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50th Anniversary Invited Article

City Logistics: Challenges and Opportunities

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Today, around 54% of the world's population lives in urban areas. By 2050, this share is expected to go up significantly. As a result, city logistics, which focuses on the efficient and effective transportation of goods in urban areas while taking into account the negative effects on congestion, safety, and environment, is critical to ensuring continued quality of life in cities. We review and discuss a variety of current and anticipated challenges and opportunities of city logistics. We hope this helps shaping an appropriate research agenda and stimulates more researchers to enter this exciting field.

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1. Introduction

There are many definitions of city logistics, but common to all is that city logistics is about finding efficient and effective ways to transport goods in urban areas while taking into account the negative effects on congestion, safety, and environment. The distinguishing characteristic of city logistics is the explicit recognition that transporting goods in urban areas has a negative (as well as a positive) impact on the lives of people living in these urban areas. City logistics is also referred to as urban (freight) distribution, last mile logistics, urban logistics, or city distribution (for more discussions see, e.g., Taniguchi 2014; Taniguchi, Thompson, and Yamada 2014; Bektas, Crainic, and van Woensel 2015; Cattaruzza et al. 2015). That city logistics is not just a recent phenomenon can be seen in *Law of Caesar on Municipalities* (44 B.C., §§(14)–(16)), quoted below (Johnson et al. 1961):

> (14): After January 1 next no one shall drive a wagon along the streets of Rome or along those streets in the suburbs where there is continuous housing after sunrise or before the tenth hour of the day, except whatever will be proper for the transportation and the importation of material for building temples of the immortal gods, or for public works, or for removing from the city rubbish from those buildings for whose demolition public contracts have been let. For these purposes permission shall be granted by this law to specified persons to drive wagons for the reasons stated.
> (15): Whenever it is proper for the vestal virgins, the king of the sacrifices, or the flamens to ride in the city for the purpose of official sacrifices of the Roman people; whatever wagons are proper for a triumphal procession when any one triumphs; whatever wagons are proper for public games within Rome or within one mile of Rome or for the procession held at the time of the games in the Circus Maximus, it is not the intent of this law to prevent the use of such wagons during the day within the city for these occasions and at these times.
> (16): It is not the intent of this law to prevent ox wagons or donkey wagons that have been driven into the city by night from going out empty or from carrying out dung from within the city of Rome or within one mile of the city after sunrise until the tenth hour of the day.

Times have changed since the Roman Empire and so have the challenges of city logistics. In fact, the challenges of city logistics change continually. The recent growth of e-commerce, for example, has lead to a significant increase in direct-to-consumer deliveries (mostly in urban areas), and associated "last mile" challenges.

Because the challenges of city logistics change continually, so do the opportunities to improve city logistics. That is exactly what this paper is all about: reviewing and discussing current and anticipated challenges and opportunities of city logistics. Of course, given the wide range of activities that constitute city logistics, our coverage is necessarily biased and guaranteed to be incomplete. However, we hope that our personal perspective will be of interest. Furthermore, because the world population continues to grow and urbanization advances unabated, city logistics will impact the lives of more and more people, and, if not done well, will cause unnecessary congestion and greenhouse gas emissions, and hence negatively impact quality of life. Consequently, a concerted and sustained research effort focused on improving city logistics is needed and we hope that this article helps shape an appropriate research agenda and stimulates more researchers to enter this exciting field of research.

It is important to realize that geographic, economic, social, and cultural circumstances affect city logistics and people's perception of critical issues related to city logistics. For example, attitudes towards and aspirations for city logistics differ in Europe and the United States. When relevant and appropriate, we will try to point out differences in such attitudes and aspirations.

To be able to anticipate future challenges of city logistics, it is imperative that we recognize the trends that critically impact city logistics. Thus, in §2, we start our investigation of city logistics with an exploration of relevant (global) trends and advances in technology. In §3, the most important part of the paper, we focus on research opportunities for the transportation science and logistics community in the field of city logistics. We strongly believe that there are many opportunities to push the boundaries of science and, at the same time, have an enduring societal impact. Even though our investigation of city logistics is focused on freight transportation, it is impossible to completely ignore passenger transportation since both often share the same publicly funded road infrastructure. Therefore, in §4, we briefly touch on urban mobility. Urban mobility is in the midst of a major transformation and technological advances in the next few years are likely to result in even more revolutionary changes in urban mobility. Finally, in §5, we finish up with some concluding remarks on the bright future outlook for research in the area of city logistics.

2. Trends and Advances in Technology Impacting City Logistics

In this section, we review trends and advances in technology impacting city logistics. Our intention is not to be exhaustive, but rather to highlight a few relevant and important drivers of the changing world of city logistics. DHL provides a much more elaborate overview of trends and advances in technology impacting the broader field of logistics in their yearly Logistics Trend Radar (DHL 2014).

To be able to discuss how trends and advances in technology impact city logistics, it is helpful, at times, to refer to an extremely simple, although not completely unreasonable, approach to city logistics: minimize the number of freight movements required to satisfy demand. This strategy seeks, at the same time, to minimize cost and to minimize negative impacts.

2.1. Trends

We focus on a few trends that we believe are driving (and will continue to drive) changes in city logistics. Specifically, we provide recent data on urban population growth, the growing importance of e-commerce, the desire for speed in supply chains, the rise of the sharing economy, and the increased attention to sustainability. We supplement the information with views on the impact of these trends on city logistics.

2.1.1. Population Growth and Urbanization. Today, around 54% of the world's population lives in urban areas and produces around 80% of the global gross domestic product (GDP) (Dobbs et al. 2011). In 1950, only 30% of the world's population was living in urban areas, but it is expected that by 2050, this share will go up to 66% of the world's population. The OECD (2015b) looks even further and expects that 85% of the world's population will live in cities by 2100. In a period of 150 years, the urban population will have increased from less than 1 billion in 1950 to 9 billion by 2100.

The United Nations (2014) points out that there are different urbanization levels depending on the region. North America (82% urban population), Latin America and the Caribbean (80%) and Europe (73%) have the highest urbanization levels. Africa and Asia are still rural, with an urbanization level of around 40%, with an expectation to grow up to around 60% by 2050.

The population in developing economies is thus moving rapidly into cities, and mega-cities (having more than 10 million inhabitants) are becoming a (more) common phenomenon in these countries. Today, it is estimated that around one in eight people live in mega-cities (United Nations 2014). Interestingly, the United Nations (2014) expect to see most of the future mega-cities in developing regions. Finally, they also observe that the fastest growing urban areas are the medium-sized and large cities (up to one million inhabitants) located in both Asia and Africa.

It goes without saying that the unabating urbanization and the growth of cities gives rise to numerous city logistics challenges. Blanco and Fransoo (2014) argue that the especially high population density makes mega-cities logistically even more challenging than other cities (Mumbai, India, for example, has an average population density of about 30,000 people per square kilometer).

2.1.2. E-Commerce Growth. The rise of online Internet sales and e-commerce (i.e., the e-channel) gave a big boost to retail companies' sales and gave rise to new and different business models (Cap Gemini 2013;

Nielsen 2014). Estimates reported by the Ecommerce Foundation (2015) show that business-to-consumer (B2C) e-commerce sales worldwide reached $1.9 trillion in 2014, representing a doubling in sales compared to 2011.

Enabled and driven by an increasing Internet penetration, mobile phones, and other technology, e-commerce has seen double digit growth over the past years. Again, there are big differences across regions. Europe and North America see growth rates of around 12%–14%, while the Asia-Pacific region had a growth rate of over 40% in 2014. In absolute terms, China had the biggest annual turnover (over $500 billion in 2014), leading the United States and the United Kingdom (Ecommerce Foundation 2015).

Maybe as important, the consumer is allowed, more and more, to take part in defining the e-logistics that suits her, in terms of price, quality, time, green and/or fair. That is, the "logsumer" (DHL 2014) has more and more power to dictate how the last mile needs to be organized. It goes without saying that this trend, even though it may enhance a consumer's shopping experience, may become a logistics service provider's nightmare.

It is important to realize that having to transport goods to consumers' homes rather than to retail stores is going to increase the number of freight movements. Furthermore, because the size of the deliveries will typically be small, the relative increase in the number of freight movements is even larger. Thus, from a city logistics perspective, the increase in direct-to-consumer deliveries is a curse rather than a blessing.

2.1.3. The Desire for Speed. In recent years, many e-tailers have started to offer their customers a same-day delivery option, sometimes even going down to 1-hour and 2-hour delivery options (see, e.g., Amazon Prime in select U.S. cities). The rationale for offering these options, is mainly to compete with brick-and-mortar retailers as they can provide instant product delivery. Interestingly, end-consumers in the B2C market are often not willing to pay extra for this service and, in fact, are often not even asked to pay for it. Of course, many customers may not necessarily need (or want) same-day delivery.

When delivering from a relatively small number of distribution centers, the typical situation for pure e-tailers, these speedy delivery options are affordable only when the drop density (i.e., the number of deliveries in a given geographic area) is high. Traditional retailers with many physical locations may thus have an advantage as these locations can do double duty and also function as (small) distribution centers with much closer proximity to the end customer (Mueller, Schmahl, and Tipping 2013). Home improvement giant The Home Depot, for example, announced plans to do so in 2013 (Banjo 2013). The fact that brick-and-mortar retailers can make use of their physical infrastructure for serving their online customers is, in fact, one of the reasons for the rise of omni-channel logistics.

Walmart is contemplating taking this concept even further, and considers employing "crowdshipping" for same-day deliveries, i.e., getting its in-store customers to deliver items that its online customers have ordered (Barr and Wohl 2013). Not surprisingly, Amazon is exploring similar ideas (Bensinger 2015).

From a city logistics perspective, offering these speedy delivery options will further increase the number of freight movements as it will make the coordination and consolidation of direct-to-consumer deliveries even more challenging.

2.1.4. The Sharing Economy. The last DHL (2014) Trend Radar report identifies two important variants of the sharing economy or shareconomy: collaborative consumption and collaborative business. The former is focused on Consumer to Consumer networks (C2C) while the latter is focused on Business to Business models (B2B).

Collaborative consumption refers to a class of economic arrangements in which participants share access to products or services, rather than having individual ownership and is facilitated by the Internet and mobile technology. Hamari, Sjöklint, and Ukkonen (2015) define collaborative consumption as "the peer-to-peer-based activity of obtaining, giving, or sharing the access to goods and services, coordinated through community-based online services." Geron (2013) estimates that the peer-to-peer shareconomy was worth more than $3.5 billion in 2013, with a growth exceeding 25%. Vella (2012) notes that investors are spending lots of money into shareconomy start-up companies.

Collaborative business involves sharing logistics infrastructure and services with competitors. In this way, new business models for logistics service providers and companies arise, again supported and enabled by new online and digital (data) sharing platforms (DHL 2014). This enables companies to share existing assets and capacities, especially when these assets need a large amount of capital (Matzler, Veider, and Kathan 2015).

Sharing assets and capacities may result in increased consolidation and higher capacity utilization, which may reduce the number of freight movements, the fleet size, and empty travel for collaborating logistics service providers.

2.1.5. Climate Change and Sustainability The increased freight activity in urban areas results in traffic congestion, air and noise pollution, traffic accidents, and greenhouse gas emissions (Demir et al. 2015). Focusing on the environmental (planet), social (people), and economic (profit) sustainability of cities, there is a need to ensure that increased urban freight transport does not eventually lower the quality of life and attractiveness of urban areas, and does not impact urban citizens' health and the global climate. Despite the negative impact of urban freight transport, it is needed to support urban lifestyles, retain industrial and trading activities, and contribute to the competitiveness of the industry in the area (Macharis and Melo 2011; Browne et al. 2012).

There is thus a need to reduce the impact of goods and service distribution and collection on living conditions in urban areas without penalizing key city activities. The demand for urban freight transport however is clearly growing, and will continue to do so. In Europe, "transport is the most problematic emitting sector, with upward emission trends" (European Environment Agency 2009, p. 8). An important contemporary challenge for cities is thus to improve the air quality. Between 1990 and 2007, CO_2 emissions from transport rose by 29% in Europe. Road transport accounts for a sizable portion of CO_2 transport related emissions, nearly 73% in 2000 (Demir, Bektas, and Laporte 2011). Within road transport related CO_2 emissions, urban traffic accounts for 40% of CO_2 emissions, and 70% of emissions of other air pollutants. In terms of traffic congestion, in Europe, every year nearly €100 billion, or 1% of the European Union's (EU's) GDP, are lost to the European economy as a result of this phenomenon. To satisfy the European norms for NO_x, cities have to improve their air quality considerably. High concentrations of NO_x and PM10 have negative consequences for the residents' health. Just over 41 million Europeans are exposed to excessive noise from road traffic alone in the largest European cities (Kopanezou 2007; European Environment Agency 2009).

In the United States, transportation represented 27% of total U.S. greenhouse gas emissions in 2013 and increased more from 1990 to 2013 in absolute terms than any other sector (Environmental Protection Agency 2015). Even though passenger cars (and other light-duty vehicles) are responsible for the majority of greenhouse gas emissions in the transportation sector (with about 60%), greenhouse gas emissions of medium and heavy duty trucks (second largest subsector with about 23%) increased by 76.4% from 1990 to 2013 (compared to an increase of 16.2% of passenger cars). The estimated cumulative cost of traffic congestion in the United States by 2030 is \$2.8 trillion—the same amount Americans collectively paid in U.S. taxes in 2013 (Centre for Economics and Business Research 2014).

The increased (public) attention to sustainability, will have far-reaching consequences for future city logistics solutions and decision support systems. The pressure to explicitly consider the impact on people and planet will continue to rise. This implies that multiple, typically competing, objectives need to be considered and handled appropriately during system design, planning, and execution. The most immediate manifestation will be pressure, and maybe even regulation, to curtail emissions resulting from city logistics activities.

2.2. Advances in Technology

The trends discussed above, for the most part, lead to an increase in the complexity of city logistics, and, as a result, can lead to an increase in the negative effects on congestion, safety, and the environment. The new and emerging technologies discussed below, on the other hand, can drive city logistics innovation, and potentially decrease the negative effects on congestion, safety, and environment. We discuss digital connectivity, big data, and automation, automotive technology, and unmanned aerial vehicles.

2.2.1. Digital Connectivity, Big Data, and Automation. Data are everywhere. Furthermore, the volume, velocity, and variety of data arriving in real-time and containing high-value information continues to accelerate. Being able to quickly transform these data into decisions is increasingly becoming a reality (OECD 2015a) and a key technological enabler for improving city logistics.

This data and communications revolution is paving the way for a transformation of city logistics. The availability of real-time "rich" data from multiple sources, such as transportation infrastructure sensors and automatic vehicle location systems, but also from the various information systems from the logistics service providers, shippers, etc., can be used to improve the reliability, operational efficiency, and visibility of city logistics operations. Furthermore, data tend to be more and more openly available and shared in the supply chain, and consumers too appear very willing to share data via mobile devices, online platforms, etc.

However, there are many challenges still to overcome. Information needs to be extracted and analyzed in real-time (i.e., monitoring and control), calling for advanced data analytics methods (i.e., optimization). Additionally, embedding and effectively using high-quality information and insights (e.g., dynamically updating distributions associated with any system uncertainty—demand, supply, travel times, etc.) in decision support (systems) is critical, but nontrivial.

Ultimately, real-time data availability, monitoring, control, and optimization will lead to a certain level of autonomy. It is expected that many future systems will function with a large amount of autonomy, applying advanced algorithms that utilize data about their performance and their environment (Porter and Heppelmann 2014).

In the context of city logistics, this may lead, for example, to systems that re-route in-route transport vehicles and/or re-sequence stops, based on current congestion information, pickup requests as they come in, and pickup requests that are anticipated. That is, the information value of the incoming data is converted in near real-time into (autonomous) operational decisions.

2.2.2. Automotive Technology. There are several automotive technology developments that have or will have a significant impact on city logistics. We briefly discuss three: alternative fuel vehicles, autonomous or self-driving vehicles, and controlled access to the trunk of a vehicle.

Alternative fuel vehicles (AFVs) are a small but increasingly important part of the transportation system. Powered by rechargeable batteries, natural gas, hydrogen, or other non-petroleum-based fuels, AFVs hold the potential to provide significant public benefits by reducing greenhouse gas emissions (Greene and Plotkin 2011). The AFV fueling infrastructure has experienced significant growth in recent years, especially electric vehicle charging stations. As of March 2014, the United States, for example, had 8,421 publicly available fueling stations for natural gas, electric, or hydrogen vehicles; in more than 95% of the United States 7,689 public electric charging stations have been installed since 2010. In the EU, around 47,000 AFV fueling stations were active in 2012. EU policy seeks to have 795,000 electric vehicle charging stations by 2020 (Hughes-Cromwick and Cregger 2013).

Self-driving vehicles have been a topic of discussion for at least the past decade. However, their actual introduction may be closer than many of us realize: Toyota expects to launch its first self-driving car in 2020 (Caddy 2015) and U.S. Secretary of Transportation Anthony Foxx stated at the 2015 Frankfurt Auto show that he expects self-driving cars to be in use all over the world by 2025 (Hauser 2015). That self-driving vehicles will have an impact on city logistics is clear from the recently announced partnership between Ford and Amazon (Murgia 2016). However, how to assess the benefits of self-driving vehicles for city logistics, how to most effectively employ self-driving vehicles, and how to best transition from an environment with 0% self-driving vehicles to (perhaps) 100% self-driving vehicles is far from obvious.

A smaller, but not less useful, innovation is the ability to control access to the trunk of your car, which makes it possible to allow companies to deliver to the trunk of your car (rather than to the door of your home). Volvo and Ericsson demonstrated such technology at the 2014 Mobile World Conference, and a trial of this delivery method has been conducted in Belgium by start-up Cardrops. Audi has partnered with Amazon and DHL to pilot a similar program in Germany (della Cava 2015).

2.2.3. Unmanned Aerial Vehicles. Amazon CEO Jeff Bezos captured headlines when he announced on the CBS broadcast of 60 Minutes that his company has developed a fleet of unmanned aerial vehicles (UAVs) for small parcel delivery (Rose 2013). Bezos envisions UAVs delivering parcels from distribution centers directly to customers via Amazon's Prime Air.

Poised to challenge our definition of transportation, UAVs will significantly enhance company supply chains and logistics operations by delivering smaller items within the last mile of the transportation system. Furthermore, it is anticipated that in the near future, UAVs will have the ability to carry huge loads while hovering just a few feet above the ground. These UAVs could be remotely monitored and guided using a system of sensors on special cross-country or intra-city roadways.

Some Silicon Valley companies, such as Matternet, are betting heavily on this new technology. The Matternet ONE (https://mttr.net), for example, "is exclusively designed for transportation. Its centrally-located payload makes it exceptionally easy to load and unload. Its unique architecture makes it light and strong enough to transport 1 kilogram over 20 kilometers on a single battery charge. Secure routes that adapt to weather, terrain and airspace allow Matternet ONE to fly autonomously beyond line of sight, without the need for a human pilot."

3. Opportunities

In its essence, logistics and supply chain management has always been about providing good service (the right product at the right time and at the right place) at a low cost. As most of the trends in the previous section highlight, doing so in an urban environment is becoming exceedingly difficult due to the increased complexity, dynamics, and uncertainty. We note that investing in transportation (infrastructure) capacity to ease any stresses in logistics systems, which may be an option in other settings, is typically not viable in city logistics. There is either not enough space for expansions, or the costs of expansions are prohibitive. Therefore, providing good service at a low cost necessitates better *coordination* of the flows of goods, higher *consolidation* of the freight volumes, and multi-organization *cooperation*. This, in turn, will require creative, innovative, and out-of-the-box concepts and ideas at all levels of system design, operations planning, and real-time execution. This, of course, is where the opportunities for the transportation science and logistics community arise. However, it is critical to recognize and acknowledge that real-life city logistics does not fit neatly into a deterministic and static straitjacket, which has been assumed by too many published models and industry tools. Any plan, schedule, decision, or action built on unrealistic assumptions is bound to be less than optimal.

We organize the initial part of our discussion of research opportunities around two complementary concepts: *package-to-consumer* (P2C) and *consumer-to-package* (C2P). The former focuses on system designs and optimization models for delivering to customer home locations, whereas the latter focuses on system designs and optimization models in which deliveries are made to "intermediate" locations and customers actively participate in the city logistics system. We follow this by a discussion of a few other research opportunities, namely omni-channel logistics, the integration of public and freight transportation networks, horizontal and vertical cooperation, and sustainability.

3.1. Multiechelon Networks

One of the most commonly seen designs for handling and reducing the many freight vehicles going into cities, each delivering small quantities per drop, is to consolidate this fragmented volume at the border of the city, in so-called urban distribution centers. From these centers, the freight is then forwarded into the city with clean and highly utilized vehicles (Taniguchi and van der Heijden 2000; Quak 2009; Cattaruzza et al. 2015). Depending on the size and geography of the city, a second layer of (smaller) satellite facilities can be introduced, in which case a delivery can be made either from an urban distribution center or from a satellite. In practice, the success of these multiechelon network designs seems to be highly dependent on the location and characteristics of the urban distribution centers, on the local city logistics policies, and on the volume going through the urban distribution centers (Quak and de Koster 2009). For more detailed discussions, we refer to Quak and Tavasszy (2011).

Cuda, Guastaroba, and Speranza (2015) review the literature on two-echelon distribution systems (in their setting, deliveries can only be made from satellite facilities, but by allowing an urban distribution center and a satellite facility to be co-located the more general setting can be handled as well). Vehicles with different characteristics are used in each of the two levels (i.e., transport from urban distribution center to satellite facility and transport from satellite facility to final customer). The two-echelon capacitated vehicle routing problem (2E-CVRP) represents this distribution system very well. Figure 1 illustrates a solution for an instance of the problem with three urban distribution centers, four satellite facilities, and eight drop locations.

Even though Cuda, Guastaroba, and Speranza (2015) observe that two-echelon routing problems are receiving more and more attention, both from practitioners and from researchers, their survey of the state-of-the-art shows that it is still a relatively unexplored area as most of the existing research has focused on basic problem variants. Many important real-life issues still need to be incorporated and analyzed. Think of time windows, synchronization issues, multiple commodities, capacity constraints at both levels, joint pickup and delivery, perishability, combinations with location and inventory problems, heterogeneous fleets, etc.

In addition to allowing the use of different, more environmentally friendly, vehicles at the different levels

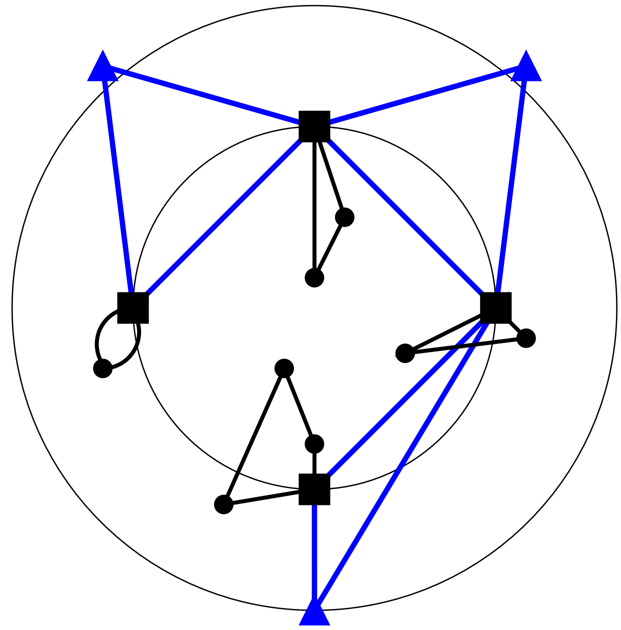

Figure 1 (Color online) A 2E-CVRP Example

of the distribution system, the distribution system also allows multiple shipments to the same drop location to be consolidated (either at an urban distribution system or at a satellite facility). Similar to one-stop shopping, one-stop dropping reduces the number of freight movements to retailers and consumers. Suppliers gain from lower logistics costs, stores benefit from fewer deliveries, and the environment profits from a reduction of emissions. Combining deliveries from multiple companies into a single drop is also at the heart of joint delivery systems, see, e.g., Taniguchi (2014). Much more research is needed to better understand the planning and synchronization mechanisms required for effective one-stop dropping. Combining different types of flows (e.g., combinations of small and large volumes) and the related inventory management is challenging and currently unexplored.

We note that multiechelon models (i.e., with more than two levels) are probably more relevant for large to mega-cities and that to our knowledge, very few papers deal with multiechelon vehicle routing problems and its variants (Dondo, Méndez, and Cerdá 2011; Hamidi, Farahmand, and Sajjadi 2012; Gonzalez-Feliu 2013).

Another interesting research path deals with mobile satellite facilities. A mobile satellite facility is a trailer fitted with a loading dock, warehousing facilities, and an office. This mobile satellite facility serves as a small inner city distribution center from where last-mile deliveries and first-mile pick-ups can be executed, using environmentally friendly vehicles, e.g., cargo-bikes (Verlinde et al. 2014). Adequate decision support for multiechelon models considering mobile satellite facilities, like trailers, barges, etc., is missing in the literature and offers an interesting path for future research.

Many of the ideas and concepts presented above can also be found, in one form or another, in the notion of the Physical Internet (Montreuil 2011), which seeks global logistics efficiency and sustainability by transforming the way physical objects are handled, moved, and stored by applying concepts from Internet data transfer to real-world shipping processes. A discussion of the application of Physical Internet ideas and concepts to city logistics can be found in Crainic and Montreuil (2015).

3.2. Dynamic Delivery Systems

Regardless of the organization of freight flows into and in the city, the aspiration of many companies to offer same-day delivery leads to interesting new optimization challenges, among others related to effectively handling the *dynamic* nature of same-day delivery operations.

Even though there is a vast literature on dynamic vehicle routing (see Berbeglia, Cordeau, and Laporte 2010, Pillac et al. 2013, and Psaraftis, Wen, and Kontovas 2016 for recent surveys), the "demand" invariably refers to orders to be picked up, to orders to be picked up and delivered, or to a service performed by the driver. The structure of a dynamic vehicle routing problem changes significantly when demand refers to orders to be *delivered*, since there are few, if any, opportunities to accommodate additional deliveries after a delivery vehicle has left the depot (because the vehicle would have to return to the depot to pick up the additional deliveries). Developing strategies for effectively managing the delivery of dynamically arriving orders therefore is challenging. The two basic controls are: (1) the timing of a delivery vehicle's departure and (2) the assignment of orders to be delivered on a vehicle's route. For example, making several short trips delivering a small number of orders may be preferable to making one long trip delivering many orders, so as to be able to accommodate future orders. The shape of the route (the sequence of deliveries) can also provide an opportunity for control. By placing deliveries to customers relatively close to the depot strategically in a route, possibilities to return to the depot are created.

Two natural variants of same-day delivery can be considered: (1) all orders have to be delivered by the end of the day, and (2) all orders have to be delivered within a given period after receiving the order. The first variant captures what The Home Depot hopes to offer its customers (Banjo 2013). The second variant, with very short service times, captures the delivery problem faced by GrubHub when delivering meals to customers' homes (Primack 2015). Again, the critical decisions are when to dispatch a vehicle, what orders the vehicle should serve, and in what sequence they should be served. By waiting with the dispatch of a vehicle, additional orders may arrive, which may result in more cost-effective delivery routes. On the other hand, by waiting with the dispatch of a vehicle, less time is available for deliveries, which increases the risk of not being able to fulfill all orders and may also result in more, shorter, less cost-effective delivery routes. Klapp, Erera, and Toriello (2015) study dispatch wave policies for same-day delivery when all delivery locations are on a line.

In the context of crowdshipping, as envisioned by Walmart (Barr and Wohl 2013), this trade-off manifests itself as follows. By not immediately assigning a delivery to an in-store customer who announces his willingness to deliver an online customer's order, which we will refer to as an occasional driver, it is possible that (1) a more appropriate occasional driver shows up for the delivery or (2) a more appropriate delivery materializes for this occasional driver. Crowdshipping provides a fertile environment for the study of dynamic delivery routing problems as it is not only the demand that arrives over time, in the form of online purchases, but (some of) the resources to deliver the demand also arrive over time, in the form of occasional drivers.

Effective use of *anticipation* is likely going to be critical to the success of any solution approach, e.g., anticipating when orders and occasional drivers will arrive. The big data revolution, i.e., the capture and statistical analysis of enormous amounts of data, will facilitate and enhance anticipation. Large-scale highly dynamic delivery systems will be the norm in the future and novel solution approaches that effectively handle the size and dynamics and creatively and successfully exploit anticipated, but uncertain, events will be critical. (Relevant references on anticipatory routing include Thomas and White 2004; Ghiani, Manni, and Thomas 2012, and Goodson, Ohlmann, and Thomas 2013.)

Another interesting aspect of the crowdshipping setting envisioned by Walmart is that to guarantee same-day delivery to online customers, the company has to employ company drivers in addition to occasional drivers (the in-store customers willing to deliver an order of an online customer). Even the underlying static vehicle routing and scheduling problem differs significantly from those traditionally studied. The number of drivers available to make deliveries is likely to be much larger, available occasional drivers do not have to be used, occasional drivers do not return to the depot after making a delivery, and occasional drivers are (most likely) cheaper than a company driver. A preliminary investigation of some of these issues can be found in Archetti, Speranza, and Savelsbergh (2016), who study the so-called vehicle routing problem with occasional drivers (VRPOD). One of the findings of that study is, not surprisingly, that the compensation scheme for occasional drivers has a significant impact on the cost effectiveness of crowdshipping.

The topics of dynamic delivery routing and crowdshipping are virtually unexplored and offer fertile ground for groundbreaking research. Furthermore, we are only just starting to recognize the various pricing issues that can arise in crowdshipping. The field for research on that topic is wide open.

3.3. Pickup Points Networks

Pickup points are locations where customers can pick up their orders. They can be unattended, e.g. locker boxes, or attended, e.g. fuel stations. The kind and number of goods that can be stored in locker boxes, but also the services offered at a station, depend on the features of the boxes and the layout of the stations.

Pickup point networks provide a mechanism for mitigating some of the negative effects of direct-to-consumer deliveries by reducing the congestion and environmental pollution generated by urban freight trips. Pickup point networks also have economic benefits as they increase the number of successful first-time deliveries and allow more effective optimization of delivery routes (due to reduced location uncertainty).

It is obvious that the design of a pickup point network is a challenging, but interesting optimization problem. It involves, among others, deciding on the mix of locker boxes and stations, the number of locker boxes and stations, and the locations of locker boxes and stations. The location choice has to be based on the points most likely to be visited frequently by the potential users, such as railway stations or even premises of large employers.

Examples of pickup point networks include E-box (France), Locker Bank (UK), DHL PackStation (Germany), Tower24 (Germany), Kiala (Belgium), and de Buren (the Netherlands). Morganti et al. (2014) provide an in-depth look at alternative parcel delivery services in France and Germany.

Pickup point networks (either attended or unattended) are one of the prime examples of differences between Europe and the United States. Pickup point networks are already quite common and rapidly expanding in Europe, whereas they are almost unheard of in the United States.

Relatively little research has been done on how to best design and operate pickup points networks and how to quantify their benefits. Successful research along these lines may not only enhance the effectiveness of pickup point networks but also their adoption (and the rate of their adoption).

3.4. Delivery to the Trunk of a Car

Another opportunity to deliver to a more convenient location than the home of a customer is the ability to deliver to the trunk of the customer's car. The technology allows a customer to authorize a one-time keyless access to the car's trunk during a specific time period. Once the delivery is completed and the trunk is shut, access permission is automatically revoked. Interestingly, delivering to the trunk of a customer's car leads to a fundamentally different variant of the vehicle routing problem (VRP). The VRP and its variations have been studied extensively. In all these variants, one aspect is never in doubt: the customer's location, i.e., the location where the delivery occurs. When you deliver to the trunk of a customer's car, this certainty disappears, because the customer's car will likely be in different locations during the planning horizon, e.g., at home, work, the mall, church, at the kids' soccer practice, and so on. This leads to the VRP with roaming delivery locations (Reyes, Savelsbergh, and Toriello 2016).

The variant studied in the aforementioned paper is static and deterministic, i.e., it is assumed that all customers' locations during the day as well as the exact time periods during which the customers will be at these locations is known with certainty. In some circumstances, this setting may offer a fairly accurate approximation, yielding solutions that are implementable without much additional difficulty or cost. However, there may be other settings in which predicting a customer's movements is unrealistic, or where we may significantly reduce realized costs if we anticipate the uncertainty and dynamism inherent in customers' activities.

3.5. Omni-Channel Logistics

Many retailers and manufacturers have recognized that the e-commerce or e-channel offers a supplementary way to reach consumers. This has led to the rise of omni-channel strategies, i.e., reaching customers by means of a variety of marketing and distribution channels. However, even though employing an omni-channel strategy may enhance the customer experience and may increase the customer base, it comes at a price, because it introduces additional fulfillment complexity. Employing an omni-channel strategy implies managing a more complex demand portfolio and necessitates the use of multiple inventories with cross-replenishments.

Interestingly, the e-channel shortens the supply chain as manufacturers interact directly with their consumers, rather than via distributions centers, wholesalers, etc. Shortening the supply chain towards the consumer can be beneficial in terms of both costs and delivery lead times. On the other hand, the other channels still need to be handled as well. This again calls for efficient and effective omni-channel logistics.

The rise of omni-channel strategies impacts city logistics in different ways. On one hand, as we have seen before, direct-to-consumer deliveries tend to increase the number of freight movements. On the other hand, satisfying demand from online customers from retail store inventories, as opposed to distribution center inventories, shortens the freight movements, which can have a positive impact. Surprisingly, given its practical importance, there is little or no research on the implications and the effective management of omni-channel logistics.

3.6. Integrating Public and Freight Transportation Networks

Combining people and freight flows has the potential to lead to improved operations as the same transportation needs can be met with fewer vehicles and drivers (Trentini and Malhéné 2010; Ghilas, Demir, and Van Woensel 2013; Masson et al. 2015). Specifically, think of using different people-based modalities for freight flows, i.e., using spare capacity in public transport systems (e.g., rail, bus, and subway) for retail store replenishment. Taxis can move freight when transporting a passenger or during idle time. In many cities, metro, buses, and trams travel in a fine-mazed urban network: the start and end of their tours are usually in the middle of the city. Bus schedules might be adapted to accommodate delivery of small boxes to urban retail outlets. Trains can replenish inventories of railway station based stores and restaurants. This can be quite effective, because railway stations are often located in time- and vehicle-restricted urban areas. Multimodal integrated people and freight transportation networks need to be adequately designed. Moreover, coordination, planning, and scheduling policies that enable efficient and reliable delivery of both people and freight need to be developed, tested, and validated.

Integration can already be found in long-haul freight transportation, e.g., passenger planes and ferries often carry freight as well. In short-haul transportation, however, people and freight rarely share transportation modes, although they largely share the same infrastructure, indicating potential efficiency gains for an integrated system (Lindholm and Behrends 2012). In an integrated system, depending on the origin, destination, and availability and due time of freight, we have to decide whether to use a pure freight transportation network, a combination of people and freight transportation networks, or a pure people transportation network. The use can be joint (i.e., people and freight share a resource) or separate (i.e., freight is moved during times that the people transportation network is normally inactive or during repositioning trips). Very limited research on integrating public and freight transportation exists. We briefly mention a few below.

Masson et al. (2015) propose a two-echelon routing problem in which goods are transported using city buses from a distribution center to a set of bus stops. That is, in the first tier, spare capacity on buses is used to bring goods to the city center, and in the second tier, goods are transferred to city freighters that bring the goods to their final destinations.

Ghilas, Demir, and Van Woensel (2013, 2016) explore the potential of an integrated system to reduce the number of vehicles required for freight transportation. More specifically, they consider the scheduling of a set of vehicles to serve freight requests, in a system where the freight can be transported on part of its journey from origin to destination on a scheduled passenger service (i.e., a service operating with fixed routes and a known timetable). Especially during off-peak hours, the capacity utilization of fixed scheduled line (FSL) vehicles tends to be relatively low, and transferring freight requests to fixed scheduled lines (for part of their journey) can then be beneficial for the transportation system as a whole. Therefore, in the setting studied, a request can be picked up by a pickup and delivery (PD) vehicle and transported to a station-hub. From there, the request continues its journey on a scheduled public transportation system. Afterwards, the request is picked up by another PD vehicle to be delivered to its final destination.

Li et al. (2014; 2016a, b) consider conceptual and mathematical models in which people and parcels are (simultaneously) handled by the same taxi network. The Share-a-Ride Problem (SARP) is discussed and defined in detail. Specifically, for a set of people and parcel requests, the best schedules and routes are determined. A reduced problem based on the SARP, denoted as the Freight Insertion Problem (FIP), starts from a given route for handling people requests and inserts parcel requests into this route.

These type of problems resemble advanced pickup and delivery VRPs, but have many complicating features, such as transfers, synchronization, capacity constraints at transfer points and/or vehicles, time windows, multiple echelons, etc. A key consideration should also be that the standard of service for passengers does not deteriorate. In order for the integration of public and freight transportation to become a reality, there should not be a significant negative effect on people.

The discussion above highlights the enormous potential for exciting research bridging two domains: freight logistics and public transit.

3.7. Cooperation in City Logistics

Cooperation is often seen as a fruitful path to consolidating freight volumes, leading to a higher and efficient utilization of resources. Cooperation can be done in two ways: vertically and horizontally.

Vertical collaboration typically involves different partners in the supply chain (e.g. suppliers, manufacturers, 3PLs, logistics service providers (LSPs), and customers) working together (Cruijssen, Cools, and Dullaert 2007), leading to concepts such as Collaborative Planning Forecasting and Replenishment (CPFR), Efficient Consumer Response (ECR), etc.

By contrast, horizontal cooperation involves companies operating at the same level in the supply chain. Horizontal cooperation in logistics is receiving more and more attention. Cruijssen, Cools, and Dullaert (2007) report that in Belgium and the Netherlands over 30 formal logistics partnerships were active. Through close collaboration, the partnering LSPs aim to increase productivity, e.g., by optimizing vehicle capacity utilization, reducing empty mileage and cutting costs of noncore/supporting activities to increase the competitiveness of their logistics networks.

To stimulate and foster cooperations, more research is needed to better understand the benefits and pitfalls of cooperation in transportation settings, e.g., *pain and gain sharing*. This involves incorporation of ideas and concepts from cooperative and non-cooperative game theory in transportation and logistics research. Hezarkhani, Slikker, and Van Woensel (2016) discuss gain sharing options for LSPs that do joint planning of deliveries (thereby reducing empty miles). Cost and/or benefit allocation in transportation settings is extremely challenging (see, e.g., Özener, Ergun, Savelsbergh 2011, 2013), but critical to successful (practical) collaborations and fertile ground for further research.

3.8. City Logistics and Sustainability

We only briefly mention city logistics and sustainability. The recent and informative survey by Pelletier, Jabali, and Laporte (2016) discusses many of the challenges and opportunities related to the use of electric vehicles for goods distribution in cities. Another relevant stream of research investigates routing problems in which one of the objectives is minimizing emissions, e.g., Bektas and Laporte (2011), Ehmke, Campbell, and Thomas (2016a, b). One of the challenges encountered when doing so is that emissions depend on the load and the speed of the vehicle.

However, guaranteeing the environmental (planet), social (people), and economic (profit) sustainability of our cities goes beyond greenhouse gas emissions, and ideally considers all (negative) externalities. A comprehensive overview of relevant models for these externalities within freight transportation can be found in Demir et al. (2015). How to incorporate the management of these externalities in optimization models and decisions support systems is an open issue and has to involve other scientific disciplines (e.g., social science or urban science).

4. Mobility

We have focused primarily on the movement of freight, but, obviously, there are many challenges and opportunities when it comes to the movement and mobility of people in cities. Ride-sharing providers like Uber (www.uber.com), Lyft (www.lyft.com), and Flinc (www.flinc.org) are demonstrating that innovative use of technology can revolutionize personal mobility and change people's perception of transportation. The dynamic ride-sharing concept has stimulated a growing body of research on optimization technology to support and enhance the effectiveness and sustainability of dynamic ridesharing providers, e.g., Hall and Qureshi (1997); Winter and Nittel (2006); Agatz et al. (2011, 2012); Furuhata et al. (2013); Stiglic et al. (2015); Lee and Savelsbergh (2015). Furthermore, the (effective) use of (large volumes of) real-time data to enhance mobility is rapidly gaining ground. Startup Ally (www.allyapp.com), for example, combines live feeds from public transport providers as well as from the Ally user community to provide the most accurate assessment of journey options—whether that be foot, cycle, public transport, bike sharing, car sharing, or taxi—in terms of time and cost. The expected large-scale adoption of autonomous or self-driving vehicles will undoubtedly lead to another radical change in personal mobility. It may go even beyond the use of self-driving vehicles, as previewed in Proctor (2015).

5. Final Remarks

We hope that we have been able to convince our readers that city logistics is not only a relevant and critical area of research, with a huge potential for societal impact, but also an area of research with many challenging problems offering wonderful opportunities for the transportation science and logistics community. We want to emphasize again that we have presented, unquestionably, a biased and incomplete view of city logistics and its challenges and opportunities. Yet it should have become clear that there is a growing need for sound and rigorous research taking into account real-life features of city logistics, but also for demonstration and proof of concept projects to show the relevance and impact of our ideas and techniques in practice.

Finally, we want to accentuate that highly dynamic and volatile decision making environments with access to massive amounts of near real-time data, which will be seen more and more in the future, may necessitate new views, paradigms, and models for decision support. A challenge and opportunity that goes well beyond just city logistics.

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