1

Recent Developments and Prospects for Modeling City Logistics

Recent developments in digital-based technologies such as sensor networks as well as alternative fuel vehicles such as electric vans present many exciting opportunities for enhancing city logistics. New concepts based on the sharing economy including co-modality and the Physical Internet provide good prospects for improving the sustainability of urban freight systems. However, it will be important to create new models as well as adapt existing modeling approaches to effectively plan, design and operate city logistics schemes in the future. This chapter describes how developments in simulation and optimization models are being applied to facilitate the implementation of contemporary concepts and utilize emerging advanced technologies for city logistics.

1.1. Introduction

There are numerous complicated and difficult problems relating to urban freight transport systems, including how we can recognize the behavior of stakeholders, how we can evaluate and implement policy measures of city logistics and how we can promote collaboration among stakeholders. In order to overcome these problems, technological advances have contributed toward collecting data, developing mathematical models and applying them for evaluating policy measures. This paper highlights recent advances in using ITS (Intelligent Transport Systems), ICT (Information and Communication Technology), IoT (Internet of Things), Physical Internet (PI), big data, co-modality and electric vehicles. These innovative technologies and systems will have tremendous impacts on modeling, planning and managing city logistics for establishing efficient and environmentally friendly urban freight transport systems. Also, innovative modeling methods of vehicle routing and

---

Chapter written by Eiichi TANIGUCHI, Russell G. THOMPSON and Ali Gul QURESHI.

scheduling with time windows and multi-agent simulation in city logistics as well as road network strengthening are discussed toward sustainable urban freight transport.

1.2. VRPTW with consideration of environment, energy efficiency and safety

The vehicle routing and scheduling problem (VRP) can be used as a principal tool for evaluating many of such types of city logistics schemes [VAN 07]. The VRP is a well-known NP-hard problem which consists of determining a set of optimum routes covering all demands of a given set of customers without violating the capacity of vehicles. Since its inception in 1959 [DAN 60], the VRP has attracted many researchers, and a number of variants have found their way into the literature based on the inclusion of different practical constraints. The addition of the time window constraints leads to the vehicle routing problem with time windows (VRPTW) [SOL 87]. Whether or not a delayed service with penalties is allowed, the VRPTW can be further extended to include soft time window [QUR 09, BHU 14] and hard time window variants [KOH 99]. A heterogeneous fleet vehicle routing problem (HVRP) [CHO 07] deals with the availability of vehicles of different capacities at a central depot.

A relatively recent trend is to consider environmentally sustainable vehicles such as electric vehicles (i.e. EVRPTW [CON 11]). Electric trucks have the constraint of a limited range; therefore, EVRPTW models consider recharging at charging stations [AFR 14, SCH 14] or even battery swaps [YAN 15]. Earlier, a similar problem was introduced considering alternative fuel vehicles, their limited range (based on the size of the fuel tank) and limited filling station infrastructure [ERD 12]. This problem has been called the green vehicle routing problem (GVRP). Collaboration (sharing of electric vehicles, routes and customers) among different companies by formulating a multi-depot vehicle routing problem (MDVRP) has also been studied [MUÑ 17]. In addition to the routing, some researchers try to optimize the mix of conventional trucks and electric trucks (e.g. [VAN 13, GOE 15, LEB 15]). Instead of electric vehicles, a hybrid electric vehicle travelling salesman problem considering hybrid vehicles, capable of switching between electric and/or conventional fuels, has been proposed [DOP 16]. Later, the hybrid vehicle routing problem (HVRP) was developed [ZHA 17, MAN 17].

There has been considerable research interest in incorporating the environmental impact of urban freight in the vehicle routing model. For example, a pollution routing problem (PRP) considering the CO_2 emissions based on the fuel consumption along the arcs depending on the vehicle's speed and load has been formulated [BEK 11]. A number of studies can be listed in the same class, although they used somewhat different equations to calculate fuel consumption and corresponding CO_2 emissions [KUO 11, JAB 12, XIA 12, KRA 15]. A third objective of customers' satisfaction along with distance and emissions (fuel consumption) has been included [AFS 16]. An exhaustive review of the GVRP and other variants has been undertaken [LIN 14].

Although crashes and safety issues have been identified as one of the typical problems posed by the urban freight [TAN 02], crash risks have only been considered, exclusively, in hazardous material transport (HazMat) [PRA 14a, PRA 14b, LOZ 11]. A VRPTW model adding service hour regulations for drivers in order to avoid fatigue-related crashes has been presented [GOE 14]. The difference between the maximum and minimum route lengths as a social objective for fairness has also been considered [MEL 14]. Recently, another objective of the GVRP in the form of a difference between the trip durations of all vehicles to incorporate social and safety issues of equity and fatigue among drivers has been included [SHA 17].

1.3. Multi-agent models

Multi-agent models help us to understand the behavior of stakeholders who are involved in city logistics. Multi-agent simulation models are often used for the purpose of estimating the social, economic, financial, environmental and energy impacts by implementing policy measures in urban areas [TAN 07, TAM 10, VAN 07, VAN 12, ROO 10, TEO 12, TEO 14, TEO 15, ANA 14, ANA 16]. Multi-agent models can address the behavior of key stakeholders including shippers, freight carriers, residents, administrators and, in addition, other agents such as urban consolidation center operators or urban motorway operators. These models allow city logistics policy measures to be evaluated in a dynamic manner with the updated travel times on road networks given by traffic simulation. Reinforcement learning including Q-learning [TEO 12] techniques can be used for modeling the decision-making of agents to take action for adapting to a changing environment. Adaptive dynamic programming (ADP) [FIR 17] can also be used as a reinforcement learning method for the decision-making of agents in varying environments in terms of customers' demands and travel times in urban distribution systems.

Although multi-agent modeling is promising for evaluating the effects of policy measures, the validation of these models needs to be carried out carefully based on precise data sets on realistic road networks. A validation framework based on a participatory simulation game and a discussion on how the decision-making process represented in multi-agent models can be validated has been presented [ANA 16]. If public–private partnerships (PPP) are set up, multi-agent models are suitable for providing the basic information on the effects of implementing policy measures in advance and rethinking the policy measures after implementing them and monitoring their impacts. This process represents the evaluation and feedback stages in the PDCA (Plan, Do, Check and Act) cycle which is often adopted in PPP.

Multi-agent models are usually used in simulation, and the results of simulation do not produce optimal solutions. The combination of simulation and optimization has become popular in the Operation Research area and can be a good tool for optimizing urban freight transport, considering the uncertainty of interactions between stakeholders. An outline of how simulation with meta-heuristics can be combined in the city logistics area has been presented [GRU 16]. Sim-heuristics takes the uncertainty of the behavior of entities in combinatorial optimization problems into account [JUA 16].

1.4. Big data analysis

Big data on the flow of goods, freight vehicles and information are available by collecting data using GPS (Global Positioning Systems) and RFID (Radio Frequency Identification) devices as well as the IoT (Internet of Things). Big data can have large impacts on analyzing, managing and operating urban freight transport systems, since big data have the capability of changing competition by transforming processes, altering corporate ecosystems, and facilitating innovation [FOS 15]. Big data are also capable of impacting social dynamics, choices and behavior, public response to events, market trends, services and the demand for goods [DEG 16]. Big data can be characterized by five Vs [FOS 15]: (1) Volume, (2) Velocity, (3) Variety, (4) Value and (5) Veracity.

An analysis of the influence of big data on city transport operations using Markovian models has been analyzed [MEH 17]. This work demonstrates how big data could be used to improve transport efficiency and lower externalities in a smart city. A framework of big data operations and a discussion on how improvement could take place by having a car-free city environment, autonomous vehicles and shared resource capacity among providers is presented.

Analyzing big data and applying it in practice have the potential to enhance:

– sharing loads and resource capacity among stakeholders in the sharing economy,

– making both public and private entities benefit from collaborative freight transport systems by improving the efficiency of delivery by private companies as well as reducing the CO2 footprint and

– developing integrated management systems for city logistics, which is rather decentralized but well communicated among other agents.

Substantial value can be extracted from big data systems in urban environments, and new techniques are now available for big data acquisition, cleaning, aggregation, modeling and interpretation in large-scale sensor-based systems [ANG 16]. Big data collected by the IoT can help knowledge management in improving parking services [UDE 17].

1.5. Physical Internet

The Physical Internet (PI) involves a fully coordinated and integrated logistics system to improve sustainability. The main physical elements of the PI are containers, nodes and movers. The goal of the PI is to "enable the global sustainability of physical object movement, handling, storage, realization, supply and usage" [MON 10]. Hyperconnected city logistics (HCL) combines the concepts of city logistics and the PI [CRA 16] to provide a holistic view of interconnectedness which requires the commitment and coordination of many city logistics stakeholders.

HCL consists of a network of containers (e.g. boxes or pallets), nodes (shippers, transfer facilities, storage facilities and customers) and vehicles (including trucks, vans and trains). Models are required to provide decision support at the strategic, tactical and operational levels for designing and adapting current logistics networks for HCL. At the strategic level, this includes determining the location and function of nodes as well as the capacity of links. Multi-echelon networks need to be established, consisting of terminals that have both transfer and storage functions. A high degree of coordination is required at the operational level.

Containers are the load units that are used to move goods and they determine the vehicles used to transport goods as well as the loading equipment required to load and transfer goods. These typically include 20 and 40 foot shipping containers, pallets and boxes. Shipments or consignments can be smaller, consisting of one or more containers that can be bundled.

A model of formulation and solution procedures for incorporating the PI and city logistics has been developed [IME 17]. This model divides the working day into distinct time periods, and various vehicle types are able to serve pickup and delivery points. A city is split up into different types of zones, including peri-urban and central zones. The potential benefits to be gained from an integrated platform incorporating UCCs and transshipment points are described from surveys conducted in France and Japan [TAN 17].

1.5.1. *Movers*

The movers, or vehicles, provide the transport between terminals and between customers and terminals. It is important to determine the best vehicles to transport goods between nodes since the capacity (weight and size) of vehicles will influence the levels of service as well as the efficiency and productivity of networks. Operating costs for different classes of freight vehicles vary considerably [YAN 16]. Truck platooning will provide an opportunity to reduce operating costs, lower emissions and improve safety [TNO 14]. Freight lanes on main roads and freeways in urban areas have the potential for reducing operating costs and improving reliability.

High productivity vehicles (HPVs) have become popular in Australian urban areas to transport containers and general cargo between ports and warehouses. In addition to the reduced operating costs for carriers, HPVs provide a range of benefits for communities, including improved safety as well as reduced noise and emissions [THO 14b]. HPVs could be used to provide flexible, high-capacity movements between urban consolidation centers for HCL.

Urban rail shuttles also present an opportunity to reduce transport costs as well as road congestion in urban areas. However, this may require high capital costs for the construction of sidings and dedicated rail lines [KOR 16].

1.5.2. *Nodes*

Nodes or terminals are mainly used for transferring loads between vehicles as well as temporary storage. This allows consolidated loads on vehicles to be achieved. Two tiers comprised of urban consolidation centers (UCCs) and cross-docking centers (CDCs) can be established. UCCs provide both a storage and a transfer function while CDCs provide only a transfer service. Cross-docking involves a high degree of synchronization. UCCs are nodes at the first level that transfer goods received from external regions (imports) that are sent to CDCs in the city, other UCCs or CDCs within the city sent to external regions (exports), as well as other UCCs sent to other UCCs or CDCs in the city. CDCs form the second level of nodes that transfer goods received from UCCs or other CDCs sent to customers as well as goods from customers sent to other CDCs or UCCs.

An optimization model for locating urban container terminals with a rail link to a shipping port that incorporates mode choice and distribution models has been developed [TEY 16]. The best intermodal terminal location in the Sydney Metropolitan Area (SMA) was selected from a set of candidate solutions. Analysis of container movements for imports in the SMA indicated that this was influenced by several factors including access to manufacturing, access to warehouse and storage, access to key markets as well as access to multiple modes.

1.5.3. *Container loading*

HCL involves maximizing the utilization of freight vehicles as well as minimizing the transfer and storage costs at terminals. A range of models have been developed for improving the efficiency of elements of HVL, including loading containers, locating terminals and managing cross-docking facilities.

The container loading problem involves developing a packing plan for efficiently placing boxes into containers. Container loading problems have been reviewed [BOR 13]. Solution procedures for container loading problems have also been reviewed [ZHA 16].

A topology for bin-packing problems has been defined that considers the kind of assignment (maximization or minimization), the assortment of items (identical, weakly heterogeneous, strongly heterogeneous), dimensionality (1D to nD) and the shape of small items (regular or irregular) [WAS 07]. In practice, a range of practical issues need to be considered, including the orientation of boxes, weight balance, multiple containers, variable container lengths and routing.

The multiple-container loading problem involves developing a packing plan (where to put each box) that minimizes the total cost where each container has a different cost. Maximization problems involve developing a packing plan that maximizes the total volume or the value of boxes inside the available containers. The capacitated vehicle routing problem with container loading constraints (3L-CVRP) integrates routing and packing decisions. This involves consideration of volume utilization, load stability and distribution of weight. Integrating container loading with the determination of routes presents additional challenges. These include considering multi-drops, the ease of unloading, client time windows, the total route time, the number of vehicles as well as pickup and delivery tasks. The most common solution approaches for container loading problems are constructive heuristics and meta-heuristics.

1.5.4. *Cross-docking*

Strategies for transporting goods from suppliers to customers typically involve either direct shipment (good if FTL) or milk runs (good if customers are close to each other). If shippers and customers are not close to each other, then warehousing or cross-docking can be used to improve service levels and reduce transport costs. Traditional warehousing can have significant storage and order picking costs.

Cross-docking facilities can reduce transport costs by increasing consolidation. Partnerships are often necessary for trust, communication and control. Models can be used to provide support for strategic decisions (e.g. location, size and layout), tactical decisions (e.g. a mix of inbound and outbound docks as well as transport fleets) as well as operational decisions (e.g. scheduling of loading and unloading).

Simulation has been used for evaluating designs [ROH 95]. Optimization models have been developed to assist with the allocation of vehicles to doors and sequencing of vehicles to docks in order to minimize the total operation time and distances travelled in staging areas [MCW 05]. In practice, it is necessary to consider reliability by considering truck breakdowns, earliness and tardiness as well as time windows.

1.6. Co-modality

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 [TRE 10, GHI 13, MAS 15]. Specifically, using different people-based modalities for freight flows has to be considered, 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 times. Bus schedules can be adapted to accommodate the 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. Multi-modal integrated people and freight transportation networks need to be adequately designed. Moreover, coordinating, planning and scheduling policies that enable an 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 transport modes, although they generally share the same infrastructure, indicating potential efficiency gains for an integrated system [LIN 12]. With an integrated system, depending on the origin, destination, availability and due time of freight, it needs to be decided 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). Limited modeling has been undertaken on integrating public and goods transport.

Integrating passenger and freight transport systems is becoming more feasible due to recent developments in Information and Communication Technologies (ICT), such as smartphones and global positioning systems (GPS). This has led to interest from researchers [TRE 10, LIN 12, GHI 16, SAV 16]. A combination of passenger and freight transport can be realized by using buses or taxis for carrying goods as well as passengers. Passenger transport companies can benefit from carrying goods by utilizing space on less-crowded vehicles, while shippers benefit by having a convenient courier service as an option [THO 14b].

Using passenger vehicles for freight transport is becoming more common. In some real-world cases, vehicles are able to dynamically change between carrying passengers and goods. For instance, Uber frequently runs special offers to deliver certain items within a service area. A case study performed in the urban area of La Rochelle in France confirmed that it is efficient to use spare capacity on buses for distributing goods [TRE 12]. Despite the relatively limited number of implementations both in the literature and in practice, the benefits that co-modality offers warrant a more thorough investigation. In particular, proper strategies and approaches need to be determined to improve the financial viability and the service quality of a co-modal on-demand service.

A two-echelon routing problem in which goods are transported using city buses from a distribution center to a set of bus stops has been proposed [MAS 15]. 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.

The potential of an integrated system to reduce the number of vehicles required for freight transportation has recently been explored [GHI 13, GHI 16]. More specifically, they consider scheduling a set of vehicles to serve freight requests, in a system where the freight can be transported on part of its journey from an origin to a 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.

Conceptual and mathematical models in which people and parcels are (simultaneously) handled by the same taxi network have been developed [LI 14, LI 16a, LI 16b]. 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 types of problems resemble advanced pickup and delivery vehicle routing problems, but have many complicating features, such as transfers, synchronization, capacity constraints at transfer points and/or in vehicles, time windows and multiple echelons. 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.

A simulation and optimization model was developed to investigate the benefits associated with co-modality using an on-demand transportation scheme [RON 16]. The model found that co-modality can provide improved services among system operators, passengers and receivers.

There have been studies that have addressed the optimization of passenger–freight services, where optimization is mainly concerned with the vehicle routing aspects of the service, which is typically modeled as a mixed-integer programming problem. The formulation ranges from simple linear programming without any constraints to more complex ones that involve linearized constraints and cost/objective function. One of the more simple formulations does not involve any constraints but use a linear objective function [FAT 15]. Other models have more constraints yet, similarly, utilize a linear objective function [MAS 15, MIR 16]. More complicated formulations require constraint linearizations in order to simplify the problem [LI 14]. Furthermore, a unique variant of the problem, where scheduled public transport can be used in the routing, has been proposed [GHI 16].

Despite the commonality of these works in using MILP, it can be noted that most use a simple linear objective function that optimizes some form of “weighted distance” of the routes. Arguably, financial feasibility is the most important aspect of a DRT operation. Therefore, an appropriate objective function is required for implementation in practice. Only the most complex one [LI 14] considers, to some level, the trade-off between profit, cost and service level, whereas [MAS 15] it minimizes the fleet size separately. However, demand rejection is still allowed, and the costs considered are still a form of “weighted distance” of the routes. In addition, looking toward a more sustainable future where nobody owns a private vehicle, demand rejection is undesirable.

The capacitated pickup and delivery (or drop-off) problem with time windows (C-PDPTW) is a variant of the vehicle routing problem in which a customer request contains a pickup and drop-off between a pair of locations and are served by vehicles that have a certain maximum capacity. A definition of this problem is presented in [SAV 95]. The problem essentially creates a route plan for the fleet that minimizes a certain objective function, while ensuring that a pickup is visited before the corresponding drop-off. The objective function typically minimizes the total weighted distance of the route plan, which originates and finishes at a pre-specified depot. Typically, hard time windows are assumed where customers must be visited within nominated time windows for a solution to be feasible. However, with soft time windows, vehicle routes are penalized but still considered feasible if vehicles reach customers outside of the time window.

The C-PDPTW is typically considered to be a static problem with customer requests being fixed in advance. A number of exact solution methods have been developed for the C-PDPTW, including dynamic programming [PSA 86, DES 86], mixed-integer programming [ROP 09, BAL 11] and constraint programming [ZHO 09]. In addition, a number of approximation solution methods have been applied [XU 03, KON 11]. Some have focused on solution construction [LU 06, GRO 03] and others on solution improvement [HAS 07, BEN 06, ROP 06]. Also, a number of genetic algorithms have been applied [PAN 05, HOS 09, NAG 10] as well as ant colony optimization [BAD 08, HUA 10]. A survey of the C-PDPTW has been undertaken [PAR 08]. Neighborhood search heuristics have also been used [BEN 04, ROP 06, PIS 10, DEM 12, RIB 12, AZI 14]. Column generation has been used to reduce the scale of the resulting optimization problem [FEI 10].

A dynamic vehicle routing problem occurs when some of the trip requests only appear during the day and have not been considered in the initial route plan (such as in a DRT service). In a dynamic vehicle routing problem, it is possible that an optimal solution becomes a relatively poor one when new *ad hoc* requests emerge. Therefore, it can be beneficial to exploit some known stochastic information about the demand. This topic has gained traction in recent years [LAR 00, FLE 04, PIL 13]. Typically, sources of the stochastic information have been from either probabilistic models [GEN 96, YAN 00, LAP 02, SEC 09, LI 16b] or historical data [GEN 99, BEN 04].

The MSA approach samples fictitious demands from an historical demand data set to be considered in the vehicle routing optimization [BEN 04]. Thus, the resulting route plan anticipates and leaves room for future *ad hoc* demand if it materializes.

A model developed for co-modality based on anticipatory demand for the dynamic vehicle routing problem has shown promising results [KUT 16]. This model includes a comprehensive objective function, which allows acceptance of all demands, includes a realistic cost function and considers service levels. Historical information from travel surveys was used to predict passenger demand.

1.7. Electric vehicles

There has been a considerable concern among city logistics stakeholders about the environmental footprint of urban freight [DAB 07, MUÑ 10]. Electric vehicles (EVs), with their low emissions and operating costs, can provide a plausible solution, acceptable to all stakeholders. The European Union funded a large scale project for evaluating the viability of EVs in urban freight during 1998–2000, called the Electric Vehicle City Distribution (ECLIDIS). However, their relatively high initial cost [VER 02], limited driving range, and speed and acceleration make them less attractive for freight carriers [JEE 02]. Since then, many comparisons of EVs with conventional vehicles have been presented in the literature.

A comparison of three different types of electric with conventional trucks under varying scenarios has been undertaken [DAV 13]. This showed that electric trucks can be a viable alternative with the following conditions: the maximum distance travelled matches the range of EVs (taken as 100 miles (about 160 km)), low speed or congestion and frequent stops. A similar conclusion was found in a study that compared electric vehicles and conventional diesel trucks in terms of energy consumption, greenhouse gas emissions and ownership cost [LEE 13]. An analysis of the competitiveness of electric vehicles from an economic point of view considering subsidies, taxes, insurance, maintenance, car inspection costs along with initial cost and fuel consumption in the Brussels-Capital Region, found that EVs are advantageous in the lower payload range (less than 1,000 kg) [MAC 13]. A conjoint-based choice model considering the daily range, charging time, environmental performance, the type of vehicle, purchase cost and operating cost as the attributes defining vehicle choice has been developed [LEB 16]. A more precise analysis compared different types of EV trucks, (with 270 and 400 kWh motors) with not only conventional heavy duty trucks, but also hybrid, CNG and biodiesel trucks [SEN 17]. This study concluded that if the electricity generation mix is based on sustainable/renewable sources, then EV heavy trucks have an advantage over all other types of trucks tested in their study, despite their high initial cost.

The choice of vehicle type is based on the operational characteristics for the freight carriers, which led to the introduction of various fleet sizes and fleet mix models based on the vehicle routing framework. For example, the fleet size and mix vehicle routing problem with time windows (FSMVRPTW), considering electric vehicles as one of the vehicle options, has been presented [VAN 13]. Based on a case study in Amsterdam, they concluded that the use of electric vehicles in combination with urban consolidation centers can result in a 19% reduction of vehicle kilometers and a 90% reduction of CO_2 emissions. A realistic energy consumption model based on the speed, gradient and cargo load distribution has also been considered [GOE 15], whereas, [LEB 15] estimated a nonlinear regression equation for energy consumption using experimental results and theoretical values defined by speed, gradient, air drag, etc. A mathematical formulation of the electric vehicle routing problem with time windows (EVRPTW), considering a predefined range and possible recharges along their routes at charging stations, has also been developed [AFR 14]. Another study presented an EVRPTW where vehicles can recharge at customer locations [CON 11]. However, no computational example was given in their paper. In order to determine an optimal fleet mix and size, a portfolio optimization approach considering the total cost and the associated variances of the uncertain parameters such as the initial cost of EVs and the price fluctuation of fossil fuels has been developed [AHA 16].

Various trial implementations of the EVs have also been reported in the literature; for example, a trial of cooperative use of 28 electric vehicles in Osaka, Japan, was conducted [TAN 00]. EVs were parked at various public parking spaces and could be used by participating companies with advance booking. A micro-consolidation center in London operates with a last-mile delivery using electric vans and tricycles [BRO 11]. A report of the e-mobility NSR Project has summarized assessment of examples of using electric vehicles in about 60 cases in Denmark, Germany, the Netherlands and Norway [TUD 13]. This report mentioned that the current drive to introduce lower emission zones, lower operational costs, higher driving comfort and the possibility of night deliveries as well as companies' interest in environmental friendly solutions as part of their CSR strategies are the positive factors for EVs. The report also identified the main barriers as higher vehicle purchase price and charging infrastructure costs, a lower payload (due to the smaller size or loading capacity loss with heavy batteries), a limited range, uncertainties in vehicle performance and maintenance, and incompatibility with existing public charging infrastructure. A study of the policy requirements for the future growth of EVs in Germany from the perspective of the two key stakeholders, namely policy makers and the freight carriers, has been conducted [TAE 16]. They suggest that apart from subsidizing the purchase price of EVs, other policy measures such as patronage by the governmental bodies, setup of city tolls (pricing), tax incentives (as a long-term subsidy) and financial support to EV pilot projects would increase EV usage in the private sector (i.e. freight carriers).

1.8. Road network strengthening

The increasing frequency and severity of natural disaster events combined with growing levels of urbanization are creating the need to develop improved models to address the vulnerability, exposure and resilience of urban logistics systems [TAN 13]. In 2015, the United Nations launched a set of Sustainable Development Goals that include "Make cities and human settlements inclusive, safe, resilient and sustainable". This includes substantially decreasing the direct economic losses caused by disasters.

Planning for post-disaster reconstruction and recovery efforts of damaged transportation networks is a challenging and complex task due to (1) the limited availability of repair and construction resources including funding, materials and human resources, and (2) the conflicting planning and management objectives that need to be considered [LAM 02, OPR 02, MIL 12a, MES 11, ORA 09]. A comprehensive methodology should be able to consider and integrate a number of concepts such as risk, vulnerability and resilience within the disaster management cycle for improving the management of road transport infrastructure [MUR 06].

Although bridges and roads are difficult to protect from disasters, it is important to consider how to make them less vulnerable [HUS 05]. Some bridges and road links if damaged have a major disruption on the overall system especially if the topology of the network does not provide many alternative routes. Methods are required to be developed to identify the most critical components of road transport networks that should then be protected and strengthened.

There is a need to identify cost effective treatments for enhancing the post-disaster residual functionality of roads and bridges before extreme events occur. Before future disaster events occur, there is an opportunity to reduce their impact by strengthening elements of the transport network that are likely to be damaged and have a major role in the functionality of the transport system. This can involve strengthening bridges and increasing the geometry standard of roads.

An important issue is determining what facilities should be strengthened or protected from natural or man-made disasters. Key issues relate to identifying the most vulnerable elements of the road system from both transport and structural health condition perspective. Cost-effective methods for increasing the ability of road links and bridges to withstand the impacts of disasters should then be determined and implemented. Methods for identifying opportunities for increasing the redundancy, connectivity and modal substitution of vulnerable road elements also need to be developed. Methodologies for identifying the most vulnerable elements of rail transport system for a range of man-made disasters have been developed [MIL 12a, MIL 12b]. However, new methodologies need to be created to additionally consider the structural health of transport infrastructure in identifying the vulnerability of urban transport systems and its elements in one integrated system.

Analyzing and modeling the reliability of road networks has attracted substantial international research attention but has primarily been focused on the likelihood that urban congested networks will be able to operate at a required level of service [BEL 00, BEL 03]. The concept of network vulnerability as well as algorithms and visualization tools for identifying specific “weak spots” in road networks has already been developed [DES 03]. Methods for undertaking vulnerability analyses allowing for the interaction between a degraded network and network users have also been constructed [TAY 08, SUS 08]. A methodology for the scheduling of road strengthening works considering the disruption to traffic network-wide effects, using traffic assignment modeling over an extended time horizon, has been developed [TAP 01].

An Intelligent Disaster Decision Support System (IDDSS) has been created for improving the resilience of transport systems [RAJ 15]. The IDDSS combines visualization with simulation and optimization models that can be used to improve disaster management of urban road freight networks. A new technique has been developed that allows vulnerable road links in urban traffic networks to be identified efficiently [BAG 17].

There have been numerous studies investigating road network resilience that have used various approaches to either assess the resilience of networks or to make a network's level of service more resilient against disruptive events exploiting a variety of methods [CHE 12, FAN 10, FAT 14b, FEI 00, FIS 10, GUT 12, NAG 12, ROS 04, ZHA 14]. Many of them optimize either pre- or post-disaster activities or both of them together so that a chosen measure of resilience is maintained at the highest level [CHE 12, FAT 14a, MIL 12a, ZHA 14]. These studies concentrate on either mitigation actions that could be performed before an incident or post-incident recovery actions. Most of these studies optimize a measure of performance toward improving their objective function by changing one or multiple decision variables with regard to mitigation or recovery actions and scheduling.

Although there are various terms that overlap with the concept of resilience, such as robustness, reliability or survivability, a system's performance under disruptive conditions can be described qualitatively [MUR 06]. However, the concept of resilience for road networks is defined differently and applied quantitatively in various studies in the literature. Various measures of effectiveness (MOE) used for quantifying resilience have been defined [FAT 14a]. In general, these measures can be grouped into three main categories: functional, topological and economic measures. Travel time is an MOE which is applied to quantify resilience of a network in a vast amount of the literature. For instance, a method to quantify travel time resilience of roadway networks for disaster management has been proposed [FAT 14b].

1.9. Conclusions

Emerging digital and vehicle technologies have good potential for improving the sustainability of urban freight systems. To achieve the aims of city logistics, there is a need to incorporate a wider range of objectives such as environment and social costs into vehicle routing and scheduling procedures. This chapter provides an overview of the recent developments and prospects in city logistics as well as a summary of recent modeling approaches and issues.

For promoting electric vehicles, improved financial models are required as well as procedures that consider the range limits and location of charging stations. New models also need to be developed for integrating electric van fleets with initiatives such as UCCs and road pricing.

Procedures are necessary for integrating data and disseminating information from sensor networks for increasing the efficiency of distribution in the sharing economy. Enhanced models are required for handling dynamic demand and incorporating past demand patterns into operational procedures for efficiently allocating vehicles, including public transport vehicles.

A combination of simulation and optimization procedures are required for planning, designing and operating connected city logistics schemes based on the Physical Internet concept as well as co-modality systems. To minimize disruption from disasters, enhanced procedures will be required for identifying vulnerable links and evaluating strengthening options, considering network effects in order to improve the resilience of urban freight systems.

1.10. Bibliography

[AFR 14] AFRODITI A., BOILE M., THEOFANIS S. *et al.*, "Electric vehicle routing problem with industry constraints: trends and insights for future research", *Transportation Research Procedia*, vol. 3, pp. 452–459, 2014.

[AFS 16] AFSHAR-BAKESHLOO M., MEHRABI A., SAFARI H. *et al.*, "A green vehicle routing problem with customer satisfaction criteria", *Journal of Industrial Engineering International*, vol. 12, pp. 529–544, 2016.

[AHA 16] AHANI P., ARANTES A., MELO S., "A portfolio approach for optimal fleet replacement toward sustainable urban freight transportation", *Transportation Research Part D*, vol. 48, pp. 357–368, 2016.

[ANA 14] ANAND N., VAN DUIN J.H.R., VAN TAVASSZY L., "Ontology-based multi-agent system for urban freight transportation", *International Journal of Urban Sciences*, vol. 18, no. 2, pp. 133–153, 2014.

[ANA 16] ANAND N., MEIJER D., VAN DUIN J.H.R. *et al.*, "Validation of an agent based model using a participatory simulation gaming approach: the case of city logistics", *Transportation Research Part C*, vol. 71, pp. 489–499, 2016.

[ANG 16] ANG L.-M., SENG K.P., "Big sensor data applications in urban environments", *Big Data Research*, vol. 4, pp. 1–12, 2016.

[AZI 14] AZI N., GENDREAU M., POTVIN J.-Y., "An adaptive large neighborhood search for a vehicle routing problem with multiple routes", *Computers & Operations Research*, vol. 41, pp. 167–173, 2014.

[BAD 08] BADALONI S., FALDA M., SAMBO F. *et al.*, "Addressing temporally constrained delivery problems with the swarm intelligence approach", in BURGARD W., DILLMAN R., PLAGEMANN C. *et al.* (eds), *Intelligent Autonomous Systems*, vol. 10, 2008.

[BAG 17] BAGLOEE S., SARVI M., THOMPSON R.G. *et al.*, "Identifying Achilles-heel roads in real sized networks", *Journal of Modern Transportation*, pp. 1–11, 2017.

[BAL 11] BALDACCI R., BARTOLINI E., MINGOZZI A., "An exact algorithm for the pickup and delivery problem with time windows", *Operations Research*, vol. 59, no. 2, pp. 414–426, 2011.

[BEK 11] BEKTAS T., LAPORTE G., "The pollution-routing problem", *Transportation Research Part B*, vol. 45, pp. 1232–1250, 2011.

[BEL 00] BELL M.G.H., CASSIR C., *Reliability of Transport Networks*, Research Studies Press, Baldock, 2000.

[BEL 03] BELL M.G.H., IIDA Y., *The Network Reliability of Transport*, Pergamon-Elsevier, 2003.

[BEN 04] BENT R., HENTENRYCK P.V., "A two-stage hybrid local search for the vehicle routing problem with time windows", *Transportation Science*, vol. 38, no. 4, pp. 515–530, 2004.

[BEN 06] BENT R., HENTENRYCK P.V., "A two-stage hybrid algorithm for pickup and delivery vehicle routing problems with time windows", *Computers & Operations Research*, vol. 33, no. 4, pp. 875–893, 2006.

[BHU 14] BHUSIRI N., QURESHI A.G., TANIGUCHI E., "The trade-off between fixed vehicle costs and time-dependent arrival penalties in a routing problem", *Transportation Research Part E*, vol. 62, pp. 1–22, 2014.

[BOR 13] BORTFELDT A., WASCHER G., "Constraints in container loading – A state-of-the-art review", *European Journal of Operational Research*, vol. 1, pp. 1–20, 2013.

[BRO 11] BROWNE M., ALLEN J., LEONARDI J., "Evaluating the use of an urban consolidation centre and electric vehicles in central London", *IATSS Research*, vol. 35, no. 1, pp. 1–6, 2011.

[CHE 12] CHEN L., MILLER-HOOKS E., "Resilience: an indicator of recovery capability in intermodal freight transport", *Transportation Science*, vol. 46, no. 1, pp. 109–123, 2012.

[CHO 07] CHOI E., TCHA D.W., "A column generation approach to the heterogeneous fleet vehicle routing problem", *Computers & Operation Research*, vol. 34, pp. 2080–2095, 2007.

[CON 11] CONRAD R.G., FIGLIOZZI M.A., "The recharging vehicle routing problem", in DOOLEN T., VAN AKEN E. (eds), *Proceedings Industrial Engineering Research Conference*, Reno, 2011.

[CRA 16] CRAINIC T.G., MONTREUIL B., "Physical internet enabled hyperconnected city logistics", *Transportation Research Procedia*, vol. 12, pp. 383–98, 2016.

[DAB 07] DABLANC L., "Goods transport in large European cities: Difficult to organize, difficult to modernize", *Transportation Research Part A*, vol. 41, pp. 280–285, 2007.

[DAN 60] DANTZIG G.B., WOLFE P., "Decomposition principle for linear programs", *Operations Research*, vol. 8, pp. 101–111, 1960.

[DAV 13] DAVIS B.A., FIGLIOZZI M.A., "A methodology to evaluate the competitiveness of electric delivery trucks", *Transportation Research Part E*, vol. 49, pp. 8–23, 2013.

[DEG 16] DE GENNARO M., PAFFUMI E., MARTINI G., "Big data for supporting low-carbon road transport policies in Europe: Applications, challenges and opportunities", *Big Data Research*, vol. 6, pp. 11–25, 2016.

[DEM 12] DEMIR E., BEKTAS T., LAPORTE G., "An adaptive large neighbourhood search heuristic for the pollution-routing problem", *European Journal of Operational Research*, vol. 223, no. 2, pp. 346–359, 2012.

[DES 86] DESROSIERS J., DUMAS Y., SOUMIS F., "A dynamic programming solution of the large-scale single-vehicle dial-a-ride problem with time windows", *American Journal of Mathematical and Management Sciences*, vol. 6, nos 3–4, pp. 301–325, 1986.

[DES 03] D'ESTE G.M., TAYLOR M.A.P., "Network vulnerability: an approach to reliability analysis at the level of national strategic transport networks", in BELL M.G.H., IIDA Y., (eds), *The Network Reliability of Transport*, 2003.

[DOP 16] DOPPSTADT C., KOBERSTEIN A., VIGO D., "The hybrid electric vehicle – Traveling salesman problem", *European Journal of Operational Research*, vol. 253, pp. 825–842, 2016.

[ERD 12] ERDOGAN S., MILLER-HOOKS E., "A green vehicle routing problem", *Transportation Research Part E*, vol. 48, pp. 100–114, 2012.

[FAN 10] FAN Y., LIU C., "Solving stochastic transportation network protection problems using the progressive hedging-based method", *Networks and Spatial Economics*, vol. 10, no. 2, pp. 193–208, 2010.

[FAT 14a] FATURECHI R., MILLER-HOOKS E., "Measuring the performance of transportation infrastructure systems in disasters: A comprehensive review", *Journal of Infrastructure Systems*, available at: http://ascelibrary.org/doi/abs/10.1061/(ASCE)IS.1943-555X.0000212, 2014.

[FAT 14b] FATURECHI R., MILLER-HOOKS E., "Travel time resilience of roadway networks under disaster", *Transportation Research Part B: Methodological*, vol. 70, pp. 47–64, 2014.

[FAT 15] FATNASSI E., CHAOUACHI J., KLIBI W., "Planning and operating a shared goods and passengers on-demand rapid transit system for sustainable city-logistics", *Transportation Research Part B*, vol. 81, no. 2, pp. 440–460, 2015.

[FEI 00] FEITELSON E., SALOMON I., "The implications of differential network flexibility for spatial structures", *Transportation Research Part A: Policy and Practice*, vol. 34, no. 6, pp. 459–479, 2000.

[FEI 10] FEILLET D., "A tutorial on column generation and branch-and-price for vehicle routing problems", *4OR*, vol. 8, no. 4, pp. 407–424, 2010.

[FIR 17] FIRDAUSIYAH N., TANIGUCHI E., QURESHI A.G., "Multi-agent simulation using adaptive dynamic programming for evaluating city logistics policy of urban consolidation centers", *Proceedings of the Tenth International Conference on City Logistics*, Phuket, 2017.

[FIS 10] FISHER R., NORMAN M., "Developing measurement indices to enhance protection and resilience of critical infrastructure and key resources", *Journal of Business Continuity & Emergency Planning*, vol. 4, no. 3, pp. 191–206, 2010.

[FLE 04] FLEISCHMANN B., GNUTZMANN S., SANDVOB E., "Dynamic vehicle routing based on online traffic information", *Transportation Science*, vol. 38, no. 4, pp. 420–433, 2004.

[FOS 15] FOSSO-WAMBA S., AKTER S., EDWARDS A. *et al.*, "How 'big data' can make big impact: Findings from a systematic review and a longitudinal case study", *International Journal of Production Economics*, vol. 165, pp. 234–246, 2015.

[GEN 96] GENDREAU M., LAPORTE G., SEGUIN R., "Stochastic vehicle routing", *European Journal of Operational Research*, vol. 88, no. 1, pp. 3–12, 1996.

[GEN 99] GENDREAU M., GUERTIN F., POTVIN J.-Y. *et al.*, "Parallel tabu search for real-time vehicle routing and dispatching", *Transportation Science*, vol. 33, pp. 381–390, 1999.

[GHI 13] GHILAS V., DEMIR E., VAN WOENSEL T., Integrating passenger and freight transportation: model formulation and insights, Beta Working Paper series, vol. 441, 2013.

[GHI 16] GHILAS V., DEMIR E., VAN WOENSEL T., "An adaptive large neighborhood search heuristic for the pickup and delivery problem with time windows and scheduled lines", *Computers & Operations Research*, vol. 72, pp. 12–30, 2016.

[GOE 14] GOEL A., VIDAL T., "Hours of service regulations in road freight transport: An optimization-based international assessment", *Transportation Science*, vol. 48, pp. 391–412, 2014.

[GOE 15] GOEKE D., SCHNEIDER M., "Routing a mixed fleet of electric and conventional vehicles", *European Journal of Operational Research*, vol. 245, pp. 81–99, 2015.

[GRO 03] GRONALT M., HARTL R.F., REIMANN M., "New savings based algorithms for time constrained pickup and delivery of full truckloads", *European Journal of Operational Research*, vol. 151, no. 3, pp. 520–553, 2003.

[GRU 16] GRULER A., DE ARMAS J., JUAN A.A., "Behavioral factors in city logistics from an operations research perspective", in ALBA E., CHICANO F., LUQUE G. (eds), *Smart Cities. Smart-CT 2016*, Springer, Cham, 2016.

[GUT 12] GUTFRAIND A., BRADONJIĆ M., NOVIKOFF T., "Optimal recovery of damaged infrastructure network", *arXiv: 1207.2799*, 2012.

[HAS 07] HASLE G., KLOSTER O., "Industrial vehicle routing", in HASLE G., LIE K., QUAK E. (eds), *Geometric Modelling, Numerical Simulation, and Optimization*, Springer, pp. 397–435, 2007.

[HOS 09] HOSNY M., MUMFORD C., "New solution construction heuristics for the multiple vehicle pickup and delivery problem with time windows", *MIC2009, Metaheuristic International Conference*, Hamburg, Germany, 13–16 July 2009.

[HUA 10] HUANG Y.-H., TING C.-K., "Ant colony optimization for the single vehicle pickup and delivery problem with time window", *Technologies and Applications of Artificial Intelligence (TAAI)*, Hsinchu, 18–20 November 2010.

[HUS 05] HUSDAL J., The vulnerability of road networks in a cost-benefit perspective, TRB 84th Annual Meeting, available at: www.husdal.com/gis/trb2005_final.pdf, 2005.

[IME 17] IMEN B.M., KLIBI W., LABARTHE O. *et al.*, "Modelling and solution approaches for the interconnected city logistics", *International Journal of Production Research*, vol. 55, no. 9, pp. 2664–2684, 2017.

[JAB 12] JABALI O., VAN WOENSEL T., DE KOK A., "Analysis of travel times and CO_2 emissions in time-dependent vehicle routing", *Production and Operations Management*, vol. 21, pp. 1060–1074, 2012.

[JAN 14] JANSSEN R., ZWIJNENBERG H., BLANKERS I. *et al.*, Truck Platooning: Driving the Future of Transportation, TNO Mobility and Logistics, Delft, 2014.

[JEE 02] JEENINGA H., VAN ARKEL W.G., VOLKERS C.H., Performance and Acceptance of Electric and Hybrid Vehicles, Municipality of Rotterdam, 2002.

[JUA 16] JUAN A.A., CHICA M., DE ARMAS J. *et al.*, "Simheuristics: a method of first resort for solving real-life combinatorial optimization problems", *Keynote Papers and Extended Abstracts, OR58 Annual Conference*, pp. 147–156, University of Portsmouth, Portsmouth, 2016.

[KOH 99] KOHL N., DESROSIERS J., MADSEN O.B.G. *et al.*, "2-path cuts for the vehicle routing problem with time windows", *Transportation Science,* vol. 33, pp. 101–116, 1999.

[KON 11] KONING D., VAN DEN AKKER J., HOOGEVEEN J., Using column generation for the pickup and delivery problem with disturbances, Master's thesis, Department of Computer Science, Utrecht University, 2011.

[KOR 16] KORDNEJAD B., "Stakeholder analysis in intermodal urban freight transport", *Transportation Procedia*, vol. 12, pp. 750–764, 2016.

[KRA 15] KRAMER R., SUBRAMANIAN A., VIDAL T. *et al.*, "A matheuristic approach for the pollution-routing problem", *European Journal of Operational Research*, vol. 243, pp. 523–539, 2015.

[KUO 11] KUO Y., WANG C., "Optimizing the VRP by minimizing fuel consumption", *Management of Environmental Quality: An International Journal*, vol. 22, pp. 440–450, 2011.

[KUT 16] KUTADINATA R.J., THOMPSON R.G., WINTER S., "Cost-efficient co-modal ride-sharing scheme through anticipatory dynamic optimisation", *23rd ITS World Congress*, Melbourne, 10–14 October, 2016.

[LAM 02] LAMBERT J.H., PATTERSON C.E., "Prioritizing of schedule dependencies in hurricane recovery of transportation agency", *Journal of Infrastructure System*, vol. 8, no. 3, 2002.

[LAP 02] LAPORTE G., LOUVEAUZ F.V., VAN HAMME L., "An integer l-shaped algorithm for the capacitated vehicle routing problem with stochastic demands", *Operations Research*, vol. 50, no. 3, pp. 415–423, 2002.

[LAR 00] LARSEN A., The dynamic vehicle routing problem, PhD thesis, Technical University of Denmark*,* 2000.

[LEB 15] LEBEAU P., DE CAUWER C., VAN MIERLO J. *et al.*, "Conventional, hybrid, or electric vehicles: Which technology for an urban distribution centre?", *The Scientific World Journal*, pp. 1–11, 2015.

[LEB 16] LEBEAU P., MACHARIS C., VAN MIERLO J., "Exploring the choice of battery electric vehicles in city logistics: A conjoint-based choice analysis", *Transportation Research Part E*, vol. 91, pp. 245–258, 2016.

[LEE 13] LEE D.Y., THOMAS V.M., BROWN M.A., "Electric urban delivery trucks: energy use, greenhouse gas emissions, and cost-effectiveness", *Environmental Science & Technology*, vol. 47, pp. 8022–8030, 2013.

[LI 14] LI B., KRUSHINSKY D., REIJERS H.A. *et al.*, "The share-a-ride problem: people and parcels sharing taxis", *European Journal of Operational Research*, vol. 238, pp. 31–40, 2014.

[LI 16a] LI B., KRUSHINSKY D., VAN WOENSEL T. *et al.*, "The share-a-ride problem with stochastic travel times and stochastic delivery locations", *Transportation Research Part C*, vol. 67, pp. 95–108, 2016.

[LI 16b] LI B., KRUSHINSKY D., VAN WOENSEL T. *et al.*, "An adaptive large neighborhood search heuristic for the share-a-ride problem", *Computers & Operations Research*, vol. 66, pp. 170–180, 2016.

[LIN 12] LINDHOLM M., BEHRENDS S., "Challenges in urban freight transport planning – a review in the Baltic sea region", *Journal of Transport Geography*, vol. 22, pp. 129–136, 2012.

[LIN 14] LIN C., CHOY K.L., HO G.T.S. *et al.*, "Survey of green vehicle routing problem: Past and future trends", *Expert Systems with Applications*, vol. 41, pp. 1118–1138, 2014.

[LOZ 11] LOZANO A., MUÑOZ Á., MACÍAS L. *et al.*, "Hazardous materials transportation in Mexico City: Chlorine and gasoline cases", *Transportation Research Part C*, vol. 19, pp. 779–789, 2011.

[LU 06] LU Q., DESSOUKY M.M., "A new insertion-based construction heuristic for solving the pickup and delivery problem with time windows", *European Journal of Operational Research*, vol. 175, no. 2, pp. 672–687, 2006.

[MAC 13] MACHARIS C., LEBEAU P., VAN MIERLO J. *et al.*, "Electric versus conventional vehicles for logistics: A total cost of ownership", *EVS27*, Barcelona, 17–20 November 2013.

[MAN 17] MANCINI S., "The hybrid vehicle routing problem", *Transportation Research Part C: Emerging Technologies*, vol. 78, pp. 1–12, 2017.

[MAS 15] MASSON R., TRENTINI A., LEHUEDE F. *et al.*, "Optimization of a city logistics transportation system with mixed passengers and goods", *EURO Journal on Transportation and Logistics*, pp. 1–29, 2015.

[MCW 05] MCWILLIAMS D., "Simulation-based scheduling for parcel consolidation terminals: a comparison of iterative improvement and simulated annealing", *Proceedings of the Winter Simulation Conference*, pp. 2087–2093, 2005.

[MEH 17] MEHMOOD R., MERITON R., GRAHAM G. *et al.*, "Exploring the influence of big data on city transport operations: a Markovian approach", *International Journal of Operations & Production Management*, vol. 37, no. 1, pp. 75–104, 2017.

[MEL 14] MELIÁN-BATISTA B.A., DE SANTIAGO A., ANGELBELLO F. *et al.*, "A bi-objective vehicle routing problem with time windows: a real case in Tenerife", *Applied Soft Computing*, vol. 17, pp. 140–152, 2014.

[MES 11] MESBAH M., SARVI M., CURRIE G., "Optimization of transit priority in the transportation network using a decomposition methodology", *Transportation Research Part C: Emerging Technologies*, vol. 19, no. 2, pp. 363–373, 2011.

[MIL 12a] MILLER-HOOKS E., "Measuring and maximizing resilience of freight transportation networks", *Computers & Operations Research*, vol. 39, pp. 1633–1643, 2012.

[MIL 12b] MILLER-HOOKS E., "Resilience: An indicator of recovery capability in intermodal freight transport", *Transportation Science*, vol. 46, pp. 109–123, 2012.

[MIR 16] MIRZAEI S., WOHLK S., "A branch-and-price algorithm for two multi-compartment vehicle routing problems", *European Journal on Transportation and Logistics*, pp. 1–33, 2016.

[MON 10] MONTREUIL B., Physical Internet Manifesto, available at: www.physicalinternetinitiative.org, 2010.

[MUÑ 17] MUÑOZ-VILLAMIZAR A., MONTOYA-TORRES J.R., FAULIN J., "Impact of the use of electric vehicles in collaborative urban transport networks: A case study", *Transportation Research Part D*, vol. 50, pp. 40–54, 2017.

[MUÑ 10] MUÑUZURI J., VAN DUIN J.H.R., ESCUDERO A., "How efficient is city logistics? Estimating ecological footprints for urban freight deliveries", *Procedia – Social and Behavioral Sciences*, vol. 2, no. 3, pp. 6165–6176, 2010.

[MUR 06] MURRAY-TUITE P.M.A., "Comparison of transportation network resilience under simulated system optimum and user equilibrium conditions", *Proceedings of the 2006 Winter Simulation Conference*, 2006.

[NAG 10] NAGATA Y., KOBAYASHI S., "A memetic algorithm for the pickup and delivery problem with time windows using selective route exchange crossover", *Parallel Problem Solving from Nature, PPSN XI*, pp. 536–545, Springer, 2010.

[NAG 12] NAGURNEY A., QIANG Q., "Fragile networks: Identifying vulnerabilities and synergies in an uncertain age", *International Transactions in Operational Research*, vol. 19, nos 1–2, pp. 123–160, 2012.

[OPR 02] OPRICOVIC S., TZENG G.-H., "Muticriteria planning of post-earthquake sustainable reconstruction", *Computer-aided Civil and Infrastructure Engineering*, vol. 17, no. 3, pp. 211–220, 2002.

[ORA 09] ORABI W., EL-RAYES K., SENOUCI A.B. *et al.*, "Optimising postdisater reconstruction planning for damaged transport networks", *Journal of Construction Engineering and Management*, vol. 135, no. 10, pp. 1039–1048, 2009.

[PAN 05] PANKRATZ G., "A grouping genetic algorithm for the pickup and delivery problem with time windows", *OR Spectrum*, vol. 27, no. 1, pp. 21–41, 2005.

[PAR 08] PARRAGH S.N., DOERNER K.F., HARTL R.F., "A survey on pickup and delivery problems", *Journal für Betriebswirtschaft*, vol. 58, no. 1, pp. 21–51, 2008.

[PIL 13] PILLAC V., GENDREAU M., GUERET C. *et al.*, "A review of dynamic vehicle routing problems", *European Journal of Operational Research*, vol. 225, no. 1, pp. 1–11, 2013.

[PIS 10] PISINGER D., ROPKE S., "Large neighbourhood search", in GENDREAU M., POTVIN J.-Y. (eds), Handbook of Metaheuristics of International Series in Operations Research & Management Science, vol. 146, Springer, 2010.

[PRA 14a] PRADHANANGA R., TANIGUCHI E., YAMADA T. *et al.*, "Bi-objective decision support system for routing and scheduling of hazardous materials", *Socio-Economic Planning Sciences*, vol. 48, pp. 135–148, 2014.

[PRA 14b] PRADHANANGA R., TANIGUCHI E., YAMADA T. *et al.*, "Risk of traffic incident delay in routing and scheduling of hazardous materials", *International Journal of Intelligent Transportation Systems Research*, vol. 14, no. 1, pp. 1–14, 2014.

[PSA 86] PSARAFTIS H.N., “Scheduling large-scale advance-request dial-a-ride systems”, *American Journal of Mathematical and Management Sciences*, vol. 6, nos 3–4, pp. 327–367, 1986.

[QUR 09] QURESHI A.G., TANIGUCHI E., YAMADA T., “An exact solution approach for vehicle routing and scheduling problems with soft time windows”, *Transportation Research Part E*, vol. 45, pp. 960–977, 2009.

[RAJ 15] RAJABIFARD A., THOMPSON R.G., CHEN Y., “An intelligent disaster decision support system for increasing the sustainability of transport networks”, *Natural Resources Forum*, vol. 39, pp. 83–96, 2015.

[RIB 12] RIBEIRO G.M., LAPORTE G., “An adaptive large neighborhood search heuristics for the cumulative capacitated vehicle rouging problem”, *Computers & Operations Research*, vol. 39, no. 3, pp. 728–735, 2012.

[ROH 95] ROHRER M., “Simulation and cross docking”, *Proceedings of the Winter Simulation Conference*, pp. 846–849, 1995.

[RON 16] RONALD N., YANG J., THOMPSON R.G., “Exploring co-modality using on-demand transport systems”, *Transportation Research Procedia*, vol. 12, pp. 203–212, 2016.

[ROO 10] ROORDA M.J., CAVALCANTE R., MCCABE S. *et al.*, “A conceptual framework for agent-based modelling of logistics services”, *Transportation Research Part E*, vol. 46, pp. 18–31, 2010.

[ROP 06] ROPKE S., PISINGER D., “An adaptive large neighbourhood search heuristic for the pickup and delivery problem with time windows”, *Transportation Science*, vol. 40, no. 4, pp. 455–472, 2006.

[ROP 09] ROPKE S., CORDEAU J.F., “Branch and cut and price for the pickup and delivery problem with time windows”, *Transportation Science*, vol. 43, no. 3, pp. 267–286, 2009.

[ROS 04] ROSE A., “Defining and measuring economic resilience to disasters”, *Disaster Prevention and Management*, vol. 13, no. 4, pp. 307–314, 2004.

[SAV 95] SAVELSBERGH M.W., SOL M., “The general pickup and delivery problem”, *Transportation Science*, vol. 29, no. 1, pp. 17–29, 1995.

[SAV 16] SAVELSBERGH M., VAN WOENSEL T., “City Logistics: Challenges and opportunities”, *Transportation Science*, vol. 50, no. 2, pp. 579–590, 2016.

[SCH 14] SCHNEIDER M., STENGER A., GOEKE D., “The electric vehicle-routing problem with time windows and recharging stations”, *Transportation Science*, vol. 48, no. 4, pp. 500–520, 2014.

[SEC 09] SECONMANDI N., MARGOT F., “Reoptimization approaches for the vehicle-routing problem with stochastic demands”, *Operations Research*, vol. 57, no. 1, pp. 214–230, 2009.

[SEN 17] SEN B., ERCAN T., TATARI O., “Does a battery-electric truck make a difference? – Life cycle emissions, costs, and externality analysis of alternative fuel-powered Class 8 heavy-duty trucks in the United States”, *Journal of Cleaner Production*, vol. 141, pp. 110–121, 2017.

[SHA 17] SHARAFI A., BASHIRI M., “Green vehicle routing problem with safety and social concerns”, *Journal of Optimization in Industrial Engineering*, vol. 21, pp. 93–100, 2017.

[SOL 87] SOLOMON M.M., “Algorithms for the vehicle routing and scheduling problem with time windows constraints”, *Operations Research*, vol. 35, pp. 254–265, 1987.

[SUS 08] SUSILAWATI S., TAYLOR M.A.P., “An accessibility approach in assessing regional road network vulnerability”, *Proceeding of 31st Australasian Transport Research Forum*, Gold Coast, 2008.

[TAE 16] TAEFI T.T., KREUTZFELDT J., HELD T. *et al.*, “Supporting the adoption of electric vehicles in urban road freight transport – A multi-criteria analysis of policy measures in Germany”, *Transportation Research Part A*, vol. 91, pp. 61–79, 2016.

[TAM 10] TAMAGAWA D., TANIGUCHI E., YAMADA T., “Evaluating city logistics measures using a multi-agent model”, *Procedia – Social and Behavioral Sciences*, vol. 2, no. 3, pp. 6002–6012, 2010.

[TAN 00] TANIGUCHI E., KAWAKATSU S., TSUJI H., “New co-operative system using electric vans for urban freight transport”, in SUCHAROV L., BREBBIA C.A. (eds), *Urban Transport and the Environment for the 21st Century VI*, WIT Press, Southampton, pp. 201–210, 2000.

[TAN 02] TANIGUCHI E., THOMPSON R.G., “Modeling city logistics”, *Transportation Research Record*, vol. 1790, pp. 45–51, 2002.

[TAN 07] TANIGUCHI E., YAMADA T., OKAMOTO M., “Multi-agent modelling for evaluating dynamic vehicle routing and scheduling systems”, *Journal of Eastern Asia Society, Transportation Studies*, vol. 7, pp. 933–948, 2007.

[TAN 13] TANIGUCHI E., FWA T.F., THOMPSON R.G., *Urban Transportation and Logistics: Health, Safety, and Security Concerns*, CRC Press, Boca Raton, 2013.

[TAN 17] TANIGUCHI E., DUPAS R., DESCHAMPS J.C. *et al.*, “Concepts of an integrated platform for innovative city logistics with urban consolidation centres and transhipment points”, *Proceedings of the Tenth International Conference on City Logistics*, Phuket, 2017.

[TAP 01] TAPLIN J., QUI M., “Using GA to optimize the selection and scheduling of road projects”, in CHAMBERS L. (ed.), *The Practical Handbook of Genetic Algorithms Applications*, Chapman & Hall / CRC Press, Boca Raton, 2001.

[TAY 08] TAYLOR M.A.P., “Critical transport infrastructure in urban areas: impacts of traffic incidents assessed using accessibility based network vulnerability analysis”, *Growth and Change*, vol. 39, pp. 593–616, 2008.

[TEO 12] TEO J.S.E., TANIGUCHI E., QURESHI A.G., “Evaluation of distance-based and cordon-based urban freight road pricing on e-commerce environment with multi-agent model”, *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2269, pp. 127–134, 2012.

[TEO 14] TEO J.S.E., TANIGUCHI E., QURESHI A.G., “Multi-agent systems modelling approach to evaluate urban motorways for city logistics”, *International Journal of Urban Sciences*, vol. 18, no. 2, pp. 154–165, 2014.

[TEO 15] TEO J.S.E., TANIGUCHI E., QURESHI A.G., “Evaluation of urban distribution centers using multiagent modeling with geographic information systems”, *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2478, pp. 35–47, 2015.

[TEY 16] TEYE C., BELL M.G.H., BLIEMER M.C.J., “Optimal location of open access urban container terminals under elastic cargo demand”, *Proceedings Australasian Transport Research Forum*, Melbourne, 2016.

[THO 14a] THOMPSON R.G., TANIGUCHI E., “Future directions”, in TANIGUCHI E., THOMPSON R.G. (eds), *City Logistics - Mapping the Future*, CRC Press, Boca Raton, 2014.

[THO 14b] THOMPSON R.G., HASSALL K., “Implementing high productivity freight vehicles in urban areas”, *Procedia – Social and Behavioral Sciences*, vol. 151, pp. 318–332, 2014.

[TRE 10] TRENTINI A., MALHN N., “Toward a shared urban transport system ensuring passengers & goods”, *TeMa*, vol. 3, pp. 37–44, 2010.

[TRE 12] TRENTINI A., MASSON R., LEHUÉDÉ F. *et al.*,, “A shared “passengers & goods” city logistics system”, *4th International Conference on Information Systems, Logistics and Supply Chain*, Quebec, 2012.

[TUD 13] TU DELFT, E-Mobility NSR Comparative Analysis of European Examples of Schemes for Freight Electric Vehicles – Compilation report, Aalborg, Denmark, 2013.

[UDE 17] UDEN L., HE W., “How the Internet of Things can help knowledge management: a case study from the automotive domain”, *Journal of Knowledge Management*, vol. 21, no. 1, pp. 57–70, 2017.

[VAN 07] VAN DUIN J.H.R., VAN TAVASSZY L.A., TANIGUCHI E., “Real time simulation of auctioning and re-scheduling processes in hybrid freight markets”, *Transportation Research, Part B*, vol. 41, no. 9, pp. 1050–1066, 2007.

[VAN 12] VAN DUIN J.H.R., VAN KOLCK A., VAN ANAND N. *et al.*, “Towards an agent based modelling approach for the dynamic usage of urban distribution centres”, *Procedia – Social and Behavioral Sciences*, vol. 39, pp. 333–348, 2012.

[VAN 13] VAN DUIN J.H.R., VAN TAVASSZY L.A., QUAK H.J., “Towards E(lectric)-urban freight: first promising steps in the electric vehicle revolution”, *European Transport \ Trasporti Europei*, vol. 54, pp. 1–19, 2013.

[VER 02] VERMIE T., Electric Vehicle City Distribution, Final report, European Commission Project, 2002.

[WAS 07] WASCHER G., HAUBNER H., SCHUMANN H., "An improved typology of cutting and packing problems", *European Journal of Operational Research*, vol. 3, pp. 1109–1130, 2007.

[XIA 12] XIAO Y., ZHAO Q., KAKU I. *et al.*, "Development of a fuel consumption optimization model for the capacitated vehicle routing problem", *Computers & Operations Research*, vol. 39, pp. 1419–1431, 2012.

[XU 03] XU H., CHEN Z.-L., RAJAGOPAL S. *et al.*, "Solving a practical pickup and delivery problem", *Transportation Science*, vol. 37, no. 3, pp. 347–364, 2003.

[YAN 00] YANG W., MATHUR K., BALLOU R., "Stochastic vehicle routing problem with restocking", *Transportation Science*, vol. 34, pp. 99–112, 2000.

[YAN 15] YANG J., SUN H., "Battery swap station location-routing problem with capacitated electric vehicles", *Computers & Operations Research*, vol. 55, pp. 217–232, 2015.

[YAN 16] YAN Y., PERERA L.P., THOMPSON R.G. *et al.*, "Determining optimal toll levels for City Logistics", *Proceedings 27th ARRB Conference*, Melbourne, 2016.

[ZHA 14] ZHANG X., MILLER-HOOKS E., "Scheduling short-term recovery activities to maximize transportation network resilience", *Journal of Computing in Civil Engineering*, vol. 29, no. 6, 2014.

[ZHA 16] ZHAO X., BENNELL J.A., BEKTAS T. *et al.*, "A comparative review of 3D container loading algorithms", *Internal Transactions in Operational Research*, vol. 1, no. 2, pp. 287–320, 2016.

[ZHA 17] ZHANG D., CAI S., YE F. *et al.*, "A hybrid algorithm for a vehicle routing problem with realistic constraints", *Information Sciences*, vols 394–395, pp. 167–182, 2017.

[ZHO 09] ZHOU J., "Routing by mixed set programming", *Proceedings of the 8th International Symposium on Operations Research and its Applications*, pp. 155–166, 2009.