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TRANSPORTATION SCIENCE
Articles in Advance, pp. 1–25
ISSN 0041-1655 (print), ISSN 1526-5447 (online)

Vehicle Routing and Location Routing with Intermediate Stops: A Review

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Received: June 22, 2017
Revised: October 24, 2017; February 4, 2018
Accepted: February 8, 2018
Published Online in Articles in Advance: February 8, 2019

https://doi.org/10.1287/trsc.2018.0836

Abstract. This paper reviews the literature on vehicle routing problems and location routing problems with intermediate stops. We classify publications into different categories from both an application-based perspective and a methodological perspective. In addition, we analyze the papers with respect to the algorithms and benchmark instances they present. Furthermore, we provide an overview of trends in the literature and identify promising areas for further research.

Funding: G. Laporte gratefully acknowledges funding from the Canadian Natural Sciences and Engineering Research Council [Grant 2015-06189].

Keywords: intermediate stops • intra-route facilities • vehicle routing • location routing • survey

1. Introduction

Routing problems with intermediate stops (RPIS) are highly relevant in logistics, arising, for example, in freight transportation and municipal waste collection. However, the interest of the research community in these problems has for a long time mainly been limited to single application cases. In recent years, researchers have started to pay increasing attention to RPIS, especially regarding applications in city logistics and logistics fleets with alternative fuel vehicles (AFVs). The purpose of this review is to guide the reader through the literature on RPIS by providing a discussion of research fields, application cases, and methodological classifications. We assume that the reader has a basic knowledge of vehicle routing (cf. Golden, Raghavan, and Wasil 2008; Toth and Vigo 2014), location theory (cf. Daskin 1995; Laporte et al. 2015), and exact and heuristic solution methods for combinatorial optimization problems in general (cf. Wolsey 1998; Desaulniers, Desrosiers, and Solomon 2005; Gendreau and Potvin 2010).

We start the discussion with a precise definition of the terms *intermediate stop* and *intra-route facility*. These definitions are necessary to characterize the considered problem class, but they are ambiguously used in the literature and in different research streams. In this work, an intermediate stop is an optional stop en route to keep a vehicle operational while fulfilling its main service task. Thus, an intermediate stop differs from a regular stop (e.g., providing service at a customer) and also from an optional customer stop that, for example, arises in vehicle routing problems (VRPs) with profits (cf. Archetti, Speranza, and Vigo 2014). Although intermediate stops are optional, they may prove unavoidable to keep vehicles operational. Intermediate stops take place at so-called intra-route facilities, which enable vehicles to replenish a certain resource. An intra-route facility is planned at the same echelon as the customers. It is visited en route and thus differs from a so-called intermediate facility, which is often used as a synonym for a depot or a hub in multiechelon and cross-docking operations. Therefore, we exclude work on multiechelon routing problems from this survey and refer to Guastaroba, Speranza, and Vigo (2016) for a deep overview of the topic.

Before detailing the aim and organization of this survey, we first outline application areas in which RPIS arise. Next, we show how these problems can be categorized from a modeling point of view cutting across the described application areas. Both the application-based and the problem-based classification are then used to organize this survey in a concise fashion.

1.1. Application Areas

Since the early 1970s, researchers have studied RPIS. While this research was very sparse until the year 2000, it increased significantly from then on because of new challenges arising in city logistics and AFV fleets. More general, RPIS arise in three main application areas:

(i) *Replenishment and disposal of goods or waste*. In certain distribution networks, satellite facilities are used to avoid deadheads caused by return trips to the depot to replenish freight (cf. Angelelli and Speranza 2002b; Crevier, Cordeau, and Laporte 2007; Tarantilis, Zachariadis, and Kiranoudis 2008). Real-world examples for such a distribution structure can be found in heating oil distribution (Prescott-Gagnon, Desaulniers, and Rousseau 2014), road maintenance (Amaya, Langevin, and Trépanier 2007), and city logistics (Crainic, Ricciardi, and Storchi 2009). Analogous concepts can be used to dispose of freight in collection problems. Two main application areas belong into this context, namely, waste collection (cf. Kim, Kim, and Sahoo 2006; Benjamin and Beasley 2010) and snow plowing (cf. Perrier, Langevin, and Campbell 2006; Salazar-Aguilar, Langevin, and Laporte 2012).

(ii) *Refueling*. Routing problems with refueling stops are encountered in dense or in sparse refueling network structures. In dense network structures, problems arise for economic reasons (e.g., company contracts with lower prices or large price differences between stations located in close vicinity). If AFVs are used as sustainable means of transportation, the necessary refueling infrastructure for such new technologies is often still sparse. In addition, the driving range of several types of AFVs, for example, electric commercial vehicles (ECVs), is limited. Thus, refueling stops have to be considered explicitly in the respective routing problems.

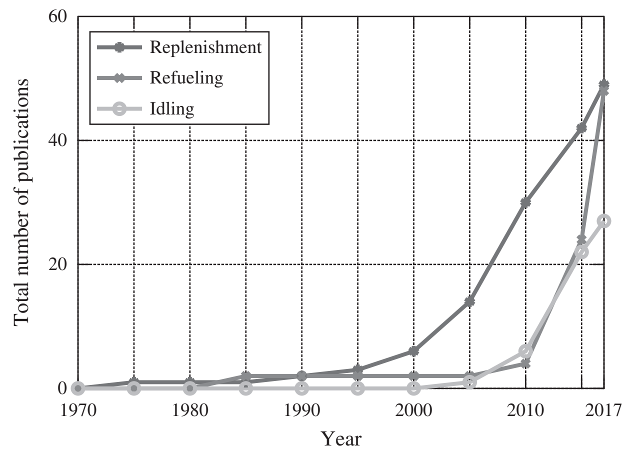
(iii) *Idling for rest periods and breaks*. Focusing on long-haul distribution or multiday trips, intermediate stops for idling times take place because of hours of service (HOS) regulations in freight transportation (Goel 2009) or because of hotel selection (Vansteenwegen, Souffriau, and Sörensen 2012) to prevent drivers' fatigue.

The research interest in these three application areas evolved differently in the last years. Figure 1 shows this development by illustrating the total number of publications over time. Intermediate stops for replenishing or unloading were studied first, and the number of papers on this topic is constantly rising. The papers mainly focus on conventional applications in municipal services (e.g., waste collection) and logistics systems (e.g., freight replenishment), which have been and still are relevant for practitioners. Up to 2010, papers on refueling issues were mainly limited to routing of internal combustion engine vehicles (ICEVs) in a dense infrastructure. Because of a significant interest of researchers and practitioners in routing problems with AFVs, especially ECVs, we can observe a huge increase in the number of papers from then on. Publications on intermediate stops for idling due to HOS regulations and hotel selection in routing problems experienced the strongest increased between the years 2000 and 2015.

1.2. Problem Categorization

RPIS can also be classified according to the characteristics of different problem variants (cf. Schiffer et al. 2017a). Common characteristics are time constraints, that is, problem variants with a maximum route duration and problem variants restricted by time windows

Figure 1. Total Number of Publications Over Time for the Three Application Areas



at customers. RPIS can be further differentiated with respect to the characteristics of the replenishment process, which is closely linked to overall time constraints if replenishment is time consuming. In addition, the replenished resource (from here on referred to as the operational resource) can differ with respect to its consumption. Detailing the characteristics listed previously, the following nomenclature to characterize RPIS can be derived:

(i) *Time constraints* can be given either by time windows (TW) or by a maximum route duration (MRD), or can be neglected (none).

(ii) *Replenishment time* can either be dependent (D) or independent (I) of the quantity of the operational resource that has to be replenished.

(iii) *Replenishment processes* can either be restricted to full replenishment (F) or allow partial replenishment (P).

(iv) *Operational resources* can be characterized with regard to the type of consumption of the operational resource, which can either be node based (N) (e.g., freight) or arc based (A) (e.g., fuel).

The resulting nomenclature is shown in Table 1. Problems are separated into node-based and arc-based problems in the first dimension. Furthermore, problems can be characterized by the types of time restrictions. The second dimension divides these problems further into quantity-dependent and quantity-independent replenishment processes. Quantity-dependent processes can be further separated into full and partial replenishment processes. Partial replenishment is not considered for time-independent models because the time savings it yields are irrelevant.

1.3. Aim and Organization

The contribution of this survey is twofold. First, the past, current and future application areas of RPISs are highlighted to provide researchers with a knowledge

Table 1. Nomenclature of RPIS Variants

		Dependent replenishment		Independent replenishment
Consumption	Time restriction	Full replenishment	Partial replenishment	Full replenishment
Node based	None	NDF	NDP	NIF
	Route duration	NDFMRD	NDPMRD	NIFMRD
	Time windows	NDFTW	NDPTW	NIFTW
Arc based	None	ADF	ADP	AIF
	Route duration	ADFMRD	ADPMRD	AIFMRD
	Time windows	ADFTW	ADPTW	AIFTW

Note. Classification of different RPIS variants in analogy to Schiffer et al. (2017a).

of the development of this research field over time. Second, methodological enhancements and problem-specific details are discussed. This survey contains a dedicated section for each application area. Within these sections, the application areas are further separated into sections on specific research streams and one analysis section for each application area that summarizes its main findings. The nomenclature presented in Table 1 is used in the analysis section to highlight the focus of each application area and research stream. We pay special attention to the discussion of the following aspects: (i) We analyze the scope of each publication, mainly dividing between case studies and algorithmic contributions. In this context, we categorize a publication as a case study paper if it comprises a real-world data set and if the related problem is of interest for practitioners. Thus, papers that derive only instance sets from real-world data without any context or discussion are regarded as methodological papers. Furthermore, we subdivide publications into arc routing and node routing problems, and we discuss the type of data with respect to deterministic and uncertain information. (ii) We analyze the various objectives used within the application field and discuss their relevance. (iii) We discuss the different solution methods that have been developed to show which algorithms are most suitable and popular for the specific application area. This discussion is split into a part on exact algorithms and a part on metaheuristics. (iv) We provide information on the available benchmarks for each research steam and provide a collection of publicly available instances at www.om.rwth-aachen.de/data/litrevInst. Finally, we summarize the main findings for each application area and discuss future research questions.

The remainder of this paper is structured as follows. Section 2 reviews literature on intermediate stops for replenishment and unloading. Section 3 focuses on intermediate stops for refueling. Section 4 analyzes literature on intermediate stops for idling due to breaks or rests. Section 5 concludes this survey by summarizing its main findings. In the appendix, we provide a glossary of the abbreviations used in this paper.

2. Intermediate Stops for Replenishment or Unloading of Goods

In this section, we focus on publications that address intermediate stops for the replenishment or the unloading of goods. Classical application cases often arise in retail and distribution logistics and municipal services. Besides these classical problems, selected VRPs with synchronization constraints represent RPISs according to our definition in Section 1. Thus, Section 2.1 focuses on intermediate stops for replenishment, Section 2.2 focuses on intermediate stops for unloading, and synchronization problems are discussed in Section 2.3. In Section 2.4, we conduct an analysis of problem characteristics and solution methods.

2.1. Intermediate Stops for Goods Replenishment

Intermediate stops for goods replenishment often arise in distribution networks for raw materials or in small package shipping.

The first publication that introduced intermediate stops in this context focused on propane gas distribution. Bard et al. (1998) addressed the VRP with satellite facilities and developed a branch-and-cut (BC) algorithm for this problem. The objective was to minimize the overall distance under a maximum tour duration constraint. Another application in raw material distribution was discussed by Prescott-Gagnon, Desaulniers, and Rousseau (2014), who proposed a VRP arising in heating oil distribution, considering intra-route replenishments, heterogeneous vehicles, optional customer visits, and time windows. The authors designed a tabu search (TS) heuristic, a large neighborhood search (LNS) heuristic with a TS component, and a column generation (CG) metaheuristic to analyze a real-world instance.

In parcel logistics, several publications addressed arc routing and node routing problems. Focusing on arc routing problems, Ghiani and coauthors investigated the capacitated arc routing problem (CARP) with intermediate facilities (CARPIF) in several publications. Ghiani, Improta, and Laporte (2001) introduced the CARPIF as an extension of the pure CARP, accounting for intermediate stops for replenishment or unloading.

The authors presented a lower bound based on the rural postman problem and a linear integer program. Ghiani et al. (2004) extended the CARPIF with capacity and length restrictions and developed three heuristics, namely, a construction algorithm and two TS algorithms. Ghiani et al. (2010) provided an ant colony algorithm for the CARPIF that outperformed existing algorithms. Polacek et al. (2008) presented a variable neighborhood search (VNS) for the CARP with refill points (CARPRP) that was capable of finding the best known solution (BKS) for all 120 instances of four different benchmark sets for the CARP and the CARPRP, and improved 71 BKSs.

Focusing on node routing problems, Angelelli and Speranza (2002b) extended the periodic VRP (PVRP) to intermediate facilities. Minimizing the overall traveled distance, they proposed a TS heuristic for this problem and presented results on instances with 50–288 customers. Crevier, Cordeau, and Laporte (2007) introduced the multidepot VRP with interdepot routes (MDVRPI), which considers intermediate depots at which vehicles can be replenished during the course of a route. Tarantilis, Zachariadis, and Kiranoudis (2008) renamed this problem to the VRP with intermediate replenishment facilities and proposed a hybrid guided local search (LS) heuristic. Kek, Cheu, and Meng (2008) studied a capacitated VRP with flexible start and end depots, allowing for intermediate replenishment visits to any depot. The authors presented a mixed integer program (MIP) to minimize travel and vehicle costs and found that cost savings of 49% can be reached for a specific case study in Singapore. Muter, Cordeau, and Laporte (2014) developed a branch-and-price algorithm for the MDVRPI. The authors discussed the benefit of two different pricing subproblems and managed to solve problem instances with up to 50 customers to optimality.

Recent publications focused on generic algorithmic frameworks for RPIS. Schneider, Stenger, and Hof (2015) introduced the VRP with intermediate stops (VRPIS) and provided results on different problems. Schiffer et al. (2017a) focused on RPIS by analyzing different types of resources and replenishment options, and presented an algorithmic framework that yields new BKSs for most existing problem variants. Both publications also investigated the MDVRPI benchmarks of Crevier, Cordeau, and Laporte (2007) and Tarantilis, Zachariadis, and Kiranoudis (2008).

2.2. Intermediate Stops for Unloading of Goods

Intermediate stops for unloading of goods arise in municipal service applications, especially in waste collection problems. For an in-depth overview on waste collection problems that does not only cover problems related to intermediate stops, we refer to Beliën, De Boeck, and Van Ackere (2014).

The first publication on intermediate stops for unloading was by Beltrami and Bodin (1974), focusing on the routing of waste collection vehicles with disposal facilities for a real-world problem arising in New York and Washington. Mourão and Almeida (2000) investigated a CARP with intermediate stops for a household refuse problem in Lisbon. A lower bound and a route-first, cluster-second heuristic were presented, and the algorithm was tested on a benchmark set based on the real-world case. Mourão and Amado (2005) presented another heuristic for this problem based on a multigraph representation, which improved their previous results and performed well on large-sized instances with up to 400 nodes and 1,215 arcs. Angelelli and Speranza (2002a) applied the periodic VRP with intermediate facilities originally presented in Angelelli and Speranza (2002b) to case studies arising in waste collection. The authors presented a TS heuristic to solve large instances. De Rosa et al. (2002) introduced the arc routing and scheduling problem with transshipment as a variant of the CARPRP. The problem arises in urban waste collection, where a fleet of vehicles recollects garbage, which is delivered to transfer stations, processed into compact units, and then transported to its final destination by trucks. Ghiani et al. (2005) applied the CARPIF to a waste collection problem in southern Italy, presenting a cluster-first, route-second heuristic. Del Pia and Filippi (2006) studied a real-world case on waste collection in northern Italy using a CARP with intermediate stops. The authors implemented a VNS algorithm and found that a significant reduction in overall time (approximately 30%) can be achieved compared to the current real-world solution. Another real-world case of a waste management company was studied by Kim, Kim, and Sahoo (2006), who extended Solomon's (1987) insertion algorithm to this problem. Besides the case study, an instance set for the VRP with time windows (VRPTW) was considered. Santos, Coutinho-Rodrigues, and Current (2008) investigated a CARP with intermediate stops at drop-off points for a waste collection problem in Portugal. The authors implemented a decision support system based on a path-scanning algorithm. Benjamin and Beasley (2010) focused on the waste collection VRP with multiple disposal facilities and considered time windows and driver rest periods. Coene, Arnout, and Spieksma (2010) discussed a PVRP in the context of waste collection and presented a route-first, cluster-second algorithm. Buhrkal, Larsen, and Ropke (2012) focused on a waste collection VRP in a city logistics context, considering time windows and minimizing the overall costs. In addition to numerical studies on existing benchmarks, the authors provided a case study of a Danish garbage company and proved that their algorithm is capable of improving the real-world results. Hemmelmayr et al. (2013a, b) also studied the

PVRP in the context of waste collection. The authors introduced a hybrid solution approach consisting of a VNS with a dynamic programming (DP) component. This solution procedure outperformed the approaches of Crevier, Cordeau, and Laporte (2007) and Tarantilis, Zachariadis, and Kiranoudis (2008) on the MDVRPI instances. Markov, Varone, and Bierlaire (2016) studied the waste collection VRP with intermediate facilities and investigated the impact of a heterogeneous fleet and flexible destination depots. A case study based on data of a waste company in Switzerland was presented, and the developed VNS obtained a mean improvement of 14.46% on the real-world solution. Willemse and Joubert (2016) investigated four different construction heuristics for the mixed CARPRP under time restrictions, aiming to identify a suitable heuristic for real-time support in real-world application cases.

Single publications on intermediate stops for unloading focused on other topics than waste collection. Jordan (1987) investigated a VRP with additional backhauls that can be stored at intermediate facilities instead of the home depot. The authors presented a matching problem and a greedy heuristic to solve this problem. Perrier, Langevin, and Campbell (2007) discussed VRPs with intermediate stops for unloading operations in snow plowing.

2.3. Intermediate Stops for Synchronization

Routing problems with synchronization constraints cover a wide range of application fields. Therefore, we limit the following discussion to synchronization problems that include an intermediate stop according to our definition in Section 1, and we refer to Drexl (2012) for an extensive overview on synchronization problems in general. More precisely, we restrict ourselves to problems in which the synchronization is limited to locations at a single echelon and occurs en route. Thus, multiechelon synchronization problems (e.g., Contardo, Hemmelmayr, and Crainic 2012) are not considered. According to our definition in Section 1, intermediate stops that are directly related to providing service are not considered. This means that we also exclude dial-a-ride problems (e.g., Gørtz, Nagarajan, and Ravi 2009) and school bus routing (e.g., Fügenschuh 2009) from our analysis. Furthermore, we exclude publications on staff and driver scheduling (e.g., Dohn, Kolind, and Clausen 2009) because here intermediate stops are linked to neither an intra-route facility nor to a support vehicle, which can be seen as mobile intra-route facilities.

The publications discussed in the following can be separated into truck and trailer routing problems (TTRPs) and other routing problems with synchronization constraints. TTRPs are routing problems in which some customers can be served by trucks carrying a trailer, and other customers can be served only by a truck without a trailer. Thus, trailers can be parked and later picked up by trucks if needed and allowed. In TTRPs, the parking space for trailers can be seen as an intra-route facility.

An overview on TTRPs can be found in Drexl (2013) and in Cuda, Guastaroba, and Speranza (2015). The first publication focusing on trailers in a VRP was by Semet and Taillard (1993). The authors analyzed a real-world application on a grocery store distribution network and presented a TS heuristic. Gerdessen (1996) discussed the VRP with trailers allowing trucks to leave the trailer at a parking space and developed construction heuristics as well as an LS to solve the problem. Chao (2002) presented a TS heuristic for the TTRP. The algorithm was evaluated on instances with up to 150 customers. Scheuerer (2006) presented two construction heuristics and a TS heuristic for the TTRP. The algorithm outperformed the results of Chao (2002) on all instances. Tan, Chew, and Lee (2006) focused on the TTRP, investigating a multiobjective function, minimizing the distance and the number of trucks using an evolutionary algorithm. Villegas et al. (2010) presented a greedy randomized adaptive search procedure (GRASP) and a VNS with evolutionary LS for the single TTRP with time windows. Caramia and Guerriero (2010) presented a matheuristic for the TTRP based on an MIP and an LS procedure. Villegas et al. (2011) provided a combination of GRASP, VNS, and path relinking for the TTRP, which outperformed all previous algorithms. Derigs, Pullmann, and Vogel (2013) focused on the TTRP and discussed the impact of time windows and load transfers between trucks and trailers. Villegas et al. (2013) presented a matheuristic for the TTRP, consisting of a GRASP with iterated LS and a set partitioning formulation. Drexl (2014) presented five different BC algorithms for the TTRP with transshipments and evaluated them on a large set of benchmark instances derived from real-world problems. Belenguer et al. (2016) discussed the single TTRP and included satellite facilities at which the trailer must be parked. The authors presented a BC algorithm capable of solving instances with up to 100 customers and 20 satellite facilities. Rothenbächer, Drexl, and Irnich (2018) developed a branch-and-price-and-cut (BPC) algorithm for the TTRP with time windows, considering quantity-dependent transfer time. It outperformed existing approaches on known benchmark instances and was also applied to two real-world problems. Parragh and Cordeau (2017) focused on the TTRP with time windows in the context of infrastructure service providers that operate in urban areas. The authors developed a branch-and-price (BP) algorithm and an adaptive LNS (ALNS) to create initial columns, and they managed to solve instances with up to 100 customers to optimality. Bartolini and Schneider (2018) developed a branch-and-cut algorithm based on a two-commodity flow formulation for the TTRP.

In other synchronization problems, the interchange of freight is conducted between two vehicles directly. In that case, designated support vehicles are used as mobile intra-route facilities. Such problems arise in municipal as well as logistics services. Amaya, Langevin, and Trépanier (2007) introduced the CARPRP in the context of road painting. Here, a vehicle that provides service on arcs is refilled at certain service points (in this case, road junctions) by a second vehicle. In Amaya, Langevin, and Trépanier (2010), the authors presented a route-first, cluster-second heuristic and a cutting-plane algorithm for the CARPRP and extended it to multiple loads. Using this heuristic, they solved a real-world case arising for road painting in Quebec. Salazar-Aguilar, Langevin, and Laporte (2012) studied an arc routing problem with synchronization constraints for snow plowing vehicles and presented an ALNS to study large-sized real-world instances. Salazar-Aguilar, Langevin, and Laporte (2013) focused on node and arc routing in the context of road painting and minimize the makespan. The authors developed an ALNS that provided good results on a large set of artificial instances.

Note that we do not consider pickup and delivery problems with transshipments (see, e.g., Rais, Alvelos, and Carvalho 2014) as RPIS because the main purpose of transferring load at dedicated transshipment locations in these problems is to save travel costs and not to keep the vehicles operational by freeing capacity.

2.4. Analysis of Intermediate Stops for Replenishment and Unloading

We now outline the characteristics of the publications discussed in Sections 2.1–2.3 with respect to their overall scope, objectives, and algorithmic contributions. Table 2 shows the scope of these papers, differentiating them according to (i) the type of contribution (case study versus methodological), (ii) the type of the routing problem (node routing versus arc routing), (iii) the type of replenishment (unloading versus replenishment versus synchronization), and (iv) the type of data (deterministic versus uncertain).

As can be seen from Figure 2, a large majority of the publications focus on a methodological contribution (59%), while only 41% focus on application cases. Detailing this ratio in Table 2, it can be seen that most case studies are presented in the context of municipal services (e.g., waste collection, snow plowing), while publications addressing goods replenishment for classical logistics services often focus on algorithmic enhancements. The ratio between node routing (68%) and arc routing (32%) also indicates the share of different application cases in the analyzed publications. Arc routing problems are mainly discussed for municipal operations, and thus are related to road services or maintenance, for example, snow plowing (Perrier, Langevin, and Campbell 2007), waste collection (Del Pia and Filippi 2006), and road painting (Amaya, Langevin, and Trépanier 2007). Node routing problems are mainly discussed for classical logistics applications in which the service operation is related to single customer locations. Most publications focus on unloading (40%) or synchronization (40%), while only 21% focus on replenishment operations (cf. Figure 2). However, some of the synchronization problems arise in replenishment operations, for example, Amaya, Langevin, and Trépanier (2007) and Amaya, Langevin, and Trépanier (2010). While a large majority of the publications focusing on unloading is related to waste collection, additional application cases for unloading problems arise in pickup problems in logistics networks, for example, in milk collection (cf. Rothenbächer, Drexl, and Irnich 2018). Focusing on the type of data, none of the publications address uncertain data.

To describe the characteristics of the proposed problems with respect to time and replenishment or unloading restrictions, Figure 3 and Table 3 categorize the problem variants as outlined in Section 1. Most problems have a maximum route duration, while only 24% are constrained by time windows. The reason can be seen in the underlying application cases: waste collection, other municipal services, and most of the addressed logistics services (e.g., heating oil distribution) are limited only by the daily planning horizon. Therefore, time windows arise only in specific application cases or in pure methodological contributions to challenge the algorithms.

Table 4 and Figure 4 provide a summary of the objectives. As can be seen, most publications focus on cost or distance minimization. Furthermore, the minimization of the overall route duration or of the number of vehicles is often considered. Only a few publications minimize the makespan of the longest tour to obtain tours of similar duration (cf. Salazar-Aguilar, Langevin, and Laporte 2012, 2013).

Table 5 details the solution approaches that have been used to solve RPIS for replenishment or unloading. To keep the table concise, we limited the solution methods listed in the heuristic section to algorithms that are used in more than one paper, and we merge certain algorithms in their respective class (e.g., two-phase algorithms contain route-first, cluster-second algorithms). The majority are metaheuristics, which is mainly due to the problem size of most application cases (see Tables 6 and 7). Note that the listed MIPs are mostly used to provide a formal problem definition and not to solve the problem. Exact solution methods focus on the most promising approaches for routing problems (e.g., BP algorithms; Muter,

Table 2. Scope of Publications on Intermediate Stops for Replenishment and Unloading of Goods

Case study	Beltrami and Bodin (1974); Semet and Taillard (1993); Mourão and Almeida (2000); Angelelli and Speranza (2002a); Ghiani et al. (2005); Mourão and Amado (2005); Del Pia and Filippi (2006); Kim, Kim, and Sahoo (2006); Kek, Cheu, and Meng (2008); Santos, Coutinho-Rodrigues, and Current (2008); Amaya, Langevin, and Trépanier (2010); Coene, Arnout, and Spieksma (2010); Buhrkal, Larsen, and Ropke (2012); Salazar-Aguilar, Langevin, and Laporte (2012); Hemmelmayr et al. (2013b); Prescott-Gagnon, Desaulniers, and Rousseau (2014); Markov, Varone, and Bierlaire (2016); Willemse and Joubert (2016)
Methodological	Jordan (1987); Gerdessen (1996); Bard et al. (1998); Ghiani, Improta, and Laporte (2001); Angelelli and Speranza (2002b); Chao (2002); De Rosa et al. (2002); Ghiani et al. (2004, 2010); Scheuerer (2006); Tan, Chew, and Lee (2006); Amaya, Langevin, and Trépanier (2007); Crevier, Cordeau, and Laporte (2007); Polacek et al. (2008); Tarantilis, Zachariadis, and Kiranoudis (2008); Benjamin and Beasley (2010); Villegas et al. (2010, 2011); Derigs, Pullmann, and Vogel (2013); Hemmelmayr et al. (2013a); Salazar-Aguilar, Langevin, and Laporte (2013); Drexl (2014); Muter, Cordeau, and Laporte (2014); Schneider, Stenger, and Hof (2015); Belenguer et al. (2016); Rothenbächer, Drexl, and Irnich (2018); Willemse and Joubert (2016); Bartolini and Schneider (2018); Parragh and Cordeau (2017)
Node routing	Beltrami and Bodin (1974); Jordan (1987); Semet and Taillard (1993); Gerdessen (1996); Bard et al. (1998); Angelelli and Speranza (2002a, b); Chao (2002); Kim, Kim, and Sahoo (2006); Scheuerer (2006); Tan, Chew, and Lee (2006); Crevier, Cordeau, and Laporte (2007); Kek, Cheu, and Meng (2008); Tarantilis, Zachariadis, and Kiranoudis (2008); Benjamin and Beasley (2010); Coene, Arnout, and Spieksma (2010); Villegas et al. (2010, 2011); Buhrkal, Larsen, and Ropke (2012); Derigs, Pullmann, and Vogel (2013); Hemmelmayr et al. (2013a, b); Salazar-Aguilar, Langevin, and Laporte (2013); Drexl (2014); Muter, Cordeau, and Laporte (2014); Prescott-Gagnon, Desaulniers, and Rousseau (2014); Schneider, Stenger, and Hof (2015); Belenguer et al. (2016); Markov, Varone, and Bierlaire (2016); Rothenbächer, Drexl, and Irnich (2018); Bartolini and Schneider (2018); Parragh and Cordeau (2017)
Arc routing	Mourão and Almeida (2000); Ghiani, Improta, and Laporte (2001); De Rosa et al. (2002); Ghiani et al. (2004, 2005, 2010); Mourão and Amado (2005); Del Pia and Filippi (2006); Amaya, Langevin, and Trépanier (2007, 2010); Polacek et al. (2008); Santos, Coutinho-Rodrigues, and Current (2008); Salazar-Aguilar, Langevin, and Laporte (2012, 2013); Willemse and Joubert (2016)
Replenishment	Bard et al. (1998); Ghiani, Improta, and Laporte (2001); Ghiani et al. (2004, 2010); Tan, Chew, and Lee (2006); Crevier, Cordeau, and Laporte (2007); Kek, Cheu, and Meng (2008); Tarantilis, Zachariadis, and Kiranoudis (2008); Muter, Cordeau, and Laporte (2014); Prescott-Gagnon, Desaulniers, and Rousseau (2014); Schneider, Stenger, and Hof (2015)
Unloading	Beltrami and Bodin (1974); Jordan (1987); Mourão and Almeida (2000); Ghiani, Improta, and Laporte (2001); Angelelli and Speranza (2002a, b); De Rosa et al. (2002); Ghiani et al. (2004, 2005, 2010); Mourão and Amado (2005); Del Pia and Filippi (2006); Kim, Kim, and Sahoo (2006); Polacek et al. (2008); Santos, Coutinho-Rodrigues, and Current (2008); Benjamin and Beasley (2010); Coene, Arnout, and Spieksma (2010); Buhrkal, Larsen, and Ropke (2012); Hemmelmayr et al. (2013b, a); Markov, Varone, and Bierlaire (2016); Willemse and Joubert (2016)
Synchronization	Semet and Taillard (1993); Gerdessen (1996); Chao (2002); Scheuerer (2006); Amaya, Langevin, and Trépanier (2007, 2010); Caramia and Guerriero (2010); Villegas et al. (2010, 2011); Drexl (2012); Salazar-Aguilar, Langevin, and Laporte (2012, 2013); Derigs, Pullmann, and Vogel (2013); Drexl (2013); Villegas et al. (2013); Drexl (2014); Belenguer et al. (2016); Rothenbächer, Drexl, and Irnich (2018); Bartolini and Schneider (2018); Parragh and Cordeau (2017)
Deterministic	Beltrami and Bodin (1974); Jordan (1987); Semet and Taillard (1993); Gerdessen (1996); Bard et al. (1998); Mourão and Almeida (2000); Ghiani, Improta, and Laporte (2001); Angelelli and Speranza (2002a, b); Chao (2002); De Rosa et al. (2002); Ghiani et al. (2004, 2005, 2010); Mourão and Amado (2005); Del Pia and Filippi (2006); Kim, Kim, and Sahoo (2006); Scheuerer (2006); Tan, Chew, and Lee (2006); Amaya, Langevin, and Trépanier (2007, 2010); Crevier, Cordeau, and Laporte (2007); Kek, Cheu, and Meng (2008); Polacek et al. (2008); Santos, Coutinho-Rodrigues, and Current (2008); Tarantilis, Zachariadis, and Kiranoudis (2008); Benjamin and Beasley (2010); Coene, Arnout, and Spieksma (2010); Villegas et al. (2010, 2011); Buhrkal, Larsen, and Ropke (2012); Salazar-Aguilar, Langevin, and Laporte (2012, 2013); Derigs, Pullmann, and Vogel (2013); Hemmelmayr et al. (2013a, b); Drexl (2014); Muter, Cordeau, and Laporte (2014); Prescott-Gagnon, Desaulniers, and Rousseau (2014); Schneider, Stenger, and Hof (2015); Belenguer et al. (2016); Markov, Varone, and Bierlaire (2016); Rothenbächer, Drexl, and Irnich (2018); Willemse and Joubert (2016); Bartolini and Schneider (2018); Parragh and Cordeau (2017)
Stochastic	None

Cordeau, and Laporte 2014; Parragh and Cordeau 2017; Prescott-Gagnon, Desaulniers, and Rousseau 2014). A first BPC algorithm for the TTRP was proposed by Rothenbächer, Drexl, and Irnich (2018). In addition, several metaheuristic algorithms incorporate dynamic programming components to optimally locate intermediate stops on routes (e.g., Hemmelmayr et al. 2013a; Schiffer et al. 2017a). As can be seen, TS and VNS are the most popular algorithms for this problem class. Contrary to other VRP variants, evolutionary algorithms, which turned out to be effective for a wide class of VRPs (cf. Vidal et al. 2012, 2013, 2014), are only rarely used.

Tables 6 and 7 provide an overview of the benchmark sets that have been published for node routing (Table 6) and arc routing (Table 7) with intermediate stops for replenishment and unloading. The tables show the number of instances #I, the number of nodes (N) or arcs (A), and the number of intra-route facilities (IF). Some instance sets were established as

Figure 2. Characteristics of Publications on Intermediate Stops for Replenishment and Unloading

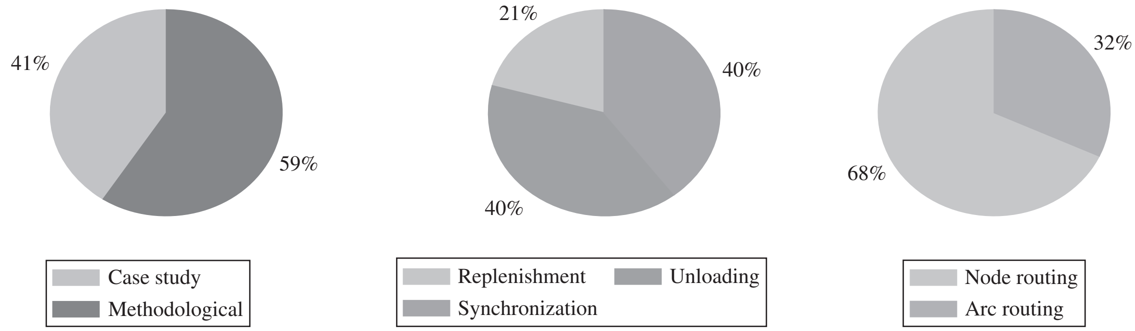
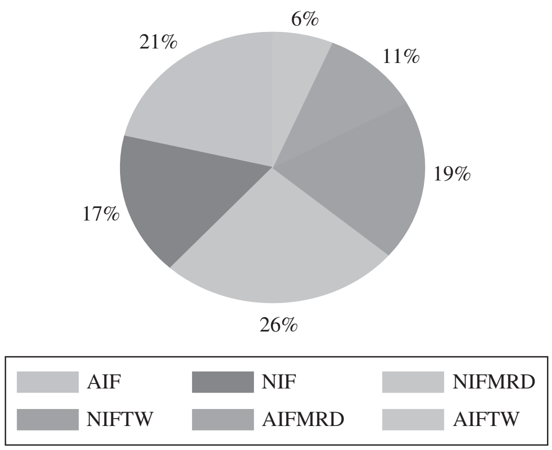


Figure 3. Types of Problem Variants for Intermediate Stops for Replenishment and Unloading



standard benchmark sets in the last years, while others have been used only by the authors themselves. For TTRPs, the benchmark set of Chao (2002) is the most used. For VRPs with replenishment stops, this role is taken by the benchmark sets of Crevier, Cordeau, and Laporte (2007) and by Tarantilis, Zachariadis, and Kiranoudis (2008). Large-scale instances were developed by Benjamin and Beasley (2010) and Kim, Kim, and Sahoo (2006) from the case studies on waste collection.

Concluding, RPIS for unloading and synchronization represent the majority of problems in the analyzed application area, while problems focusing on intermediate stops for replenishing in classical logistics applications account for a share of only 21%. Both arc routing and node routing problems have been solved. While the first are often related to municipal services, the latter arise mostly in classical distribution services. Most notably, uncertainties have not been considered so far. While neglecting uncertainties seems to be appropriate for some of the application cases (e.g., waste collection, road painting, small package shipping), considering uncertain demand in delivery problems with raw materials (e.g., propane distribution) or uncertain travel times in problem variants with time windows seems to constitute a promising research direction. Another promising research direction arises within the context of city logistics. Besides considering uncertainty, dynamic and stochastic problems arise in the context of e-commerce and same-day or express deliveries, and online algorithms are required to address these challenges.

3. Intermediate Stops for Refueling

We now consider publications that focus on intermediate stops for refueling. This type of intermediate stop arises in both dense and sparse refueling

Table 3. Types of Problem Variants for Intermediate Stops for Replenishment and Unloading

AIF	Mourão and Almeida (2000); Ghiani, Improta, and Laporte (2001); Mourão and Amado (2005); Del Pia and Filippi (2006); Amaya, Langevin, and Trépanier (2007, 2010); Santos, Coutinho-Rodrigues, and Current (2008); Salazar-Aguilar, Langevin, and Laporte (2012, 2013); Belenguer et al. (2016)
NIF	Beltrami and Bodin (1974), Jordan (1987), Gerdessen (1996), Angelelli and Speranza (2002b), Chao (2002), Scheuerer (2006), Villegas et al. (2011), Bartolini and Schneider (2018)
NIFMRD	Bard et al. (1998); Crevier, Cordeau, and Laporte (2007); Kek, Cheu, and Meng (2008); Tarantilis, Zachariadis, and Kiranoudis (2008); Benjamin and Beasley (2010); Coene, Arnout, and Spieksma (2010); Buhrkal, Larsen, and Ropke (2012); Hemmelmayr et al. (2013a, b); Muter, Cordeau, and Laporte (2014); Schneider, Stenger, and Hof (2015); Willemse and Joubert (2016)
NIFTW	Kim, Kim, and Sahoo (2006); Benjamin and Beasley (2010); Villegas et al. (2010); Buhrkal, Larsen, and Ropke (2012); Drexl (2014); Prescott-Gagnon, Desaulniers, and Rousseau (2014); Markov, Varone, and Bierlaire (2016); Rothenbächer, Drexl, and Irnich (2018); Parragh and Cordeau (2017)
AIFMRD	De Rosa et al. (2002); Ghiani et al. (2004); Tan, Chew, and Lee (2006); Polacek et al. (2008); Ghiani et al. (2010)
AIFTW	Semet and Taillard (1993); Kim, Kim, and Sahoo (2006); Derigs, Pullmann, and Vogel (2013)

Table 4. Objectives for Intermediate Stops for Replenishing and Unloading

Objective	References
Min. costs	Mourão and Almeida (2000); Ghiani, Improta, and Laporte (2001); De Rosa et al. (2002); Ghiani et al. (2004, 2005, 2010); Mourão and Amado (2005); Amaya, Langevin, and Trépanier (2007, 2010); Crevier, Cordeau, and Laporte (2007); Kek, Cheu, and Meng (2008); Polacek et al. (2008); Buhrkal, Larsen, and Ropke (2012); Hemmelmayr et al. (2013a, b); Drexl (2014); Schneider, Stenger, and Hof (2015); Belenguer et al. (2016); Markov, Varone, and Bierlaire (2016); Rothenbächer, Drexl, and Irnich (2018); Willemse and Joubert (2016); Bartolini and Schneider (2018); Parragh and Cordeau (2017)
Min. distance	Jordan (1987); Semet and Taillard (1993); Bard et al. (1998); Angelelli and Speranza (2002a, b); Chao (2002); Scheuerer (2006); Tan, Chew, and Lee (2006); Benjamin and Beasley (2010); Villegas et al. (2010, 2011); Derigs, Pullmann, and Vogel (2013); Prescott-Gagnon, Desaulniers, and Rousseau (2014)
Min. duration	Beltrami and Bodin (1974); Gerdessen (1996); Del Pia and Filippi (2006); Kim, Kim, and Sahoo (2006); Santos, Coutinho-Rodrigues, and Current (2008); Tarantilis, Zachariadis, and Kiranoudis (2008); Coene, Arnout, and Spieksma (2010); Salazar-Aguilar, Langevin, and Laporte (2012, 2013); Muter, Cordeau, and Laporte (2014)
Min. vehicles	Beltrami and Bodin (1974); Kim, Kim, and Sahoo (2006); Tan, Chew, and Lee (2006); Willemse and Joubert (2016)

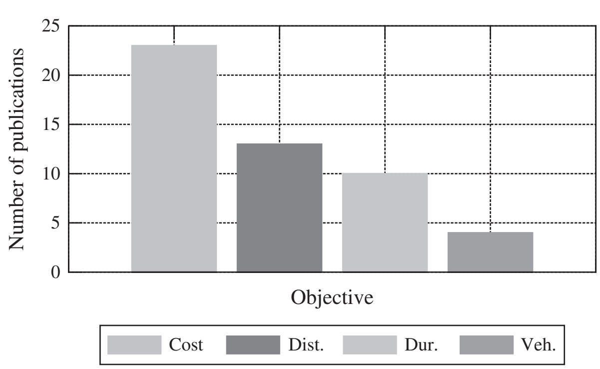
infrastructures. While dense infrastructures exist for ICEV fleets, sparse infrastructures arise mainly for AFV fleets. Section 3.1 focuses on refueling stops in dense refueling infrastructure. Intermediate stops for sparse refueling infrastructures are discussed in Section 3.2. Finally, Section 3.3 concludes this discussion with a detailed analysis of problem variants and algorithms.

3.1. Intermediate Stops for Refueling in Dense Refueling Networks

RPIS for refueling in dense refueling networks are relevant for ICEV fleets for economic reasons, for example, to take advantage of price differences at spatially close gas filling stations.

The first papers in this context were written by Ichimori and Ishii (1981) and Ichimori, Ishii, and Nishida (1983), focusing on a shortest path problem (SPP) for vehicles with limited fuel capacity and refueling options that are limited to dedicated nodes. The authors presented a modified Dijkstra algorithm to solve this problem. Bousonville et al. (2011) included refueling decisions for ICEVs into a VRPTW and analyzed the impact of price variations, especially on the tour length. The objective focused on minimizing the overall costs for refueling, and Solomon's I1

Figure 4. Objectives for Intermediate Stops for Replenishing and Unloading



construction heuristic was applied. Khuller, Malekian, and Mestre (2011) studied SPPs and traveling salesman problems (TSPs) with price varying refueling options. Suzuki (2012) focused on a TSP with time windows and time-sensitive demand, considering refueling options. In addition, Suzuki and Dai (2012) proposed a variable reduction technique for this problem.

3.2. Intermediate Stops for Refueling in Sparse Refueling Networks

Intermediate stops for refueling with sparse refueling structures arise mainly for ECVs and other AFVs. VRP variants, SPPs and TSPs, as well as location-routing problem (LRP) variants have been studied in this context.

Gonçalves et al. (2011) considered a VRP with pickups and deliveries and a mixed fleet of ICEVs and ECVs to study the integration of ECVs in the fleet of a battery distributor. The authors presented an MIP minimizing fixed vehicle costs and routing costs. Although recharging time for intermediate stops is considered, dedicated charging station vertices are not used. Conrad and Figliozzi (2011) introduced the recharging VRP in which vehicles with a limited driving range are allowed to recharge en route at certain customer locations, while considering a fixed recharging time and customer time windows. The authors used a lexicographic objective function to first minimize the number of vehicles and then the routing cost. Erdoğan and Miller-Hooks (2012) proposed the green VRP (GVRP) that considers a limited fuel capacity for AFVs and refueling options on routes, while restricting the maximum duration of a route. The authors proposed a modified savings algorithm (cf. Clarke and Wright 1964) and a density-based route-first, cluster-second algorithm. Focusing on an airport shuttle service, Barco et al. (2017) presented a comprehensive approach for integrating ECVs into a fleet of shuttle vehicles. Schneider, Stenger, and Goeke (2014) were the first to address the electric VRP (EVRP) with time

Table 5. Solution Methods for Routing Problems on Intermediate Stops for Replenishment and Unloading

	Exact
(M)I(L)P	Jordan (1987); Bard et al. (1998); Mourão and Almeida (2000); Ghiani, Improta, and Laporte (2001); Chao (2002); Amaya, Langevin, and Trépanier (2007, 2010); Crevier, Cordeau, and Laporte (2007); Kek, Cheu, and Meng (2008); Coene, Arnout, and Spieksma (2010); Buhrkal, Larsen, and Ropke (2012); Hemmelmayr et al. (2013a, b); Drexl (2014); Schneider, Stenger, and Hof (2015); Belenguer et al. (2016); Markov, Varone, and Bierlaire (2016)
BC	Bard et al. (1998); Amaya, Langevin, and Trépanier (2010); Drexl (2014); Belenguer et al. (2016); Bartolini and Schneider (2018)
DP component	Hemmelmayr et al. (2013a), Schiffer et al. (2017a)
BP, CG	Muter, Cordeau, and Laporte (2014); Prescott-Gagnon, Desaulniers, and Rousseau (2014); Parragh and Cordeau (2017)
LB techniques	Mourão and Almeida (2000), Mourão and Amado (2005)
BPC	Rothenbächer, Drexl, and Irnich (2018)
	Heuristic
TS	Semet and Taillard (1993); Angelelli and Speranza (2002a, b); Chao (2002); De Rosa et al. (2002); Ghiani et al. (2004); Scheuerer (2006); Crevier, Cordeau, and Laporte (2007); Tarantilis, Zachariadis, and Kiranoudis (2008); Benjamin and Beasley (2010); Prescott-Gagnon, Desaulniers, and Rousseau (2014)
(A)LNS	Buhrkal, Larsen, and Ropke (2012); Salazar-Aguilar, Langevin, and Laporte (2012, 2013); Derigs, Pullmann, and Vogel (2013); Schiffer et al. (2017a); Parragh and Cordeau (2017)
(A)VNS	Del Pia and Filippi (2006); Polacek et al. (2008); Tarantilis, Zachariadis, and Kiranoudis (2008); Benjamin and Beasley (2010); Villegas et al. (2010, 2011); Hemmelmayr et al. (2013a, b); Prescott-Gagnon, Desaulniers, and Rousseau (2014); Schneider, Stenger, and Hof (2015); Markov, Varone, and Bierlaire (2016)
LS	Gerdessen (1996); Del Pia and Filippi (2006); Tarantilis, Zachariadis, and Kiranoudis (2008); Derigs, Pullmann, and Vogel (2013); Hemmelmayr et al. (2013a); Markov, Varone, and Bierlaire (2016); Schiffer et al. (2017a)
Two-phase algorithm	Mourão and Almeida (2000); Ghiani et al. (2005); Kim, Kim, and Sahoo (2006); Coene, Arnout, and Spieksma (2010); Amaya, Langevin, and Trépanier (2010); Willemse and Joubert (2016)
Path scanning	Santos, Coutinho-Rodrigues, and Current (2008); Willemse and Joubert (2016)
EA	Tan, Chew, and Lee (2006); Ghiani et al. (2010)
Other	Beltrami and Bodin (1974); Jordan (1987); Ghiani, Improta, and Laporte (2001); Mourão and Amado (2005); Crevier, Cordeau, and Laporte (2007); Santos, Coutinho-Rodrigues, and Current (2008); Villegas et al. (2010, 2011)

Note. (M)I(L)P, (Mixed) integer (linear) program; LB, lower bound; (A)VNS, (adaptive) VNS; EA, evolutionary algorithm.

Table 6. Instances for Node Routing Problems with Intermediate Stops for Replenishment or Unloading

Reference	Type	#I	N	IF	Used within
Gerdessen (1996)	NIF	150	50–200	50–200	
Chao (2002)	NIF	21	50–199	13–150	Scheuerer (2006); Villegas et al. (2011); Derigs, Pullmann, and Vogel (2013); Belenguer et al. (2016)
Angelelli and Speranza (2002b)	NIF	42	50–288	1–4	
Kim, Kim, and Sahoo (2006)	NIFTW	10	102–2,100		Benjamin and Beasley (2010); Buhrkal, Larsen, and Ropke (2012)
Crevier, Cordeau, and Laporte (2007)	NIFMRD	22	48–288	3–7	Tarantilis, Zachariadis, and Kiranoudis (2008); Hemmelmayr et al. (2013a); Muter, Cordeau, and Laporte (2014); Schneider, Stenger, and Hof (2015); Markov, Varone, and Bierlaire (2016); Schiffer et al. (2017a)
Tarantilis, Zachariadis, and Kiranoudis (2008)	NIFMRD	54	50–175	3–8	Hemmelmayr et al. (2013a); Schneider, Stenger, and Hof (2015); Schiffer et al. (2017a)
Drexl (2014)	NIFTW	109	16–106		Rothenbächer, Drexl, and Irnich (2018); Bartolini and Schneider (2018)
Prescott-Gagnon, Desaulniers, and Rousseau (2014)	NIFTW	18	250–750		
Willemse and Joubert (2016)	NIFMRD	3	1,012–2,755	2	
Parragh and Cordeau (2017)	NIFTW	18	25–100	7–75	Rothenbächer, Drexl, and Irnich (2018)
Case studies		2	184–387	1–3	Hemmelmayr et al. (2013b); Markov, Varone, and Bierlaire (2016)

Note. If the number of intra-route facilities is not known, IF is left empty.

Table 7. Instances for Arc Routing Problems with Intermediate Stops for Replenishment or Unloading

Reference	Type	#I	A	IF	Used within
Mourão and Almeida (2000)	AIF	30	13–97	1	
Ghiani, Improta, and Laporte (2001)	AIF	51	11–97	1–2	Ghiani et al. (2004), Polacek et al. (2008), Ghiani et al. (2010), De Rosa et al. (2002)
Mourão and Amado (2005)	AIF	30	94–743	1	
Amaya, Langevin, and Trépanier (2007)	AIF	180	50–595	3–5	Amaya, Langevin, and Trépanier (2010)
Salazar-Aguilar, Langevin, and Laporte (2012)	AIF	45	113–795		
Salazar-Aguilar, Langevin, and Laporte (2013)	AIF	60	200–350	60–100	
Case studies		2	376–422		Ghiani et al. (2005), Del Pia and Filippi (2006)

Note. If the number of intra-route facilities is not known, IF is left empty.

windows (EVRPTW) focusing on a pure electric vehicle fleet and dedicated vertices for recharging activities considering quantity-dependent recharging times. The authors also used the lexicographic objective function of Conrad and Figliozzi (2011).

Felipe et al. (2014) introduced the GVRP with multiple technologies and partial recharges (GVRPMTPR), focusing on different types of recharging stations for ECVs and taking different costs, different charging speeds, and partial recharging into consideration. Sassi, Cherif-Khettaf, and Oulamara (2015c) presented an EVRP with partial recharging and a heterogeneous ECV fleet, with a lexicographic objective function that first minimizes the number of vehicles and then the distance and charging cost. The same authors presented a multistart iterated local search in Sassi, Cherif-Khettaf, and Oulamara (2015b) and an iterated TS in Sassi, Cherif-Khettaf, and Oulamara (2015a) for this problem. Goeke and Schneider (2015) analyzed an EVRP with a mixed fleet of ICEVs and ECVs, considering a realistic energy consumption function using data on vehicle speed, vehicle load, and gradients. Bruglieri et al. (2015a, b) proposed a matheuristic based on a variable neighborhood branching for the EVRPTW. Montoya et al. (2016) developed a multispace sampling heuristic for the GVRP. Verma, Lamsal, and Keough (2015) investigated the EVRPTW for battery swapping stations instead of recharging stations. The authors developed a VNS to solve this problem and calculated results on the instances of Schneider, Stenger, and Goeke (2014). Hiermann et al. (2016) investigated the EVRPTW with heterogeneous electric vehicles that have different acquisition costs and vehicle-independent routing costs.

Desaulniers et al. (2016) developed a BPC algorithm for the EVRPTW, covering four variants with single and multiple recharge stops per route as well as full and partial recharging. The authors presented a monodirectional and a bidirectional pricing labeling algorithm and found that multiple recharges improve the overall solution with respect to the number of vehicles and costs. Keskin and Çatay (2016) addressed the EVRPTW and partial recharging (EVRPTWPR) and developed an ALNS. Koç and Karaoglan (2016) focused on the GVRP and introduced a BC algorithm to improve lower bounds and a simulated annealing (SA) algorithm to calculate upper bounds. Yavuz and Çapar (2017) discussed the adoption of AFVs in service fleets. Montoya et al. (2017) investigated an EVRP allowing for partial recharging and considering a nonlinear charging function. The authors presented a hybrid algorithm based on VNS and LS. Additionally, they presented a component to insert charging stations into routes, either based on a greedy heuristic or on a mixed integer program. Yavuz (2017) proposed an iterated beam search algorithm for the GVRP. Andelmin and Bartolini (2017) presented a column generation based approach to solve the GVRP exactly up to 111 customers. Schiffer et al. (2017b) introduced the EVRP with truck driver scheduling and analyzed the impact of HOS regulations on the competitiveness of ECVs compared to ICEVs, synchronizing idle times for recharging and breaking. The authors presented an ALNS-based algorithm with a time-efficient HOS scheduling component and analyzed European Union (EU) as well as U.S. HOS regulations. Froger et al. (2017a) introduced an alternative formulation for the EVRP based on a multigraph and Froger et al. (2017b) focused on capacitated charging stations.

The first publications on generic VRP variants only appeared recently. Schneider, Stenger, and Hof (2015) developed a generalized VRP model and presented an adaptive VNS that provided good results on the GVRP and EVRP variants with full recharging options. Schiffer et al. (2017a) developed a generic algorithmic framework for VRPISs based on an ALNS with an additional DP element. This algorithm yields the best known results for several EVRP variants, namely, the EVRPTW, the EVRPTWPR, the EVRP with maximum route duration, and the GVRP.

Besides publications on VRP variants, SPPs and TSPs have been investigated. Liao, Lu, and Shen (2016) introduced the electric vehicle touring problem that accounts for a shortest route that can be chosen by an

ECV to get from an origin to a destination. On this route, the ECV may stop at one or several battery swapping stations to switch its battery. The authors presented a polynomial-time algorithm for this problem. Roberti and Wen (2016) introduced the electric TSP with time windows and presented a three-phase heuristic based on a VNS and dynamic programming to solve instances with up to 200 customers. Further work on routing pure ECVs has been presented by Sweda, Dolinskaya, and Klabjan (2017), accounting for uncertain recharging options over time, so that adaptive routing and recharging decisions can be optimized.

The first papers focusing on hybrid electric vehicles (HEVs) were published only recently. Arslan, Yildiz, and Karasan (2015) presented the minimum cost path problem for plug-in hybrid electric vehicles, considering refueling and recharging stations with different cost structures. The authors presented a dynamic programming and a shortest path algorithm, minimizing overall costs. Doppstadt, Koberstein, and Vigo (2016) introduced the hybrid electric vehicle TSP in which vehicles can switch between different engine modes and presented a TS heuristic to solve large-sized instances. Another publication on hybrid electric vehicles was presented by Mancini (2017), who introduced the hybrid VRP in which vehicles can either switch their engine mode once the battery is discharged or be recharged at specific charging stations. Nejad et al. (2017) focused on optimal routing for plug-in hybrid electric vehicles and provided different exact DP-based algorithms for this problem.

The first publications on LRPs in the context of ECVs were also published recently. Because decisions on vehicle routing and charging station locations are interdependent, a simultaneous consideration bears a significant improvement potential at strategic level (cf. Schiffer and Walther 2017b). These publications consider variants of the LRP with intra-route facilities (LRPIF; Schiffer and Walther cf. 2017a). The LRPIF differs from conventional LRPs because the decision is on locating intra-route facilities, as introduced in Section 1, instead of depots. In the following, we focus on LRPIF variants and refer to recent surveys (Lopes et al. 2013; Drexl and Schneider 2014; Prodhon and Prins 2014; Cuda, Guastaroba, and Speranza 2015; Albareda-Sambola 2015; Schneider and Drexl 2017) for an overview of conventional LRPs.

The first LRP in this context was by Yang and Sun (2015), who introduced the battery swap station electric vehicle LRP (BSS-EV-LRP) that simultaneously determines battery swapping station locations and vehicle routes. Hof, Schneider, and Goeke (2017) extended the VNS developed in Schneider, Stenger, and Hof (2015) to the BSS-EV-LRP and significantly improved the results of Yang and Sun (2015). Schiffer and Walther (2017b) introduced the electric LRP with time windows and partial recharging (ELRPTWPR), which extends the BSS-EV-LRP to a more general problem formulation, accounting for partial recharging, time windows and time-dependent recharging. The authors discussed different objective functions and highlighted the impact of simultaneous charging station location and vehicle routing decisions. Schiffer, Stütz, and Walther (2017) presented a case study for the ELRPTWPR based on the distribution network of a German retail company and showed that ECVs are on the verge of breaking even for certain application cases. Since customer patterns heavily affect the routing and the interdependent charging station location decision, Schiffer and Walther (2018) introduced a robust ELRPTWPR that considers uncertainty in customer patterns with regard to the spatial distribution, demand, and time windows. The authors presented a parallelized ALNS to solve this problem. In a more generic fashion, Schiffer and Walther (2017a) introduced the LRPIF that is not limited to ECVs and charging stations but also accounts for conventional vehicles or other AFVs and intra-route facilities for freight replenishment. The authors presented new benchmark instances and an ALNS with a DP component. Schiffer, Schneider, and Laporte (2018) extended the LRPIF for combined facilities at which recharging energy and replenishing freight can take place simultaneously. Furthermore, the authors integrated lower bounding techniques to avoid unpromising facility configurations in an ALNS. This algorithm yields the best results for all LRPIF variants discussed previously.

3.3. Analysis of Intermediate Stops for Refueling

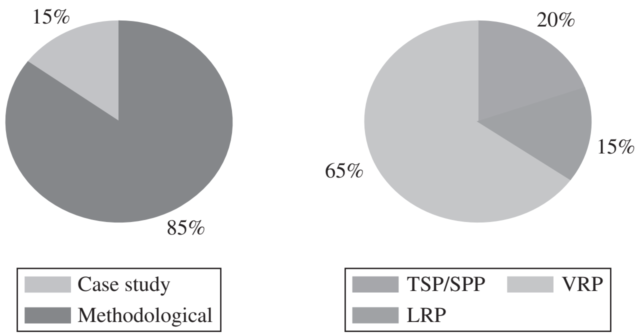
Table 8 summarizes the scope of the publications discussed in this section. Besides (i) the type of publication and (ii) the type of the routing problem, which have also been discussed in Section 2, we include additional characteristics. We further differentiate between (iii) the vehicle type, (iv) the type of data (as in Section 2), (v) the modeling approach, and (vi) the refueling infrastructure. As can be seen in Figure 5, the share of publications that describe case studies is rather low (15%), while most publications focus on methodological improvements (85%). Problems on intermediate stops for refueling are mostly tackled as pure routing problems (85%; TSP/SPP, VRP); a much smaller proportion (15%) also considers the location component. All publications consider node routing problems. The large majority of publications focus on ECVs (67%), while only a limited number of publications focus on HEVs (8%) or on AFVs (15%) (cf. Figure 6). Only 10% consider ICEVs. This corresponds to the proportion of problems in which a dense refueling structure is considered (11%), while all publications that are related to any kind of AFVs consider a sparse refueling structure.

Figure 7 and Table 9 detail the problem types, based on the definition given in Table 1. Because all problems

Table 8. Scope of Publications on Intermediate Stops for Refueling

Case study	Gonçalves et al. (2011); Barco et al. (2017); Sassi, Cherif-Khettaf, and Oulamara (2015c); Schiffer, Stütz, and Walther (2017); Yavuz and Çapar (2017); Nejad et al. (2017); Schiffer et al. (2017b)
Methodological	Ichimori and Ishii (1981); Ichimori, Ishii, and Nishida (1983); Bousonville et al. (2011); Conrad and Figliozzi (2011); Khuller, Malekian, and Mestre (2011); Erdoğan and Miller-Hooks (2012); Suzuki (2012); Felipe et al. (2014); Hiermann et al. (2016); Schneider, Stenger, and Goeke (2014); Arslan, Yildiz, and Karasan (2015); Bruglieri et al. (2015a, b); Goeke and Schneider (2015); Mancini (2017); Montoya et al. (2016, 2017); Sassi, Cherif-Khettaf, and Oulamara (2015a, b); Schiffer and Walther (2017b); Schneider, Stenger, and Hof (2015); Verma, Lamsal, and Keough (2015); Yang and Sun (2015); Desaulniers et al. (2016); Doppstadt, Koberstein, and Vigo (2016); Keskin and Çatay (2016); Koç and Karaoglan (2016); Roberti and Wen (2016); Andelmin and Bartolini (2017); Froger et al. (2017a, b); Hof, Schneider, and Goeke (2017); Schiffer and Walther (2017a, 2018); Schiffer et al. (2017a); Schiffer, Schneider, and Laporte (2018); Sweda, Dolinskaya, and Klabjan (2017); Yavuz (2017)
Node routing	Ichimori and Ishii (1981); Ichimori, Ishii, and Nishida (1983); Bousonville et al. (2011); Conrad and Figliozzi (2011); Gonçalves et al. (2011); Khuller, Malekian, and Mestre (2011); Erdoğan and Miller-Hooks (2012); Suzuki (2012); Barco et al. (2017); Felipe et al. (2014); Hiermann et al. (2016); Schneider, Stenger, and Goeke (2014); Arslan, Yildiz, and Karasan (2015); Bruglieri et al. (2015a, b); Goeke and Schneider (2015); Mancini (2017); Montoya et al. (2016, 2017); Sassi, Cherif-Khettaf, and Oulamara (2015a, b, c); Schiffer and Walther (2017b); Schneider, Stenger, and Hof (2015); Verma, Lamsal, and Keough (2015); Yang and Sun (2015); Desaulniers et al. (2016); Doppstadt, Koberstein, and Vigo (2016); Keskin and Çatay (2016); Koç and Karaoglan (2016); Roberti and Wen (2016); Schiffer, Stütz, and Walther (2017); Andelmin and Bartolini (2017); Froger et al. (2017a, b); Hof, Schneider, and Goeke (2017); Nejad et al. (2017); Schiffer and Walther (2017a, 2018); Schiffer et al. (2017a, b); Schiffer, Schneider, and Laporte (2018); Sweda, Dolinskaya, and Klabjan (2017); Yavuz and Çapar (2017); Yavuz (2017)
Arc routing	None
ECV	Conrad and Figliozzi (2011); Gonçalves et al. (2011); Barco et al. (2017); Felipe et al. (2014); Hiermann et al. (2016); Schneider, Stenger, and Goeke (2014); Bruglieri et al. (2015a, b); Goeke and Schneider (2015); Montoya et al. (2017); Sassi, Cherif-Khettaf, and Oulamara (2015a, b, c); Schiffer and Walther (2017a, b, 2018); Schneider, Stenger, and Hof (2015); Verma, Lamsal, and Keough (2015); Yang and Sun (2015); Desaulniers et al. (2016); Keskin and Çatay (2016); Koç and Karaoglan (2016); Roberti and Wen (2016); Schiffer, Stütz, and Walther (2017); Froger et al. (2017a, b); Hof, Schneider, and Goeke (2017); Schiffer et al. (2017a, b); Schiffer, Schneider, and Laporte (2018); Sweda, Dolinskaya, and Klabjan (2017)
HEVs	Arslan, Yildiz, and Karasan (2015); Mancini (2017); Doppstadt, Koberstein, and Vigo (2016); Nejad et al. (2017)
ICEVs	Ichimori and Ishii (1981); Ichimori, Ishii, and Nishida (1983); Bousonville et al. (2011); Khuller, Malekian, and Mestre (2011); Suzuki (2012)
AFVs	Erdoğan and Miller-Hooks (2012); Schneider, Stenger, and Hof (2015); Montoya et al. (2016); Andelmin and Bartolini (2017); Schiffer et al. (2017a); Yavuz and Çapar (2017); Yavuz (2017)
Deterministic	Bousonville et al. (2011); Conrad and Figliozzi (2011); Gonçalves et al. (2011); Khuller, Malekian, and Mestre (2011); Erdoğan and Miller-Hooks (2012); Suzuki (2012); Barco et al. (2017); Felipe et al. (2014); Hiermann et al. (2016); Schneider, Stenger, and Goeke (2014); Bruglieri et al. (2015a, b); Goeke and Schneider (2015); Mancini (2017); Montoya et al. (2016, 2017); Sassi, Cherif-Khettaf, and Oulamara (2015a, b, c); Schiffer and Walther (2017b); Verma, Lamsal, and Keough (2015); Yang and Sun (2015); Desaulniers et al. (2016); Doppstadt, Koberstein, and Vigo (2016); Keskin and Çatay (2016); Koç and Karaoglan (2016); Roberti and Wen (2016); Schiffer, Stütz, and Walther (2017); Andelmin and Bartolini (2017); Froger et al. (2017a, b); Hof, Schneider, and Goeke (2017); Nejad et al. (2017); Schiffer and Walther (2017a); Schiffer et al. (2017a, b); Schiffer, Schneider, and Laporte (2018); Yavuz and Çapar (2017); Yavuz (2017)
Uncertain	Sweda, Dolinskaya, and Klabjan (2017); Schiffer and Walther (2018)
TSP/SPP	Ichimori and Ishii (1981); Ichimori, Ishii, and Nishida (1983); Khuller, Malekian, and Mestre (2011); Suzuki (2012); Arslan, Yildiz, and Karasan (2015); Doppstadt, Koberstein, and Vigo (2016); Roberti and Wen (2016); Sweda, Dolinskaya, and Klabjan (2017); Nejad et al. (2017)
VRP	Bousonville et al. (2011); Conrad and Figliozzi (2011); Gonçalves et al. (2011); Erdoğan and Miller-Hooks (2012); Barco et al. (2017); Felipe et al. (2014); Hiermann et al. (2016); Schneider, Stenger, and Goeke (2014); Bruglieri et al. (2015a, b); Goeke and Schneider (2015); Mancini (2017); Montoya et al. (2016, 2017); Sassi, Cherif-Khettaf, and Oulamara (2015a, b, c); Schneider, Stenger, and Hof (2015); Verma, Lamsal, and Keough (2015); Desaulniers et al. (2016); Keskin and Çatay (2016); Koç and Karaoglan (2016); Andelmin and Bartolini (2017); Froger et al. (2017a, b); Schiffer et al. (2017a, b); Yavuz and Çapar (2017); Yavuz (2017)
LRP	Schiffer and Walther (2017b); Yang and Sun (2015); Schiffer and Walther (2017a); Schiffer, Stütz, and Walther (2017); Hof, Schneider, and Goeke (2017); Schiffer and Walther (2018); Schiffer, Schneider, and Laporte (2018)
Dense	Ichimori and Ishii (1981); Ichimori, Ishii, and Nishida (1983); Bousonville et al. (2011); Khuller, Malekian, and Mestre (2011); Suzuki (2012)
Sparse	Gonçalves et al. (2011); Conrad and Figliozzi (2011); Erdoğan and Miller-Hooks (2012); Barco et al. (2017); Schneider, Stenger, and Goeke (2014); Felipe et al. (2014); Arslan, Yildiz, and Karasan (2015); Goeke and Schneider (2015); Bruglieri et al. (2015a, b); Sassi, Cherif-Khettaf, and Oulamara (2015a, b, c); Schneider, Stenger, and Hof (2015); Verma, Lamsal, and Keough (2015); Yang and Sun (2015); Hiermann et al. (2016); Desaulniers et al. (2016); Doppstadt, Koberstein, and Vigo (2016); Keskin and Çatay (2016); Koç and Karaoglan (2016); Montoya et al. (2016); Roberti and Wen (2016); Andelmin and Bartolini (2017); Froger et al. (2017a, b); Schiffer, Stütz, and Walther (2017); Mancini (2017); Montoya et al. (2017); Nejad et al. (2017); Schiffer and Walther (2017a, b, 2018); Hof, Schneider, and Goeke (2017); Schiffer, Schneider, and Laporte (2018); Schiffer et al. (2017b, a); Sweda, Dolinskaya, and Klabjan (2017); Yavuz and Çapar (2017); Yavuz (2017)

Figure 5. Characteristics of Publications on Intermediate Stops for Refueling



focus on fuel or energy that is consumed while driving, the resource consumption is always arc based. Considering the time restrictions, all possible characteristics are addressed. The majority of the problems considers time-dependent replenishment processes (57%), and time window restrictions are also considered (49%). Overall, 79% of the problems include time constraints. Furthermore, the models analyzed in this section are the only ones that account for partial replenishment because refueling consumes a significant amount of time for ECVs.

Figure 8 and Table 10 illustrate the different objective functions. As can be seen, most publications minimize overall costs or the total distance driven. Some publications make use of the lexicographic objective function approach used in heuristics on the classical VRPTW, minimizing the number of vehicles first and the total traveled distance second. Other objectives, for example, minimizing the overall duration or consumed energy, are only rarely applied.

Table 11 shows the different algorithms that have been used to solve routing problems with refueling stops. A majority of the problems use an MIP to define the analyzed problem in a formal way but not to create solutions on large-sized instances. Again, metaheuristics are more often used than exact algorithms. The few available exact algorithms are based on BP, BC, and BPC. Only for SPPs, a few polynomial time algorithms have been presented (e.g., Sweda, Dolinskaya, and Klabjan 2017). Metaheuristics mainly use ALNS and VNS. Contrary to problems with intermediate stops for unloading or replenishment, TS is only rarely used.

Figure 6. Characteristics of Publications on Intermediate Stops for Refueling

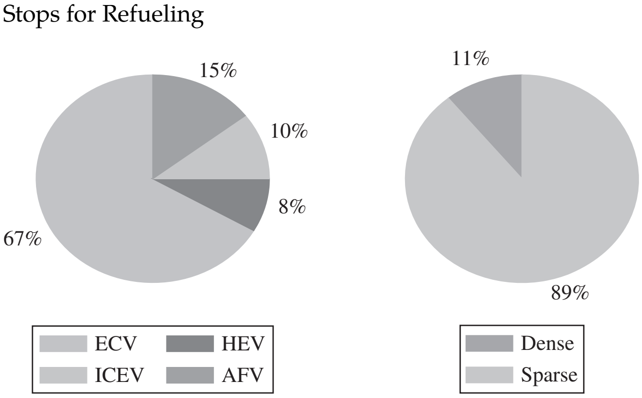


Figure 7. Types of Problem Variants for Intermediate Stops for Refueling

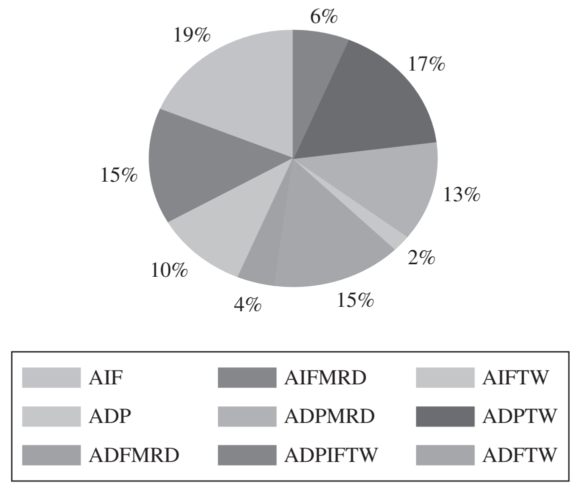


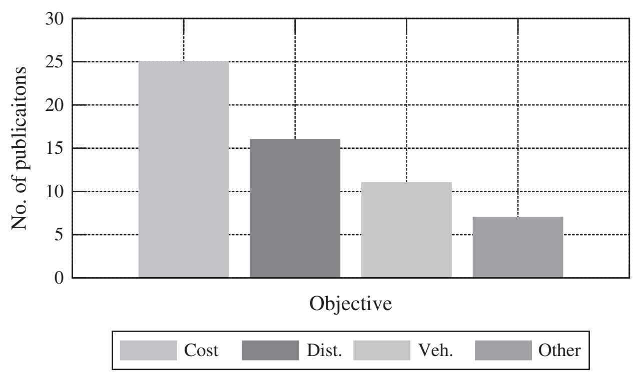
Table 12 summarizes the instance sets published so far. Three benchmark sets are used regularly to assess the competitiveness of algorithms. For the GVRP, there are the instance sets of Erdoğan and Miller-Hooks (2012), while the instance sets of Schneider, Stenger, and Goeke (2014) are used for EVRP variants. In a location routing context, the instance set of Yang and Sun (2015) is used to assess the competitiveness of LRPIF algorithms.

Concluding, most publications on intermediate stops for refueling focus on recharging stops for ECVs, which is a highly relevant topic with benefits for sustainable transport developments, for example, by reducing range anxiety concerns (Pelletier et al. 2017). Most contributions focus on algorithmic aspects or extend existing EVRP variants by additional real-world constraints (e.g., realistic energy consumption, nonlinear recharging). However, publications on case studies and real-world problems are quite sparse, which may be because the adoption rate of ECVs is still quite low, and the expected market uptake is slow because of the concerns of practitioners. Thus, case studies that help to highlight the competitiveness of ECVs (e.g., Schiffer, Stütz, and Walther 2017) and to reduce the concerns of practitioners on applicability or range anxiety seem to be an important research direction that, besides scientific contribution, adds societal value by boosting the market uptake of ECVs. In addition, alternative charging technologies constitute an interesting avenue for future research. Recharging lanes that recharge the battery while the vehicle is driving are

Table 9. Types of Problem Variants for Intermediate Stops for Refueling

AIF	Ichimori and Ishii (1981); Ichimori, Ishii, and Nishida (1983); Khuller, Malekian, and Mestre (2011); Arslan, Yildiz, and Karasan (2015); Yang and Sun (2015); Doppstadt, Koberstein, and Vigo (2016); Liao, Lu, and Shen (2016); Hof, Schneider, and Goeke (2017); Nejad et al. (2017)
AIFMRD	Gonçalves et al. (2011); Erdoğan and Miller-Hooks (2012); Schneider, Stenger, and Hof (2015); Montoya et al. (2016); Koç and Karaoglan (2016); Andelmin and Bartolini (2017); Yavuz (2017)
AIFTW	Bousonville et al. (2011); Conrad and Figliozzi (2011); Suzuki (2012); Barco et al. (2017); Verma, Lamsal, and Keough (2015)
ADFMRD	Mancini (2017); Schneider, Stenger, and Hof (2015)
ADFTW	Hiermann et al. (2016); Schneider, Stenger, and Goeke (2014); Bruglieri et al. (2015a, b); Goeke and Schneider (2015); Schneider, Stenger, and Hof (2015); Desaulniers et al. (2016)
ADP	Sweda, Dolinskaya, and Klabjan (2017)
ADPMRD	Felipe et al. (2014); Montoya et al. (2017); Sassi, Cherif-Khettaf, and Oulamara (2015c, a, b); Yavuz and Çapar (2017)
ADPTW	Desaulniers et al. (2016); Keskin and Çatay (2016); Roberti and Wen (2016); Schiffer, Stütz, and Walther (2017); Froger et al. (2017a, b); Schiffer and Walther (2017b, a)
ADPIFTW	Schiffer, Schneider, and Laporte (2018); Schiffer et al. (2017b)

Figure 8. Objectives for Intermediate Stops for Refueling



currently being tested for medium-duty ECVs in the logistics sector. A scientific evaluation of this concept and its implications on routing ECVs is still missing. Last, the consideration of uncertainties with respect to charging station availabilities should be considered in future work to generate robust route plans for ECV fleets.

4. Intermediate Stops for Rests and Breaks

The third field in which intermediate stops are required are routing problems that consider break and rest periods arising from HOS regulations or multiday planning problems. The relevant literature can be classified into truck driver scheduling problems (TDSPs) that account for HOS regulations to which logistics fleets have to abide, and into team orienteering problems (TOPs) and TSPs with hotel selection that originated from trip planning in tourism. TDSPs can be further separated into classical TDSPs, in which route plans are already fixed and only a break and rest sequence have to be scheduled on the routes, and vehicle routing and truck driver scheduling problems (VRTDSPs), in which route plans as well as break schedules are determined. Because of prefixed route plans, TDSPs do not fully match the scope of our survey. Section 4.1 gives an overview of VRTDSPs, and Section 4.2 focuses on TOPs and TSPs with hotel selection. In Section 4.3, we again analyze the characteristics of the considered publications.

Table 10. Objectives for Intermediate Stops for Refueling

Objective	References
Costs	Bousonville et al. (2011); Conrad and Figliozzi (2011); Gonçalves et al. (2011); Khuller, Malekian, and Mestre (2011); Suzuki (2012); Felipe et al. (2014); Hiermann et al. (2016); Arslan, Yildiz, and Karasan (2015); Goeke and Schneider (2015); Sassi, Cherif-Khettaf, and Oulamara (2015c, a, b); Schiffer and Walther (2017b); Verma, Lamsal, and Keough (2015); Yang and Sun (2015); Desaulniers et al. (2016); Doppstadt, Koberstein, and Vigo (2016); Schiffer and Walther (2017a); Schiffer, Stütz, and Walther (2017); Sweda, Dolinskaya, and Klabjan (2017); Yavuz and Çapar (2017); Hof, Schneider, and Goeke (2017); Schiffer, Schneider, and Laporte (2018); Schiffer et al. (2017b)
Distance	Ichimori and Ishii (1981); Ichimori, Ishii, and Nishida (1983); Erdoğan and Miller-Hooks (2012); Schneider, Stenger, and Goeke (2014); Bruglieri et al. (2015a, b); Montoya et al. (2016); Schneider, Stenger, and Hof (2015); Keskin and Çatay (2016); Koç and Karaoglan (2016); Liao, Lu, and Shen (2016); Roberti and Wen (2016); Andelmin and Bartolini (2017); Mancini (2017); Schiffer and Walther (2017b); Yavuz and Çapar (2017); Yavuz (2017)
Duration	Froger et al. (2017a, b); Montoya et al. (2017)
Num. veh./trips	Conrad and Figliozzi (2011); Schneider, Stenger, and Goeke (2014); Bruglieri et al. (2015a, b); Sassi, Cherif-Khettaf, and Oulamara (2015c, a, b); Schiffer and Walther (2017b); Schneider, Stenger, and Hof (2015); Keskin and Çatay (2016)
Energy	Barco et al. (2017); Nejad et al. (2017)
Emissions	Yavuz and Çapar (2017)
Num stations	Schiffer and Walther (2017b)

Table 11. Solution Methods

	Exact
(M)I(L)P	Conrad and Figliozzi (2011); Gonçalves et al. (2011); Erdoğan and Miller-Hooks (2012); Felipe et al. (2014); Schneider, Stenger, and Goeke (2014); Bruglieri et al. (2015a, b); Goeke and Schneider (2015); Mancini (2017); Montoya et al. (2017); Sassi, Cherif-Khettaf, and Oulamara (2015c); Schiffer and Walther (2017b); Schneider, Stenger, and Hof (2015); Doppstadt, Koberstein, and Vigo (2016); Liao, Lu, and Shen (2016); Schiffer, Stütz, and Walther (2017); Schiffer and Walther (2018)
BP/CG	Hiermann et al. (2016), Montoya et al. (2016), Andelmin and Bartolini (2017)
DP	Arslan, Yildiz, and Karasan (2015); Roberti and Wen (2016); Schiffer and Walther (2017a, 2018); Schiffer et al. (2017a); Schiffer, Stütz, and Walther (2017); Nejad et al. (2017)
BC	Koç and Karaoglan (2016)
BPC	Desaulniers et al. (2016)
Other	Ichimori and Ishii (1981); Ichimori, Ishii, and Nishida (1983); Khuller, Malekian, and Mestre (2011); Liao, Lu, and Shen (2016); Sweda, Dolinskaya, and Klabjan (2017); Yavuz (2017)
	Heuristic
TS	Schneider, Stenger, and Goeke (2014); Sassi, Cherif-Khettaf, and Oulamara (2015a); Doppstadt, Koberstein, and Vigo (2016)
(A)LNS	Hiermann et al. (2016); Goeke and Schneider (2015); Mancini (2017); Yang and Sun (2015); Keskin and Çatay (2016); Schiffer and Walther (2017a, 2018); Schiffer et al. (2017a, b); Schiffer, Stütz, and Walther (2017); Schiffer, Schneider, and Laporte (2018)
(A)VNS	Schneider, Stenger, and Goeke (2014); Bruglieri et al. (2015a, b); Montoya et al. (2017); Schneider, Stenger, and Hof (2015); Verma, Lamsal, and Keough (2015); Roberti and Wen (2016); Yavuz and Çapar (2017); Hof, Schneider, and Goeke (2017)
LS	Felipe et al. (2014); Hiermann et al. (2016); Goeke and Schneider (2015); Montoya et al. (2017); Sassi, Cherif-Khettaf, and Oulamara (2015c, b); Schneider, Stenger, and Hof (2015); Verma, Lamsal, and Keough (2015); Schiffer and Walther (2017a, 2018); Schiffer et al. (2017a, b); Schiffer, Stütz, and Walther (2017); Hof, Schneider, and Goeke (2017); Schiffer, Schneider, and Laporte (2018)
SA	Suzuki (2012); Felipe et al. (2014); Goeke and Schneider (2015); Koç and Karaoglan (2016)
Two-phase algorithm	Erdoğan and Miller-Hooks (2012), Montoya et al. (2016)
Other	Bousonville et al. (2011); Conrad and Figliozzi (2011); Barco et al. (2017); Arslan, Yildiz, and Karasan (2015); Sweda, Dolinskaya, and Klabjan (2017)

Note. (M)I(L)P, (Mixed) integer (linear) program; (A)VNS, (adaptive) VNS.

Table 12. Instance Sets for Routing Problems with Intermediate Stops for Refueling

Reference	Type	#I	N	IF	Used within
Conrad and Figliozzi (2011)	AIF	30	40		
Bousonville et al. (2011)	AIFTW	56	100	121–441	
Suzuki (2012)	AIFTW	6	10–20	10–20	
Erdoğan and Miller-Hooks (2012)	AIFMRD	52	20–500	21–28	Felipe et al. (2014), Mancini (2017), Montoya et al. (2016), Koç and Karaoglan (2016), Andelmin and Bartolini (2017), Schiffer et al. (2017a), Yavuz and Çapar (2017), Mancini (2017)
Felipe et al. (2014)	ADPMRD	60	100–400	5–9	
Schneider, Stenger, and Goeke (2014)	ADFTW	92	5–100	21	Felipe et al. (2014); Hiermann et al. (2016); Bruglieri et al. (2015a, b); Schiffer and Walther (2017a, b); Verma, Lamsal, and Keough (2015); Desaulniers et al. (2016); Keskin and Çatay (2016); Schiffer et al. (2017a)
Schneider, Stenger, and Hof (2015)	ADFMRD	34	50–480	1–20	Schiffer et al. (2017a)
Doppstadt, Koberstein, and Vigo (2016)	AIF	36	8–50		
Roberti and Wen (2016)	ADPTW	100	20–200	5–10	
Montoya et al. (2017)	ADPMRD	120	10–320	2–38	
Yang and Sun (2015)	AIF	24	16–480	det	Schiffer and Walther (2017a); Hof, Schneider, and Goeke (2017); Schiffer, Schneider, and Laporte (2018)
Schiffer and Walther (2018)	ADPTW	90	100	det	
Schiffer and Walther (2017a)	ADPTW	24	18–160	det	
Schiffer et al. (2017b)	ADPIFTW	56	100	897	
Schiffer, Schneider, and Laporte (2018)	ADPIFTW	56	100	det	

Note. If the number of intra-route facilities is not known or determined in an LRPIF, IF is left empty.

4.1. Vehicle Routing Problems with Truck Driver Scheduling

The first publication of a VRP focusing on HOS was by Xu et al. (2003). The authors investigated a pickup and delivery VRP minimizing a cost objective that contains fixed, mileage, and layover costs and paid special attention to additional real-world constraints, for example, driver work rules. A CG-based heuristic and lower bounding procedures were proposed to solve the problem. Ceselli, Righini, and Salani (2009) investigated another rich VRP with driver work rules, time windows, and additional customer and freight restrictions. The authors presented a BP algorithm with a bidirectional labeling that solves the underlying pricing problem as an elementary shortest path problem. Goel (2009) introduced the VRTDSP by extending the standard VRPTW to HOS regulations. This work focused on the EU HOS regulations and applied a LNS heuristic. The author minimized the number of vehicles as first and the overall traveled distance as a secondary objective. Benchmark instances were created based on the VRPTW instances of Solomon (1987). Further work on integrating EU HOS regulations into the VRPTW was published by Kok et al. (2010). Besides basic HOS regulations that were already addressed by Goel (2009), the authors considered additional regulations that allow for more flexibility by adding small exceptions to the daily driving time. A restricted DP heuristic was presented and was shown to outperform the algorithm of Goel (2009). The authors found that slight modifications of HOS rules yield a significant decrease for both the number of vehicles and the driven distance. Another contribution on the VRPTW with EU HOS regulations was published by Prescott-Gagnon et al. (2010). The authors presented an LNS-based CG heuristic that clearly outperformed the algorithms of Goel (2009) and Kok et al. (2010). Kok, Hans, and Schutten (2011) developed a sequential insertion heuristic, focusing on the VRPTW with HOS regulations minimizing the route duration to keep some flexibility in case of traffic congestion. Results are discussed for a real-world case as well as for the Solomon (1987) benchmark instances. Rancourt, Cordeau, and Laporte (2013) focused on U.S. HOS regulations, considering a heterogeneous fleet and multiple time windows. The authors developed a unified TS algorithm with heuristic scheduling approaches for assigning breaks. Besides benchmark instances based on the Solomon instances, the authors analyzed a real-world case. An algorithmic framework based on a hybrid genetic search was proposed by Goel and Vidal (2014), considering EU, U.S., Australian, and Canadian HOS regulations. The authors investigated the impact of different HOS with respect to safety and economic efficiency in this context. The first exact algorithm for the VRTDSP was proposed by Goel and Irnich (2016), introducing a BP algorithm for EU and U.S. HOS regulations. A bidirectional dynamic programming approach was applied to solve the pricing problem as an elementary shortest path problem. Koç, Jabali, and Laporte (2018) introduced the VRTDSP with idling options, considering idling costs beside routing and driver costs. The authors presented a matheuristic combining ALNS with an MIP and showed results on the Solomon benchmark sets. Schiffer et al. (2017b) introduced the EVRP with truck driver scheduling and analyzed the impact of HOS on the competitiveness of ECVs compared to ICEVs. The authors focused on EU as well as U.S. HOS regulations and presented an ALNS as well as new real-world based benchmark instances.

4.2. Orienteering and Traveling Salesman Problems with Hotel Selection

The TOP is also known as the multivehicle version of the selective TSP (cf. Laporte and Martello 1990). Within the TOP, a circle of maximum profit has to be determined on a weighted graph with profits associated with vertices, while this circle is not allowed to exceed a maximum distance or duration. The TOP is often applied to determine tourist trips or for traveling salespersons with limited time budgets. If multiday trips are considered, hotel selection arises within TOPs as an idling variant. In the following, we analyze TOPs and TSPs with hotel selection and refer to Vansteenwegen, Souffriau, and Van Oudheusden (2011) for a profound overview on TOPs in general.

Vansteenwegen, Souffriau, and Sörensen (2012) introduced the TSP with hotel selection and developed a LS heuristic and two constructive procedures. The authors investigated a lexicographic objective function, minimizing the number of trips first and the traveled distance second. New benchmark sets were proposed and used to show the effectiveness of the presented algorithm. Li and Keskin (2014) focused on the patrol coverage for state troopers and developed an LRP that can also be handled as a TOP with hotel selection. The authors developed an SA heuristic and designed instances based on the crash history data in Alabama. Castro et al. (2013) developed a memetic algorithm with a TS component for the TSP with hotel selection. This algorithm strongly outperforms the LS of Vansteenwegen, Souffriau, and Sörensen (2012). Divsalar, Vansteenwegen, and Cattrysse (2013) developed a VNS with an LS component for the orienteering problem with hotel selection. The authors created a large benchmark set of 224 instances to evaluate the performance of their algorithm. Divsalar et al. (2014a) proposed a memetic algorithm that clearly outperforms all other approaches on these benchmark instances. In addition, the authors developed 176 additional large-sized instances. This algorithm was also used in Divsalar et al. (2014b) to derive personalized

Table 13. Scope of Publications on Intermediate Stops for Rests and Breaks

Case study	Ceselli, Righini, and Salani (2009); Kok, Hans, and Schutten (2011); Rancourt, Cordeau, and Laporte (2013); Divsalar et al. (2014b); Li and Keskin (2014); Baltz et al. (2015); Schiffer et al. (2017b)
Methodological	Xu et al. (2003); Goel (2009); Kok et al. (2010); Prescott-Gagnon et al. (2010); Vansteenwegen, Souffriau, and Sörensen (2012); Castro et al. (2013); Divsalar, Vansteenwegen, and Cattrysse (2013); Divsalar et al. (2014a); Goel and Vidal (2014); Goel and Irnich (2016); Koç, Jabali, and Laporte (2018)
Node routing	Xu et al. (2003); Ceselli, Righini, and Salani (2009); Goel (2009); Kok et al. (2010); Prescott-Gagnon et al. (2010); Kok, Hans, and Schutten (2011); Vansteenwegen, Souffriau, and Sörensen (2012); Castro et al. (2013); Divsalar, Vansteenwegen, and Cattrysse (2013); Rancourt, Cordeau, and Laporte (2013); Divsalar et al. (2014a, b); Goel and Vidal (2014); Li and Keskin (2014); Baltz et al. (2015); Goel and Irnich (2016); Koç, Jabali, and Laporte (2018); Schiffer et al. (2017b)
Arc routing	None
HOS regulations	Xu et al. (2003); Ceselli, Righini, and Salani (2009); Goel (2009); Kok et al. (2010); Prescott-Gagnon et al. (2010); Kok, Hans, and Schutten (2011); Rancourt, Cordeau, and Laporte (2013); Goel and Vidal (2014); Goel and Irnich (2016); Koç, Jabali, and Laporte (2018); Schiffer et al. (2017b)
Other	Vansteenwegen, Souffriau, and Sörensen (2012); Castro et al. (2013); Divsalar, Vansteenwegen, and Cattrysse (2013); Divsalar et al. (2014a, b); Li and Keskin (2014); Baltz et al. (2015)
Deterministic	Xu et al. (2003); Ceselli, Righini, and Salani (2009); Goel (2009); Kok et al. (2010); Prescott-Gagnon et al. (2010); Kok, Hans, and Schutten (2011); Rancourt, Cordeau, and Laporte (2013); Goel and Vidal (2014); Goel and Irnich (2016); Koç, Jabali, and Laporte (2018); Vansteenwegen, Souffriau, and Sörensen (2012); Castro et al. (2013); Divsalar, Vansteenwegen, and Cattrysse (2013); Divsalar et al. (2014a, b); Li and Keskin (2014); Baltz et al. (2015); Schiffer et al. (2017b)
Uncertain	None
VRP	Xu et al. (2003); Ceselli, Righini, and Salani (2009); Goel (2009); Kok et al. (2010); Prescott-Gagnon et al. (2010); Kok, Hans, and Schutten (2011); Rancourt, Cordeau, and Laporte (2013); Goel and Vidal (2014); Goel and Irnich (2016); Koç, Jabali, and Laporte (2018); Schiffer et al. (2017b)
TSP/TOP	Vansteenwegen, Souffriau, and Sörensen (2012); Castro et al. (2013); Divsalar, Vansteenwegen, and Cattrysse (2013); Divsalar et al. (2014a, b); Li and Keskin (2014); Baltz et al. (2015)

multiday trips in touristic regions. Baltz et al. (2015) studied the TSP with hotel selection and multiple time windows, proposing a cheapest insertion heuristic. The authors evaluated the algorithm on existing benchmark instances and used the algorithm to investigate an additional real-world case.

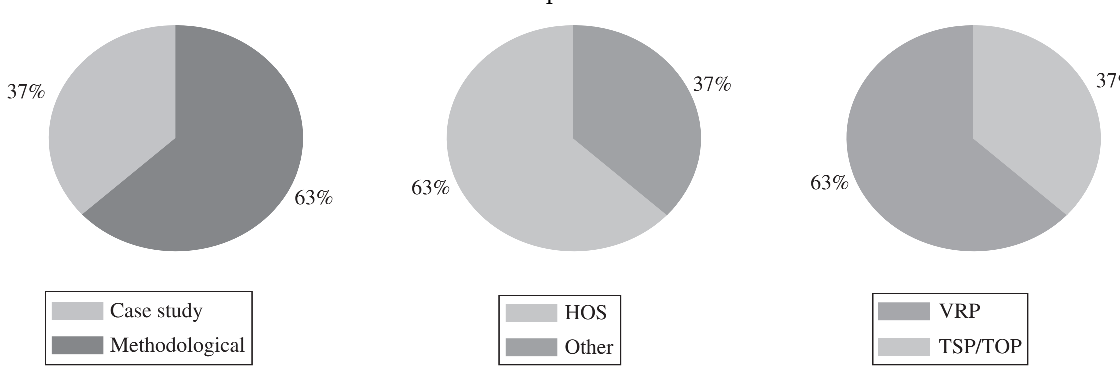
4.3. Analysis

In the following, we analyze all publications summarized in Sections 4.1 and 4.2 while focusing on their most important characteristics.

Table 13 and Figure 9 highlight the scope of these publications. As can be seen, 37% of the publications focus on case studies, while 63% of the publications focus on a methodological contribution by introducing a new problem or a new algorithm for a certain problem class. All of the analyzed publications are based on a node routing problem formulation due to the addressed application areas (logistics fleets and trips with special points of interest). None of the analyzed publications considers uncertain data. All papers that consider HOS regulations are based on a VRP approach (63%) because logistics fleets are analyzed (cf. Figure 9). All approaches that focus on application cases other than logistics fleets are modeled as TSPs or TOPs.

Figure 10 and Table 14 detail the shares of the different problem variants arising in the context of intermediate stops for idling. As time is the operational resource related to those stops, all problem variants assume arc-based consumption. Most papers consider a maximum route duration (42%) or time

Figure 9. Characteristics of Publications on Intermediate Stops for Rests and Breaks



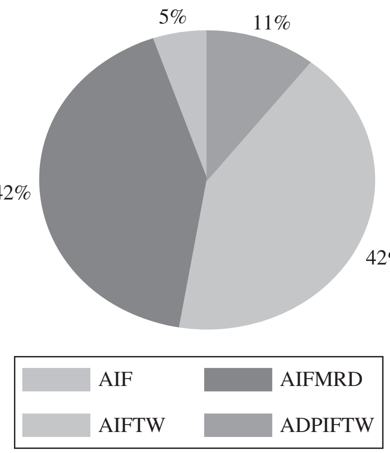


Figure 10. Types of Problem Variants for Intermediate Stops for Rests and Breaks

windows (42%), which arise out of a long-haul logistics context or a maximum trip duration for, for example, tourist trips. The problem variant ADPIFTW belongs to the EVRP with truck driver scheduling as discussed in Schiffer et al. (2017b), which is the only variant that addresses a goal conflict between two operational resources (driver time and energy).

Figure 11 and Table 15 detail the objectives. While approximately 50% of the publications focus on a cost or duration minimization, there are also many papers that use a lexicographic objective, minimizing the number of vehicles first and the total distance second. These publications often focus on the VRTDSP. Only the TOP variants maximize the score of a trip.

The solution methods listed in Table 16 cover a wide variety of exact algorithms and metaheuristics, including matheuristics. Some publications propose MIPs, and most exact solution approaches are based on BP algorithms. Also, matheuristics combining CG with a powerful metaheuristic component are often used and provide state-of-the-art results (cf. Prescott-Gagnon et al. 2010). Among metaheuristics, genetic algorithms and ALNS- or VNS-based algorithms yield the best

Table 14. Types of Problem Variants for Intermediate Stops for Rests and Breaks

AIF	Xu et al. (2003)
AIFMRD	Ceselli, Righini, and Salani (2009); Vansteenwegen, Souffriau, and Sörensen (2012); Castro et al. (2013); Divsalar, Vansteenwegen, and Cattrysse (2013); Divsalar et al. (2014a, b); Baltz et al. (2015); Koç, Jabali, and Laporte (2018)
AIFTW	Goel (2009); Kok et al. (2010); Prescott-Gagnon et al. (2010); Kok, Hans, and Schutten (2011); Rancourt, Cordeau, and Laporte (2013); Goel and Vidal (2014); Li and Keskin (2014); Goel and Irnich (2016)
ADPIFTW	Schiffer et al. (2017b)

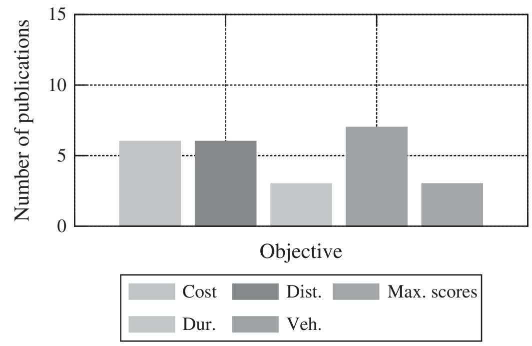


Figure 11. Objectives for Intermediate Stops for Break and Rest Periods

results. LS algorithms are successfully used for TOP and TSP variants (cf. Vansteenwegen, Souffriau, and Sörensen 2012; Divsalar, Vansteenwegen, and Cattrysse 2013).

The benchmark instance sets are summarized in Table 17 for the VRP variants, and in Table 18 for the TSP and TOP variants. The tables show the number of instances, the number of customers, the number of intermediate stop options (if applicable), and other papers that use the same instances. For the VRP variants, besides some early instance sets of Xu et al. (2003) and Ceselli, Righini, and Salani (2009), most publications use the instance set provided in Goel (2009). Only Schiffer et al. (2017b) propose different instance sets, limited to a one-day planning horizon in midhaul logistics and accounting for the characteristics of ECVs. Instance sets for the TSP variants with up to 1,002 customers are given in Vansteenwegen, Souffriau, and Sörensen (2012), and the most common benchmarks for the TOP with hotel selection are presented in Divsalar, Vansteenwegen, and Cattrysse (2013).

Table 15. Objectives for Intermediate Stops for Break and Rest Periods

Objective	References
Costs	Xu et al. (2003); Ceselli, Righini, and Salani (2009); Baltz et al. (2015); Goel and Irnich (2016); Schiffer et al. (2017b)
Distance	Goel (2009); Kok et al. (2010); Prescott-Gagnon et al. (2010); Vansteenwegen, Souffriau, and Sörensen (2012); Castro et al. (2013); Goel and Vidal (2014)
Duration	Kok, Hans, and Schutten (2011); Rancourt, Cordeau, and Laporte (2013); Li and Keskin (2014)
Num. veh./ trips	Goel (2009); Kok et al. (2010); Prescott-Gagnon et al. (2010); Vansteenwegen, Souffriau, and Sörensen (2012); Castro et al. (2013); Rancourt, Cordeau, and Laporte (2013); Goel and Vidal (2014)
Maximum scores	Divsalar, Vansteenwegen, and Cattrysse (2013); Divsalar et al. (2014a, b)

Table 16. Solution Methods for Intermediate Stops for Break and Rest Periods

	Exact
(M)I(L)P	Kok, Hans, and Schutten (2011); Vansteenwegen, Souffriau, and Sörensen (2012); Divsalar, Vansteenwegen, and Cattrysse (2013); Li and Keskin (2014)
BP/CG	Xu et al. (2003); Ceselli, Righini, and Salani (2009); Prescott-Gagnon et al. (2010); Goel and Irnich (2016)
Lower bound	Xu et al. (2003)
DP	Xu et al. (2003); Ceselli, Righini, and Salani (2009); Kok et al. (2010); Goel and Irnich (2016)
	Heuristic
TS	Prescott-Gagnon et al. (2010); Castro et al. (2013); Rancourt, Cordeau, and Laporte (2013)
(A)LNS	Goel (2009), Prescott-Gagnon et al. (2010), Schiffer et al. (2017b)
(A)VNS	Divsalar, Vansteenwegen, and Cattrysse (2013); Divsalar et al. (2014b)
LS	Vansteenwegen, Souffriau, and Sörensen (2012); Divsalar, Vansteenwegen, and Cattrysse (2013); Schiffer et al. (2017b)
EA	Castro et al. (2013), Divsalar et al. (2014a, b), Goel and Vidal (2014)
SA	Li and Keskin (2014)
Other	Xu et al. (2003); Kok et al. (2010); Kok, Hans, and Schutten (2011); Baltz et al. (2015)

Note. (M)I(L)P, (Mixed) integer (linear) program; (A)VNS, (adaptive) variable neighborhood search; EA, evolutionary algorithm.

Concluding, problems arising in the context of routing with intermediate stops for idling, namely, the VRTDSP as well as TSPs and TOPs with hotel selection, remain a young and active research field, which has gained interest in recent years. Methodologically, problem variants stick to the already addressed ones (mainly AIFMRD and AIFTW) due to the application cases. However, more complex variants like the ADPIFTW resulting out of the EVRP may arise when HOS regulations or other idling options are integrated into rich routing problems. Generally, specific case studies on the (known) methodologically proposed problem variants are still sparse. For the VRTDSP, it is mainly long-haul routing that has been addressed until now (except for Schiffer et al. 2017b). Aiming at real-world cases in rich VRPs, integrating HOS regulations into midhaul routing seems to be an interesting option. Furthermore, analyzing more specific regulations (e.g., as in Kok et al. 2010) may inspire researchers in this field. Besides these aspects, considering autonomous driving assistance may lead to interesting future research questions. Although completely autonomously driving cars make the consideration of HOS regulations obsolete, any intermediate level of autonomous driving offers interesting synchronization problems between (temporally or spatially limited) autonomous driving periods during which the driver can rest and conventional driving periods.

Table 17. Instances for the VRTDSP

Reference	Type	#I	*N*	IF	Used within
Xu et al. (2003)	AIF	19	50–210		
Xu et al. (2003)	AIF	15	300–500		
Ceselli, Righini, and Salani (2009)	AIFMRD	46	1–47		
Goel (2009)	AIFTW	56	100		Kok et al. (2010); Prescott-Gagnon et al. (2010); Kok, Hans, and Schutten (2011); Goel and Vidal (2014); Goel and Irnich (2016)
Rancourt, Cordeau, and Laporte (2013)	AIFTW	1	162		
Rancourt, Cordeau, and Laporte (2013)	AIFTW	56	100		
Schiffer et al. (2017b)	ADPIFTW	56	100	897	

Table 18. Instances for TSPs/TOPs with Hotel Selection

Reference	Type	#I	*N*	IF	Used within
Vansteenwegen, Souffriau, and Sörensen (2012)	AIFMRD	16	48–288	5	Castro et al. (2013), Baltz et al. (2015)
Vansteenwegen, Souffriau, and Sörensen (2012)	AIFMRD	16	10–40	1	Castro et al. (2013), Baltz et al. (2015)
Vansteenwegen, Souffriau, and Sörensen (2012)	AIFMRD	48	51–1,002	3–10	Castro et al. (2013), Baltz et al. (2015)
Li and Keskin (2014)	AIFTW	32	16–32	4–32	
Divsalar, Vansteenwegen, and Cattrysse (2013)	AIFMRD	105	32–102	1–3	Divsalar et al. (2014a, b)
Divsalar, Vansteenwegen, and Cattrysse (2013)	AIFMRD	70	32–102	5–6	Divsalar et al. (2014a, b)
Divsalar, Vansteenwegen, and Cattrysse (2013)	AIFMRD	44	64–100	10–12	Divsalar et al. (2014a, b)
Divsalar et al. (2014a)	AIFMRD	176	65–130	3–15	Divsalar et al. (2014b)
Baltz et al. (2015)	AIFMRD	210	5–50	5–50	

5. Conclusion

We have studied RPIS. An intermediate stop has been defined to be a stop en route that is not related to providing service, but is necessary to keep the vehicle operational. This definition was used to distinguish this problem class from multiechelon problem variants. Routing problems for intermediate stops have been divided into three large application areas, namely, (i) replenishment and unloading, (ii) refueling, and (iii) idling for breaks and rests. A nomenclature to characterize routing problems with intermediate stops has been introduced and used to point out the decisive modeling characteristics of these problems. Furthermore, algorithmic findings have been identified for the different problem variants, and effective solution techniques have been highlighted, for example, adding dynamic programming components to optimally locate intermediate stops on routes in metaheuristics.

This survey showed that the three application areas have known different temporal developments. While RPIS for replenishment and unloading have constantly been investigated because of their relevance in municipal services and classical logistics services, RPIS for refueling and idling have been ignored for a long time. Routing problems for refueling have traditionally been limited to ICEVs, but have become popular in recent years because of the increasing role of AFVs, especially ECVs, in sustainable transportation. RPIS for idling have known a peak in recent years as researchers have paid increasing attention to rich VRPs.

Besides providing an in-depth overview on routing problems with intermediate stops, this survey has identified some promising directions for future research. Briefly summarized, these directions are as follows.

For intermediate stops for replenishment or unloading, online algorithms for same-day and express deliveries constitute an interesting field of research. Additionally, the consideration of uncertainties, especially for customer patterns, seems to be a promising research direction for both classical replenishment networks and city logistics applications.

For intermediate stops for refueling, again, including uncertainty into the addressed problem classes seems to be a challenging and interesting research direction. Only a few recent publications include uncertain customer patterns (cf. Schiffer and Walther 2018) or uncertain charging behavior (cf. Sweda, Dolinskaya, and Klabjan 2017). Uncertain travel times have not been considered so far, but may be crucial to derive feasible route plans for ECVs. Moreover, real-world case studies on the usage of ECVs in logistics fleets are still sparse. Future works on case studies may pave the way for a market uptake of ECVs, and thus more sustainable and environmentally friendly means of transportation.

For intermediate stops for rests and breaks, future research may aim at more elaborate case studies. Additionally, the consideration of different levels of autonomous driving vehicles constitutes a promising direction for future research.

While these research directions are tailored to one application area, some research directions that combine the different application areas to realize synchronization potentials result. The first LRP approaches that highlight the interdependencies between charging station location and vehicle routing decisions have just been published. However, the resulting improvement potential has so far been neglected in network design for intermediate stops for replenishing and unloading. Regarding this issue may reveal significant cost improvements for these application cases. The first LRP paper that highlights such improvements was recently published by Schiffer, Schneider, and Laporte (2018). Focusing on ECVs, the first paper on the synchronization potential between ECV charging and breaks resulting from HOS regulations was published by Schiffer et al. (2017b).

Acknowledgments

Thanks are due to two anonymous referees for their valuable comments.

Appendix

Table A.1. Acronyms

AFV	Alternative fuel vehicle
ALNS	Adaptive LNS
BC	Branch-and-cut
BP	Branch-and-price
BPC	Branch-and-price-and-cut
BSS-EV-LRP	Battery swap station electric vehicle LRP
CARP	Capacitated arc routing problem
CARPIF	CARP with intermediate facilities
CARPRP	CARP with refill points
CG	Column generation
DP	Dynamic programming
ECV	Electric commercial vehicle
ELRPTWPR	Electric LRP with time windows and partial recharging
EU	European Union
EVRP	Electric VRP
EVRPTW	EVRP with time windows
EVRPTWPR	EVRPTW and partial recharging
GRASP	Greedy randomized adaptive search procedure
GVRP	Green VRP
HEV	Hybrid electric vehicle
HOS	Hours of service
ICEV	Internal combustion engine vehicle
LNS	Large neighborhood search
LRP	Location routing problem

Table A.1. (Continued)

LRPIF	LRP with intra-route facilities
LS	Local search
MDVRPI	Multidepot VRP with inter-depot routes
MIP	Mixed integer program
PVRP	Periodic VRP
RPIS	Routing problem with intermediate stops
SA	Simulated annealing
SPP	Shortest path problem
TOP	Team orienteering problem
TS	Tabu search
TSP	Traveling salesman problem
TTRP	Truck and trailer routing problem
U.S.	United States
VNS	Variable neighborhood search
VRP	Vehicle routing problem
VRPIS	VRP with intermediate stops
VRPTW	VRP with time windows
VRTDSP	Vehicle routing and truck driver scheduling problem

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