion of e-commerce and the rapid growth in the volume of home deliveries. The replenishment of the UMCs is typically performed at times when the traffic in the city is low. The last mile distribution can then be performed at more convenient hours during the day. In some cases, the end customers pick the goods directly from the UMCs possibly using an automated unattended service.

The mode shift enabled by the UMCs, reduces the distance travelled by heavy vehicles inside the city, which may save costs and alleviate the negative externalities of the logistics process. In particular, the use of UMCs may help to reduce traffic congestion, accidents, local air pollution, and carbon dioxide emissions [14]. In a case study, [66] report on several successful pilots and field experiments in Dutch cities that deployed networks of UMCs and promoted (or enforced) last-mile delivery using light electric vehicles. A recent white paper prepared for the National Center for Sustainable Transportation, [46] advocates planning to accommodate freight distribution facilities (from distribution and fulfillment centers to UMCs and collection points) near customers. The paper claims that this will reduce overall emissions and costs.

However, there is a clear trade-off between the savings that can be obtained from using the UMCs and their costs. The UMCs are located on expensive urban land and using them requires additional handling of the goods and parcels. Effective deployment and efficient operations of UMCs are, therefore, very important and require devising new methods for making various strategic and operational decisions. On the strategic level, it is important to correctly decide how many UMCs to deploy, where they should be located, and what their capacities should be. On the operational level, decisions regarding the scheduling of the flow of goods through the UMCs and balancing the workload among them is crucial for the efficient operations of the logistics network.

The strategic and operational decision discussed above may be further complicated by the fact that urban logistics networks are not centrally managed by a single stakeholder [14]. The hubs in the urban logistics network are typically designed and operated (or regulated) by the local government, while it is used by various private and competing logistics service providers. Some UMCs may share space and personnel with retail businesses in the city that have their own commercial interests. In the rest of this section, we briefly survey the literature on UMCs location and operation highlighting timely and open research challenges. We conclude the section with a short discussion on the related concept of Physical Internet.

#### 4.1 Locating UMCs

Determining the locations of the UMCs in the city is a long-term strategic decision that should consider current and future demand volumes as well as accessibility for both heavier replenishment vehicles and lighter delivery vehicles.

The first task is to identify potential UMC locations. [81] takes a geo-driven approach toward the problem of identifying sound locations for UMCs based on data available in geographical information systems. They apply various (heuristic) considerations. This approach may be suitable for identifying a set of potential locations for UMCs that can be served as an input for a location optimization model.

Once potential locations are identified, the locations of the UMCs should be determined with several goals in mind. First, the costs of installing and managing the UMCs should be considered. Second, the expected travel costs of the vehicles that replenish the UMCs and distribute goods from them should be considered. It should be noted that calculating the exact implications of the UMC locations on the transportation costs requires solving rich routing problems with input that is determined by unknown future demand. Nevertheless, it may be beneficial to solve the routing and location problems jointly, for example, using a representative set of demand locations.
4.2 | UMC operation

On the operational level, logistics service providers and operators of UMCs deal with various routing and scheduling problems. Effective routing is crucial for the fleet that replenishes the UMCs and for the fleet of light vehicles that distribute parcels or goods from them. Because the UMCs are limited in space, synchronization between the incoming and outgoing flow of items at the UMC is particularly important. This scheduling process is subject to constraints due to the availability and capacity of the fleets, the capacity of the handling process, which may be labor-intensive, and the uncertainty and dynamism of demand.

Perboli et al. [76] study the problem of scheduling the shipments into and out of a UMC in a two-tier logistic network. They focus on a UMC that serves a predefined area and present a model that aims to schedule the deliveries from it. Their model assumes time-dependent costs to account for the fact that the UMC is operating in a dynamic environment where the time of delivery affects the storage and handling costs at the UMC as well as the delivery cost. In this model, the number of parcels that can be delivered in a shift is determined by the number and identity of the vehicles allocated to work at it. With these simplifications, the problem becomes a variant of the bin-packing problem, for which the authors formulate a mathematical model and present an effective heuristic. The solution method is applied to a realistic case based on the operations of UMC in the city of Turin.

While the common practice is that each logistics service provider maintains a separate fleet of light vehicles to serve each UMC, a recent study, [88], presents a model of a shared fleet of delivery vehicles. They conceive of a shared fleet of ADRs that use the UMCs in the city as their depots. The logistics service providers rent them for their delivery tasks. The ADRs are capable of roaming between neighboring zones. The study presents a MILP model used to optimize the size of the ADRs fleet. A numerical study shows that such a resource pooling approach may economize the logistics process significantly.

4.3 | Physical Internet for parcel delivery

Logistics networks are traditionally built as hierarchical graphs, where goods or parcels are initially transported from the supplier to the upper tiers of the network and down to consolidation centers located near the recipient. A modern design of service networks introduces more flexibility, referred to as Physical Internet (PI). In a PI, each node in the network can serve as the entrance or exit point or as an intermediate transshipment point. The routes of the vehicles and the items in the network are determined dynamically based on the current demand and the system’s state. The concept of PI was introduced in [65] for less-than-truck-load transportation primarily in inter-urban context. An essential component of PI is standardized packaging and handling equipment, which is inspired by the well-established container transportation industry. The vision is to bring this efficiency and intermodality to short-haul transportation of light freights.

Several studies examined the possibility of using the PI concept for delivery of parcels within the limits of an urban region [73, 78]. In the PI network structure, the notion of consolidation centers is extended to Service Points (SPs). As UMCs, the SPs serve as a depot for the light vehicles that perform last-mile delivery but also for additional usage: The SPs are used (a) as pick-up and drop-off locations for recipients and shippers that prefer a cheaper alternative to home delivery and collection; (b) as intermediate transshipment points where parcels can be loaded by one vehicle and picked up by another at the same tier of the network. The number of transshipments is not limited, and each parcel may be transshipped between vehicles when this additional flexibility economizes the delivery process. The result is a hyper-connected delivery network rather than the traditional hierarchical one. Medium size vehicles may connect the various SPs in the city, and their routes are determined dynamically based on the current demand and the state of traffic in the city. Once automated vehicles’ technology is ready, these vehicles are likely to operate 24/7, which will make it easier to exploit times when the traffic is low.
The SPs will be deployed in the city densely enough to be located short walking distance for any shipper and recipient. As the share of the bricks and mortar retail industry gradually diminishes, the SPs may serve as focal points where various physical services are provided to the citizens. In this sense, they can serve as “consolidation facilities” also from the recipients’ perspective. The backbone of the PI service network can be based on a dedicated fleet that follows fixed routes, as studied in [73] or at can be dynamic. This study proposed an algorithm for routing the vehicles and parcels on top of them in the resulting service network. The vehicle routes are periodic and static, while the parcel routes are determined dynamically based on capacity consideration and the location of the vehicles when a parcel arrives. Another approach is to opportunistically outsource the transportation tasks between SPs in the network to drivers who follow their regular trips and are ready to collect parcels and drop them somewhere later on their planned route in exchange for a monetary reward [78, 93].

The research on the PI for parcel delivery in an urban environment is still young, and many research questions are still untapped. How do we locate the SPs and how do we set their capacities? What fleet should be used? Is crowdsourcing an economically viable alternative? Or, how to optimally set dynamic routes of the vehicles and the parcel simultaneously?

5 | FINAL REMARKS

The changes in the urban mobility and logistics field bring substantial new opportunities and challenges to companies as well as the operations research and transportation science and logistics community. Optimization models become more complex with a variety of new decisions to make, objectives to integrate, and constraints to consider. Furthermore, for an increasing number of problems, vast amounts of data are available allowing and requiring a detailed consideration within the optimization, for example, via data-driven decision making and machine learning. Furthermore, for more and more problems, information changes stochastically over time leading to the need for robust or dynamic decision making, often in real-time. All this, while problem sizes and complexity grow. Optimization needs to capture larger fleets, increasingly heterogeneous, as well as customer demand for individually tailored services. Thus, there is ample area for new models, methods, and analyses.

Besides the challenging and intriguing new optimization problems, the paradigm shifts in key business concepts also raise bigger questions. For example, can everyone be served by autonomous vehicles and who is responsible in case autonomous vehicles are involved in accidents? Who pays for urban security and casualty insurance in case of crowdsourced transportation? Who surrenders space in the already crowded city for micro-hubs, parcel lockers, and shared mobility systems? While operations research will likely not be able to fully answer these societal, political, and moral questions, future research should be aware of them. Integrating such questions into optimization models and analyses is a first step. For example, measures for societal costs, for participation, sustainability, or fairness might be used for comparing different optimization solutions, or alternatively, they might be integrated into the objective function or constraints directly. Also, longer term effects of decision making’s consequences on all stakeholders involved might be evaluated, for example, how a service strategy impacts the customers’ demand behavior. Ideally, the insights gained by optimizing the new and important optimization problems may go beyond the operations research community and foster societal discussions on how the future of urban mobility and logistics can lead to a more livable city.

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