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Commercial Electric Vehicle Routing in Urban Logistics: A Systematic Literature Review

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Purpose: Global supply chains increasingly demand sustainable setups, from the first to the last mile in transportation. Particularly in urban settings, the use of commercial electric vehicles for transport tasks might be a suitable measure to increase overall sustainability.
Methodology: For an initial structuring step of this growing research field, this paper conducts a systematic literature review based on Denyer and Tranfield (2010). The aim is to provide an overview regarding existing routing approaches for commercial electric vehicles, their characteristics and their suitability for typical application contexts in urban logistics (e.g. retail, parcel delivery, gastronomy).
Findings: The results point out topical gaps regarding the specific characteristics considered in the routing models and the focus of their optimization objectives. Among others, research gaps where identified regarding specific urban logistics requirements like energy management considerations for cooling/heating, mixed fleet modelling and (partial) recharging.
Originality: While the ecologic and economic impacts of electric vehicles have already been researched extensively, the OR-perspective on their commercial use still is an emerging topic. This review contributes to the structuring of this research field, which can play a key role in the practical application of electric vehicles in urban contexts.

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1 Introduction

In recent years, greenhouse gas (GHG) emissions became a central point of concern and attention in the logistics and transportation sector. The topic is becoming even more relevant as road freight transport emissions in the EU increased strongly since 1990 (Faberi, et al., 2015; European Environment Agency, 2018). In 2017, the share of transport sector GHG emissions in the EU-28 was 24.6%. More than 70% of these emissions were caused by road transportation (European Environment Agency, 2020). As continuous strong growth in freight transport is expected between 2010 and 2050, there is an urgent need for sustainability improvements in logistics worldwide (Klumpp, 2016; Barcellos de Paula and Marins, 2018; Klumpp, 2018; Okraszewska, et al., 2019).

In this context, electric vehicles are one of the most discussed options as multiple studies show their GHG-emissions-reduction-potential. (Hawkins, et al., 2013; Giordano, Fischbeck and Matthews, 2018). In recent years, the number of commercial electric vehicles used in logistics has been growing. Increasing ranges further enlarge their application fields (Cagliano, et al., 2017; Figenbaum, 2018; International Energy Agency, 2018)). Hertz, UPS, Coca-Cola or Deutsche Post DHL Group are only a few of the companies that already use electric vehicles in their transportation processes (The Coca-Cola Company, 2011; Pelletier, Jabali and Laport, 2014; Cosimato and Troisi, 2015; Quak, Nesterova and van Rooijen, 2016; Kampker, Gerdes and Schuh, 2017).

With more use of electric vehicles in logistics, the corresponding research field is growing as well: An increasing number of papers and scientific publications focuses on operational approaches and subfields of green SCM

(Sheu, Chou and Hu, 2005; Srivastava, 2007; Seuring and Müller, 2008; Min and Kim, 2012). The literature review conducted herein focuses on an OR perspective, namely vehicle routing problems for electric vehicles. This perspective is particularly important, as new approaches are needed to consider characteristics and operational challenges that distinguish electric vehicles from vehicles with combustion engines (range, charging times, etc.). Those properties need to be taken into account by companies to enable a successful practical use of electric vehicles (Altintas, et al., 2012; Klumpp, Witte and Zelewski, 2014).

This paper focuses on urban logistics, which is often seen as a promising application context for electric vehicles. According to the UN, urban areas provide huge potential for sustainability improvements as they account for more than 60% of total GHG emissions (United Nations, 2020). With ever-growing shares of the population living in cities, urban logistics are vital as cities rely on frequent deliveries of food and retail goods, deliveries to businesses and homes etc. Urban logistic systems are characterized by a high degree of complexity and diversity. Different cities of different sizes and in different locations are home to different economic sectors and supply chains. While the different urban areas are very diverse (and therefore in need of specific OR approaches), some typical segments and characteristics of urban logistics can be found in almost every urban setting. Out of the typical segments of urban logistics as classified by Behrends (2016) this paper will focus on the main segments retail, parcel delivery and gastronomy. The review analyses and synthesizes the state of the art regarding vehicle routing problems for electric vehicles in urban logistics based on these three segments.

Retail is a widely represented sector in all urban areas. Its logistics are characterized by tight schedules, time restriction (e.g. delivery times), high volumes (and weights) as well as demanding product requirements (e.g. cooling for food or pharmaceuticals) (Brewer, Button and Hensher, 2008; Behrends, 2016; Fernie and Sparks, 2019).

Parcel delivery is a strongly growing segment of city logistics – mainly due to a switch from conventional to online retail channels. The processes are often characterized by pick-up and delivery tours in large vans or small to medium-sized trucks with small time windows and multiple stops during tours (Behrends, 2016).

The gastronomy segment incorporates two major processes. The first is the transport of goods to businesses (e.g. food and beverages delivery to a restaurant), which is characterized by demanding product requirements (e.g. cooling for food), high weights of goods (e.g. beverage delivery) and limited time windows for delivery processes. The second major process is the delivery of meals from the business to the final customer, which is often performed on a just-in-time basis with changing demands, high time pressure and strong requirements regarding the product temperature (Behrends, 2016).

The purpose of this paper is to provide a comprehensive structured overview regarding the state of the art of vehicle routing models for commercial electric vehicles in urban logistics (based on retail, parcel delivery and gastronomy), to identify its research gaps and to derive a possible future research agenda.

To achieve this goal, this paper is organized as follows: In the first section, the concept of a systematic literature review and the reasons for its use are described. The methodological literature basis for this review and its guidelines are made explicit and the steps conducted in the systematic review are listed. This section is followed by the first steps of the systematic review itself – the question formulation (section 2.1) and the locating of studies (2.2). The third step of the literature review as described in Denyer and Tranfield (2010) – the study selection and evaluation – is conducted in section 2.3 of this paper. For the resulting literature basis, a systematic descriptive and thematic analysis and synthesis of the selected literature is performed (sections 2.4 and 2.5). For the purpose of this paper, the "reporting and using the results" – the last step of the structure of a systematic literature review based on Denyer and Tranfield (2010) – is incorporated into the discussion and limitations (section 3). Finally, a conclusion completes this research (section 4).

2 Systematic Literature Review: Vehicle Routing for Electric Vehicles in Urban Logistics

A systematic literature review is conducted in order to provide a comprehensive and structured overview over the state of the art of routing models for electric vehicles in urban logistics. Rousseau, Manning and Denyer (2008) define the word systematic in this context as "… comprehensive accumulation, transparent analysis, and reflective interpretation of all empirical studies pertinent to a specific question". To make sure that all relevant publications are included and to avoid bias (which often occurs in traditional narrative reviews) systematic literature reviews follow clearly defined steps (Tranfield, Denyer and Smart, 2003; Kitchenham and Charters, 2007; Denyer and Tranfield, 2010).
First standardized approaches to systematic literature reviews were developed in the medical sciences (The Cochrane Collaboration, 2008). While those are often cited, Fiori and Marzano (2018) and Denyer and Tranfield (2010) argue that the uncritical adoption of the medical model of a systematic literature review in other fields of research is not recommendable. They provide revised and specific guidelines for the conduction of systematic literature reviews in the fields of management and organization studies. The literature review in this paper is based on these steps as described in Denyer and Tranfield (2010) and Tranfield, Denyer and Smart (2003). The used method ensures transparency, reliability and completeness of the literature review (Kitchenham and Charters, 2007). In the following segments, the central steps of the review are described.

2.1 Question Formulation

A clearly defined research question is crucial for a systematic literature review. It helps to define inclusion and exclusion criteria and improves the utilization of findings (Denyer and Tranfield, 2010). The goal is to define a suitable unbiased, precise, encompassing and meaningful research question – including an explicit consideration of the OR aspect with focus on the vehicle routing problem (VRP). The resulting research questions were: i) What is the state of the art of vehicle routing problems for electric vehicles in urban logistics? ii) Which research gaps can be identified and which recommendations for a future research agenda can be derived?

2.2 Locating Studies

Based on the research questions and an initial literature scoping, keywords and search strings were identified and selected to find the relevant literature. In early 2020 the electronic databases EBSCOhost, ECONBIZ and Google Scholar were searched for papers and publications using the keywords: “electric”, “electric vehicle”, “vehicle routing”, “logistics”, “electric truck”, “urban”, “VRP” and “EVRP” These keywords were combined in different variations to create additional search strings using Boolean connectors (OR, AND, NOT) and - when necessary other operators like truncation characters (e.g. ‘*’). This procedure follows the recommendations by Denyer and Tranfield (2010). The abstracts of the publications found (by using the keywords/search strings) were scanned to ensure a fit with the research questions. In this first stage of the review, publications were only included in the review if their headings, keywords and/or abstracts clearly indicated that the publication did deal with the topic of the research questions. The hereby-achieved outcome of papers was rather low when publications were only included if they focused specifically on urban logistics. Hence publications were also included if they considered a VRP for electric vehicles but were not specifically developed for urban logistics. This process resulted in 99 potentially relevant publications. Afterwards the principle of snowballing was employed to make sure that the review is comprehensive. Through this principle, another 21 potentially relevant publications were identified. At the end of the process the same publications continued to appear, which was seen as a signal that a point of saturation was reached. Duplicates were eliminated. In total, 118 potentially relevant publications remained at the end of the locating of studies – chosen only based on the publication's headings, abstracts and keywords. All the literature considered was published between 2011 and the end of 2019. In this first step of the review all kinds of different relevant literature was collected (academic papers, books, non-peer-reviewed paper, scientific websites, conference and discussion papers and grey literature). This procedure follows the guidelines by Denyer and Tranfield (2010), who emphasize the importance of the inclusion of all relevant literature in the first step in order to ensure an all-encompassing overview. Nevertheless, the quality of the identified publications does not remain unchecked throughout the literature review. In the following section "study selection and evaluation" (2.3), a quality evaluation of the identified publications is conducted.

2.3 Study Selection and Evaluation

During the first step, 118 potentially relevant publications were collected. This section of the systematic literature review concentrates on the selection and evaluation of the found publications. To ensure a complete and unbiased structured literature review, the selection of publications based on their content follows predefined inclusion- and exclusion-criteria. Those were defined based on small pilot literature searches conducted before the locating of studies (Denyer and Tranfield, 2010). For this literature review, the following criteria for inclusion or exclusion of publications were determined:

Inclusion criteria: Publications are only included if they address vehicle routing approaches (e.g. VRPs, TSPs, etc.). Furthermore, only publications are included that mainly refer to (battery) electric vehicles (BEV) and road logistics. Because of their high practical relevance for companies worldwide, publications on mixed fleet routing problems (with electric vehicles) as well as mixed OR-problems like the routing-location-problem and similar approaches are included in this publication. To ensure timeliness and high quality of the systematic literature review only peer-reviewed journal articles and conference proceedings/contributions published between 2010 and December 2019 are considered.

Exclusion criteria: Publications are excluded if they do not mainly address vehicle routing (e.g. charging station location/charging problems) or address non-battery electric vehicles. This includes vehicles with conventional engines as well as alternatively fueled and hybrid electric vehicles. The latter are excluded, because the focus of this paper lies on the special characteristics of electric vehicles and the implications for their use in urban logistics. Additionally, the search strings - as set in section 2.2) - did not specifically target publications on hybrid vehicles, which is why the found publications would show an incomplete picture of the research on hybrid electric vehicles and therefore have to be excluded. Furthermore, all publications that do not deal with road vehicles (e.g. electric trains, ships, drones) or do not deal with logistics (e.g. public transport, taxis, etc.) are excluded. Finally, all non-English publications remain unconsidered.

While in the first step of the literature review, only the headings, abstracts and keywords were checked to collect potentially relevant literature, in this second step the full texts of the publications were used to ensure that a publication fits the inclusion- and exclusion criteria. Of the 118 potentially relevant publications found in the locating of studies (section 2.2) 77 were published in scientific journals – another 23 were conference proceedings or contributions. The excluded publications from other sources were publications in collected volumes (3), dissertations or thesis papers (8) and reports or grey literature (7). Of the 100 remaining publications, 6 had to be left out because they only (or mainly) referred to hybrid vehicles. Another 5 publications were dealing with green routing in general but did not specifically address electric vehicles. Of the remaining publications, 9 had to be left out because they did not mainly address vehicle routing approaches (for electric vehicles) but energy consumption simulations, charging and scheduling approaches or other OR approaches related to green logistics. Another 23 publications had to be excluded as they did not refer to road logistics – either because they referred to non-road vehicles or because they dealt with public transport, taxis or private vehicles. The concluding part of the study selection and evaluation is the quality evaluation of the remaining studies. To ensure high quality of the literature analyzed in the following steps of the systematic review, the sources of the remaining journal articles were checked for their quality using the online Master Journal List by Clarivate Analytics (http://mjl.clarivate.com). Based on this quality evaluation, twelve more unsuitable publications had to be excluded, resulting in a final sample of 35 journal articles and 10 conference proceedings at the end of the study selection and evaluation. These 45 publications met all the predefined inclusion and exclusion criteria and built the basis for the literature analysis and synthesis in the following section of this paper.

2.4 Descriptive Analysis and Synthesis

All preceding steps were conducted to find a final sample of literature. In this section, this sample is used for a structured analysis and syntheses of the selected literature to answer the research questions defined in section 2.1. As Denyer and Tranfield (2010) describe, analysis and synthesis in systematic literature reviews are two different, but strongly connected processes. While the analysis aims to break the publications in their constituent parts and to describe how they are related, the synthesis' goal is to "…make associations between the parts identified in individual studies" (Denyer and Tranfield, 2010).

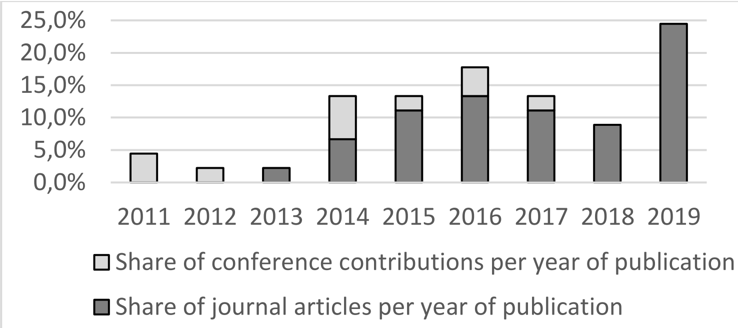

Figure 1: Yearly distribution of final sample journal articles and conference contributions (n = 45)

For the purpose of this paper, analysis and synthesis are split into a descriptive and a thematic part. The descriptive part aims at giving a general overview of different quantitative aspects of the 45 selected publications. As a first part of the descriptive analysis and synthesis, the yearly distribution of the final sample of publications was identified. All selected publications of the final sample were published between 2011 and December 2019 (see Figure 1). The timeliness of the topic is shown by the fact that more than 90% of the analyzed publications were published in 2014 or later.

Table 1: Sources of final sample journal articles

Journal	No. of articles
European Journal of Operational Research	6
Computers & Operations Research	5
Transportation Research Part B: Methodological	3
Transportation Research Part E: Logistics and Transportation Review	3
Other Journals (single publications): Algorithms, Applied soft computing, Energies, EURO Journal on Transportation and Logistics, European Transport - Trasporti Europei, IEEE Transactions on Smart Grid, IET Intelligent Transport Systems, International Journal of Production Economics, Journal of Advanced Transportation, Journal of Cleaner Production, Mathematical Problems in Engineering, Omega - International Journal of Management Science, Operations Research, OR Spectrum, SAE International Journal of Alternative Powertrains, Transportation Research Part C: Emerging Technologies, Transportation Research Part D: Transport and Environment, Transportation Science	18

When looking specifically at the 35 articles published in journals Table 1 shows that the majority of the articles were published in journals with focus on operations research (37%) or transportation research (33%). The remaining publications were published in journals on management, computing, energy, engineering, logistics and production.

2.5 Thematic Analysis and Synthesis

After having finished the descriptive analysis and synthesis, this section provides a thematic analysis and synthesis of the 45 publications. Table 2 shows all the components and characteristics that were extracted from the final sample of 35 journal articles and 10 conference proceedings.

Those components mostly refer to the newly formulated or adjusted/variated old routing problems proposed in the respective publications. In addition to the proposed routing approaches, the table shows the objective of the optimizations and a wide choice of their constraints and characteristics. Furthermore, Table 2 also shows if a publication includes algorithms/heuristics to solve the proposed routing problem.

Out of the analyzed 45 publications, seven stand out, as they do not propose - or sufficiently describe - a new or adjusted routing problem. The publications Abousleiman, Rawashdeh and Boimer (2017), Abousleiman and Rawashdeh (2014a) and Abousleiman and Rawashdeh (2014b) only refer to heuristics and algorithms for energy-efficient routing approaches for electric vehicles but do not propose own routing problems. The conference contribution by Liakos, Angelidis and Delis (2016) does propose an own routing model (EV-DPDPTW) but misses the description of the model's specifics. Similarly, the publication by Vonolfen, et al. (2011) – even though it does propose a specific routing problem for glass-waste collection with electric trucks – it does not describe the model specifics with regard to adjustments made for electric vehicles. Last but not least, publications by Juan, et al. (2016) and Erdelić and Carić (2019) stand out as they are literature reviews on routing models and environmental, strategic and operational issues associated with battery and hydrogen-based electric vehicles in logistics. Although their findings are of high interest, they do not specifically target urban logistics.

Table 2: Features of final sample journal articles (marked white) and conference contributions (marked grey)

Journal article or conference contribution	Special remarks	Proposed routing problem	Algorithms/heuristics	Objective function: Minimization of …	Multiple vehicles	Heterogeneous fleet (MF = mixed fleet)	Time windows	Linear energy need assumed	(Non-) Linear (NL/L) charge (BS = battery swapping)	Partial recharge
(Abousleiman and Rawashdeh, 2014a)		No own model	•	-	-	-	-	-	-	-
(Abousleiman and Rawashdeh, 2014b)		No own model	•	-	-	-	-	-	-	-
(Abousleiman, Rawashdeh and Boimer, 2017)		No own model	•	-	-	-	-	-	-	-
(Anderluh, et al., 2019)	Two-echelon approach	2eVRPSyn	•	Costs/ Emissions/ Social Factors	•	/	/	•	-	-
(Basso, et al., 2019)	Two-stage-approach	2sEVRP	/	Energy Consumption	•	/	•	CM	L	(•)
(Breunig, et al., 2019)	Two-echelon approach	E2EVRP	•	Costs	•	•	/	•	L	/
(Desaulniers, et al., 2016)		EVRPTW (4 variants)	•	Costs	•	/	•	•	L	(•)
(Erdelić and Carić, 2019)	Review	-	-	-	-	-	-	-	-	-
(Felipe, et al., 2014)		GVRP-MTPR (variant)	•	Recharging Costs	•	/	/	•	L	•
(Figliozzi, 2011)		RVRP	(•)	Vehicles/Routes/ Costs	•	/	•	•	L	(•)
(Froger, et al., 2019)		E-VRP-NL (variant)	•	Time	•	/	/	•	NL	•
(Ghandriz, et al., 2016)	Fleet-Composition-Routing-Problem	HVRPMF-PUP	(•)	Costs	•	MF	•	CM	L	/
(Goeke and Schneider, 2015)		E-VRPTWMF	•	Time/Costs	•	MF	•	CM	L	/
(Hiermann, et al., 2016)		E-FSMFTW	•	Costs	•	MF	•	•	L	/

Journal article or conference contribution	Special remarks	Proposed routing problem	Algorithms/heuristics	Objective function: Minimization of …	Multiple vehicles	Heterogeneous fleet (MF = mixed fleet)	Time windows	Linear energy need assumed	(Non-) Linear (NL/L) charge (BS = battery swapping)	Partial recharge
(Hiermann, et al., 2019)		H2E-FTW	•	Costs	•	MF	•	•	L	•
(Jie, et al., 2019)	Two-echelon approach	2E-EVRP-BSS	•	Costs	•	•	/	•	BS	/
(Juan, et al., 2016)	Review	-	-	-	-	-	-	-	-	-
(Juan, Goentzel and Bektaş, 2014)		VRPMDR	•	Costs	•	MF	/	•	L	/
(Keskin and Çatay, 2016)		EVRPTW-PR	•	Distance	•	/	•	•	L	•
(Keskin and Çatay, 2018)		EVRPTW-PR (variant)	•	Vehicles/Costs	•	/	•	•	L	•
(Khadraoui, et al., 2015)	Modular vehicles	MeVRP	•	Costs	•	•	•	•	L	/
(Liakos, Angelidis and Delis, 2016)		EV-DPDPTW (no model description)	•	-	-	-	-	-	-	-
(Liao, Lu and Shen, 2016)		OEVTP	•	Time	/	/	/	•	BS	•
(Macrina, et al., 2019)		GMFVRP-PRTW	•	Costs	•	MF	•	•	L	•
(Montoya, et al., 2017)		E-VRP-NL	•	Time	•	/	/	•	NL	/
(Murakami, 2017)		EDVRP	•	Costs	•	MF	/	CM	/	/
(Pelletier, Jabali and Laporte, 2019)	Considers uncertainty	EVRP-ECU		Costs	•	/		CM	-	-
(Preis, 2014)		Energy-optimizing-VRP	•	Energy Consumption	•	/	•	CM	L	/
(Rezgui, Aggoune-Mtalaa and Bouziri, 2015)	Modular vehicles	eM-FSMVRPTW	•	Costs/Distance	•	•	•	•	L	/
(Roberti and Wen, 2016)		E-TSPTW	•	Distance	/	/	•	•	L	(•)
(Schiffer and Walther, 2017)	Location-routing problem	ELRP-TWPR		Distance/Vehicles/ Charging Stations	•	/	•	•	L	•
(Schiffer and Walther, 2018)	Location-routing problem	RELRPTWPR	•	Costs	•	/	•	•	L	•

Journal article or conference contribution	Special remarks	Proposed routing problem	Algorithms/heuristics	Objective function: Minimization of …	Multiple vehicles	Heterogeneous fleet (MF = mixed fleet)	Time windows	Linear energy need assumed	(Non-) Linear (NL/L) charge (BS = battery swapping)	Partial recharge
(Schneider, Stenger and Goeke, 2014)		E-VRPTW	•	Distance	•	/	•	•	L	/
(Schneider, Stenger and Hof, 2015)		EVRPRF	•	Costs	•	/	/	•	L	/
(Shao, et al., 2017)		EVRP-CTVTT	•	Costs	•	/	•	•	L	/
(van Duin, Tavasszy and Quak, 2013)		FSMVRPTW (variant)		Costs	•	•	•	•	L	/
(Verma, 2018)		EVRPTWBSS	•	Costs	•	/	•	•	L	/
(Vonolfen, et al., 2011)	Specific waste-collection problem for e-trucks	SIRP variant (adjustment for electric vehicles not described)	•	-	-	-	-	-	-	-
(Worley, Klabjan and Sweda, 2012)	Location-routing problem	Charging station location and routing problem	/	Costs	•	/	/	•	L	/
(Yang and Sun, 2015)	Location-routing problem	BSS–EV–LRP	•	Costs	•	/	/	•	BS	/
(Yang, et al., 2015)		EV Route Opt. with TOU Electricity Price	•	Costs	/	/	/	•	L	/
(Zhang, et al., 2018)		EVRP	•	Energy Consumption	•	/	/	CM	L	/
(Zhao and Lu, 2019)	real-world EVRP by logistics company	EVRP (by Chinese parcel company)	•	Costs	•	•	•	•	L	/
(Zhenfeng, et al., 2017)		E-VRPTW (variant)	•	Costs	•	/	•	•	L	/
(Zuo, et al., 2019)		EVRPTW-CNCF	•	Costs	•	/	•	•	NL	•

All other 38 publications propose some kind of routing approach for electric vehicles in the logistics context. For 23 of the 38 proposed routing approaches the objective of the optimization is a cost minimization. The cost incorporated into this optimization differ significantly between the proposed models. In three models total time is minimized, another three objective functions aim at minimizing the total distance travelled. Three models optimize the energy consumption and the remaining six approaches have multipart objective functions.

As table 2 shows, only three of the 38 models are not multi-vehicle models. The majority of electric vehicle fleets in the routing models are homogeneous vehicle fleets. Seven out of the 13 publications in which heterogeneous fleets are modeled deal with mixed fleets of electric vehicles and vehicles with other forms of propulsion (e.g. combustion-engines and hybrid vehicles). Time windows in which customers can be served are implemented in around 61% of the models.

In 82% of the proposed routing models, vehicle energy consumption is assumed linear to the distance driven. Only in the remaining seven publications, the models incorporate an individual energy consumption model. Energy consumption models are designed to account for different factors affecting the energy consumption of the vehicles (e.g. vehicle speed, terrain, weather conditions, recuperation, cooling of products in the cargo area, auxiliaries, etc.).

With regard to vehicle charging, the models differ significantly in various characteristics. The vast majority of proposed models includes the simplifying assumption that vehicle charging is a linear process. Only the routing approaches by Montoya, et al. (2017), Zuo, et al. (2019) and Froger, et al.

(2019) include more realistic nonlinear charging functions. Three models do not model charging processes at all, and another three models implement battery-swapping stations instead of recharging stations (Yang and Sun, 2015; Liao, Lu and Shen, 2016; Jie, et al., 2019). In a swapping station, batteries are changed for fully loaded ones (Margaritis, et al., 2016). Only the model by Verma (2018), allows both recharging and battery swapping. Partial recharging is modeled in (certain variants of) 12 of the models. While most of the reviewed publications propose specified models for routing, the approaches by Worley, Klabjan and Sweda (2012), Yang and Sun (2015), Schiffer and Walther (2017) and Schiffer and Walther (2018) simultaneously optimize vehicle routes and recharging locations.

Additionally, the approaches by Breunig, et al. (2019), Jie, et al. (2019) and Anderluh, et al. (2019) need special mentioning as they belong to the class of two-echelon approaches. In these routing models, the logistics process is split into two echelons with different characteristics (e.g. first echelon: Delivery to two distribution center, second echelon: Transport to business in the city center). In the three two-echelon-models the electric vehicles are either modeled in one or in both echelons. Lastly the approach described by Zhao and Lu (2019) is of high interest as it is the only approach raised by a company. It covers a routing model for electric vehicles in Wuhan (China).

3 Discussion and Limitations

Regarding the two research questions, following results have been identified: First of all, an increasing interest in the topic can be stated, focusing on research affiliated with European, Asian and North American institutions. Journal-wise there is an interesting duality: On the one hand, there are three major outlets for publications on the topical field proposed (European Journal of Operational Research, Computers and Operational Research, Transportation Research). On the other hand, there are a large number of 13 smaller outlets also sporting publications regarding the analyzed topic, showing the broad interest and rooting of the innovative question of electric vehicle routing in logistics contexts. In the comparison between conference contributions and journal papers, it became obvious that conference contributions often address minor or specific problems – without e.g. presenting a new OR model but based on existing models or data. This can be understood as academic division of labor between these different publication categories in a perfect manner.

As regards content, most papers are – in a typical OR perspective – optimizing transport costs in the specified routing problems. The scarcity of models considering sustainability related objectives might constitute an important research gap, as one of the major objectives of the commercial use of electric vehicles is increased sustainability. The value-technology link integrating cost and energy perspectives – crucial for electric vehicles and sustainability approaches – is present in a very low number of papers and should be explored further.

As described in section 1, the three main segments of urban logistic systems that are focused in this paper (retail, parcel delivery, gastronomy) have in common that they are all characterized by tight schedules and different kinds of relevant time windows (e.g. retail delivery time windows or guaranteed time windows for parcel or food delivery). Time is a major competitive factor in all these contexts. While an explicit consideration of time in the objective function is an exemption (e.g. Liao, Lu and Shen, 2016; Montoya, et al., 2017; Froger, et al., 2019) and therefore forms a research gap, time windows are accounted for in more than 60% of the proposed routing models in the final sample of publications.

Another aspect of urban logistics (as described in section 1), which poses challenges for routing models is the cooling or heating of goods during transport. In retail, guaranteeing a constant temperature for pharmaceuticals or cooling food on the transport to supermarkets are typical examples. In gastronomy, similar challenges can be found in the delivery of fresh ingredients for restaurants or the heating of food delivered to customers (e.g. pizza delivery). Here, a major research gap can be found as more than 80% of the examined routing models make the simplifying assumption that vehicle energy consumption is linear to the distance driven. Only seven of the analyzed routing models propose a more realistic energy consumption model. These models, which are implemented into the proposed routing approaches, account for different factors that can affect the energy consumption on a tour. The energy consumption of auxiliaries (e.g. cooling system), which – for example is included in the model by Basso, et al. (2019) – is only one of many aspects that can be included in such models. Other important aspects are topography, speed, acceleration, weight of load, outdoor temperature, rain (wipers), media consumption, road conditions, etc. With respect to urban logistics especially speed, acceleration and weight of the load are of high interest. As described in section 1, parcel delivery as well as food delivery processes (in gastronomy) are characterized by multiple stops and accelerations during tours. Beverage deliveries in retail and gastronomy (e.g. delivery to a restaurant) are high-weight transports. These examples show that – in order to route electric vehicles efficiently in urban contexts – energy consumption models (considering all relevant aspects e.g. auxiliaries, speed, load) need to be included in more approaches and should be an essential part of the future research agenda.

Another result of interest is the fact, that most of the examined routing approaches model homogeneous vehicle fleets. In this context, another research gap can be identified. Especially in the transition period towards electric vehicle logistics, there will be need for heterogenous and especially mixed fleet vehicle routing models. Such vehicle fleets comprising combustion engines and electric vehicles are and will be relevant due to investment and transition costs. One of many practical examples is the parcel delivery company DHL (Kampker, Gerdes and Schuh, 2017). This need for mixed-fleet-models is not reflected sufficiently in the analyzed sample of publications, as only 13 publications model heterogeneous fleets and only seven of them deal with mixed fleets of electric vehicles and vehicles with other forms of propulsion.

The literature review also showed that only about one third of the examined routing models incorporate partial recharging. Most other approaches only model full charging of vehicles. These findings might constitute an additional research gap as for example, for gastronomy and especially food delivery, partial recharging could be of high interest as it could be realized

in the limited time windows between customer's orders in which full battery-charging cannot be completed. Therefore, partial recharging should ideally be modeled in routing problems for urban logistics. Additionally, most models lack more realistic nonlinear charging functions. Less than 10% of models account for nonlinearity in vehicle charging processes. As energy demand and supply are crucial factors for the use of electric vehicles (e.g. range problematic), a greater number of models implementing nonlinear charging processes would be beneficial.
The literature review showed that, while there are quite a few approaches tackling the requirements of urban logistics routing for electric vehicles (e.g. Basso, et al. (2019), who model an extensive energy consumption model), to the best of our knowledge, a routing model combining all major relevant aspects for the urban context (e.g. energy consumption model, mixed fleet modelling, partial recharging modelling, etc.) is still missing.

Limitations of this literature review are as follows: Strict inclusion and exclusion criteria were applied to ensure a clear research focus and high scientific standard of the examined publication. For example, only peer-reviewed journals and conference proceedings were included – therefore, other publications are not analyzed. Moreover, – as with all structured literature reviews – only the applied search words were connected to the titles, keywords and abstracts of the identified papers; therefore, some publications might be missed with different but content-related titles, keywords and abstracts. Additionally, this paper focused on three main segments of urban logistics (retail, parcel delivery, gastronomy). This focus was chosen to reduce the complexity of the very diverse and complex field of urban logistics. However, other important segments of urban logistics (e.g. waste logistics, construction, etc.) might require different features in routing models and should therefore be targeted specifically in future research in order to draw a broader picture (Behrends, 2016). As regards the analysis, this paper is somewhat limited due to its objective which is to provide a general overview over the approaches. In consequence, in-detail analysis of the examined routing approaches is not the focus of this paper. While (for example) the objective functions of the models were distinguished by their overall goal (e.g. cost minimization), an in-detail analysis of the considered cost components is not covered by this paper.

4 Conclusion

The aim of this paper was to provide an overview of existing routing approaches for commercial electric vehicles, their characteristics and their suitability for typical application contexts in urban logistics (in particular: retail, parcel delivery, gastronomy). On this basis, it was the second goal of this paper to identify specific research gaps and to derive recommendations for a future research agenda. The literature review showed a growing interest in the field of routing approaches for electric vehicles in urban contexts, with growing numbers of relevant publications in the very recent years. Journal-wise, an interesting duality of major (e.g. EJOR) and smaller outlets was observed.

As regards content, most routing models are – in a typical OR perspective – optimizing transport costs. The scarcity of routing approaches considering the value-technology link integrating cost and energy perspectives, as well as sustainability and time related objectives forms a first part of the research agenda that can be derived based on this paper. This is especially true, as sustainability aspects are a major reason for the use of electric vehicles and as time is a crucial factor in many segments of urban logistics (e.g. retail, parcel and food delivery). However, it was found that, while very few models included time in their objective functions, time windows (as they occur in many urban contexts, e.g. parcel delivery) were integrated in more man 60% of the analyzed approaches.

One of the major aspects that could be derived from the literature review for the future research agenda was the need for more models including precise context-adjusted energy consumption models. Here a major research gap was identified between the requirements of urban logistics (e.g. food cooling/heating on transports, weight of the load, multiple stops during tours, etc.) and the fact that more than 80% of the examined routing models simply assume energy consumption linear to the distance driven, without considering any of these effects.

Only very few routing models include energy consumption models that meet (parts of) the requirements that typical urban logistics contexts pose (Basso, et al., 2019). The literature reviewed also revealed that the existing examined routing approaches merely model homogeneous fleets only. Especially for the transition period towards electric mobility, the future research agenda should include more heterogenous and especially mixed fleet vehicle routing approaches fitting the typical real-world fleet compositions. Similar findings consider the recharging process in general and partial recharging and nonlinearity of recharging in particular, which are accounted for in a minority of approaches and should form part of the future research agenda in this field. In general, the result of the literature review showed that, a vehicle routing model combining all major relevant aspects for urban logistics (e.g. energy consumption model, mixed fleets, partial recharging, etc.) forms an additional important research gap.

As this paper focused on three major segments of the diverse field of urban logistics system (retail, parcel delivery, gastronomy), interesting further aspects of a future research agenda would be an analysis of other important segments of urban logistics (e.g. waste logistics, construction, etc.), which might require different routing model features. Altogether, research has an important task to analyze and provide further information regarding the use of electric commercial vehicles as these will be the backbone for most urban delivery fleets in the coming decades.

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