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Vehicle routing: Review of benchmark datasets

Aldy GUNAWAN
Singapore Management University, aldygunawan@smu.edu.sg

Graham KENDALL
University of Nottingham

Barry McCollum
Queen's University Belfast

Hsin-Vonn SEOW
University of Nottingham

Lai Soon LEE
Universiti Putra Malaysia

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Aldy Gunawan[a] , Graham Kendall[b,c] , Barry McCollum[d] , Hsin-Vonn Seow[b] and Lai Soon Lee[e]

a Singapore Management University, Singapore, Singapore;
b University of Nottingham Malaysia, Semenyih, Malaysia;
c University of Nottingham, Nottingham, UK;
d Queen's University Belfast, Belfast, UK; e Institute for Mathematical Research, Universiti Putra Malaysia, Serdang, Malaysia

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Abstract: The Vehicle Routing Problem (VRP) was formally presented to the scientific literature in 1959 by Dantzig and Ramser (DOI:10.1287/mnsc.6.1.80). Sixty years on, the problem is still heavily researched, with hundreds of papers having been published addressing this problem and the many variants that now exist. Many datasets have been proposed to enable researchers to compare their algorithms using the same problem instances where either the best known solution is known or, in some cases, the optimal solution is known. In this survey paper, we provide a list of Vehicle Routing Problem datasets, categorized to enable researchers to have easy access to the problem(s) that are of interest. We also make some suggestions as to the type of datasets that might be useful in the future in order to provide the scientific community with even more challenging problems, which are suited to the problems that we face today. This paper, as well as providing a list of benchmarks, also provides a checkpoint for the scientific community so that other researchers have an opportunity of comparing the growth of VRP instances that are available.

Keywords: Vehicle routing, VRP, datasets

Corresponding author: Graham Kendall, Graham.Kendall@nottingham.edu.my

1. Introduction and related work

The Vehicle Routing Problem, formally introduced in (Dantzig & Ramser, 1959), is one of the most widely studied problems in combinatorial optimization. There have been several survey papers published on the VRP with perhaps the earliest being published in 1968 (Bellmore & Nemhauser, 1968), with more recent surveys including Adewumi and Adeleke (2018), Gansterer and Hartl (2020), Koc¸ et al. (2016), Laporte (2009), Wang and Wasil (2021). Unlike this paper, these surveys considered the Vehicle Routing Problem, whereas we survey the datasets that have been proposed to support research in this domain.

It is interesting to observe how vehicle routing problems have changed to meet ever changing demands. In Erdelic and Caric (2019) the VRP is extended to the Electric VRP (E-VRP), which takes into account the characteristics of electric vehicles. A previous survey (Lin et al., 2014) had reviewed the literature from the viewpoint of green logistics, which was one of the motivations for using electric vehicles. A 2018 survey (Gansterer & Hartl, 2018) reviewed the literature on Collaborative Vehicle Routing. In this variant, operators work together, enabling them to work in a more cost effective way.

Labadie and Prodhon (2014) surveyed multi-criteria analysis in logistics, with a focus on the VRP and Jozefowiez et al. (2008) surveyed multi-objective routing problems. In Matl et al. (2018) the issue of workload equity is surveyed. This variant assumes that there is more than one objective to be optimised. This means searching for pareto-optimal solutions, which may mean that a solution may not be a TSP-optimal solution. Whereas Matl et al. (2018) treated the VRP as a multi-objective problem, Caceres-Cruz et al. (2015) looked at the VRP through the lens of combinations of constraints. Vidal et al. (2013a) also surveyed the multi-attribute aspects of the VRP problem, with a focus on the heuristic and meta-heuristic methodologies that have been employed for these type of problems and Hashimoto et al. (2013) reviews results from local search approaches when handling time window constraints of the VRP. Synchronized constraints, were surveyed in (Drexl, 2012) where synchronization is required between various constraints of the problem such as between the vehicles and spatial/temporal considerations. Caceres-Cruz et al. (2015) surveyed the scientific literature for the Rich VRP, which combines multiple constraints for addressing realistic problems. Other surveys have focused on the underlying methodologies. Masutti and de Castro (2017) surveys the VRP from the perspective of bee inspired algorithms and also propose a new algorithm for the TSP. Karakatic and Podgorelec (2015) reviews how genetic algorithms have been utilised for the

Table 1. Number of "Vehicle Routing" papers published with that phrase appearing in the Title, or in the Title, Keywords and Abstract (Topic).

	WoS	Scopus		
<2001	312	486	311	590
2001	32	65	29	60
2002	51	97	60	121
2003	40	84	49	93
2004	68	132	80	157
2005	79	151	99	191
2006	123	229	168	315
2007	142	263	197	417
2008	187	341	226	460
2009	207	388	262	510
2010	177	362	321	573
2011	171	340	261	550
2012	178	385	276	564
2013	225	478	341	717
2014	248	556	317	710
2015	297	659	331	748
2016	287	654	358	770
2017	329	763	384	795
2018	339	859	451	972
2019	349	856	531	1,089
2020*	329	759	472	975
TOTAL	4,170	8,907	5,524	11,377

*2020 is not yet complete. The data reported here was extracted on 14 Dec 2020.

multi depot VRP. Elshaer and Awad (2020) presented a taxonomic review of metaheuristic algorithms for VRPs, classifying 299 papers published between 2009 and 2017. Exact Branch-Price-and-Cut Algorithms for Vehicle Routing were surveyed in (Costa et al., 2019) and Braysy and Gendreau presented two papers which surveyed local search algorithms (Braysy & Gendreau, 2005a) and metaheuristics (Braysy & Gendreau, 2005b). Braysy and Gendreau also surveyed evolutionary approaches for vehicle routing (Bräysy et al., 2004).

Further surveys have viewed VRPs as dynamic and stochastic problems (Ilin et al., 2015; Pillac et al., 2013a; Ritzinger et al., 2016) and looked at exact algorithms for VRPs (Baldacci et al., 2007). Other surveys have considered Simultaneous Pickup and Delivery (Koç et al., 2020), split VRPs (Archetti & Speranza, 2008, 2012), where the constraint to visit each customer only once is relaxed, online VRP's (Jaillet & Wagner, 2008), where details of the problem instance is not available at the start of the solution process but is revealed incrementally, how roads can be maintained during the winter period (Perrier et al., 2007a, 2007b), vehicle routing with backhauls (Koç & Laporte, 2018), location routing with intermediate stops (Schiffer et al., 2019) and multiple trip routing problems (Cattaruzza et al., 2018). Mole (1979) had previously (over 40 years ago) looked at the problem from a local delivery point of view. This topic is still of interest as there has been some work on delivery to the last mile, which can have a large impact on how the problem is solved. Indeed, there is a number of survey papers looking at VRP for city logistics (Cattaruzza et al., 2017; Kim et al., 2015).

In this survey paper, we review the datasets and instances that have been proposed by the vehicle routing, scientific community. There have been many vehicle routing survey papers written, as evidenced by those cited above but we do not believe that there has been a survey paper on the wide range of datasets that have been presented. The rest of this paper is structured as follows. In the next section we briefly analyze the number of VRP papers that have been published to demonstrate the interest in this research area. In Section 3, the VRP variants are presented to help the reader decide which dataset is the most suitable for them. Section 4 details the datasets, providing the citation where they were introduced, along with the variant as defined in Section 3. In Section 5, we give some ideas for future datasets before concluding the paper in Section 6.

2. Analysis of publications

Accessing Web of Science (resp. Scopus) and searching for "Vehicle Routing" in article titles (not keywords, abstracts or article text) returned 4,170 (resp. 5,524) articles. Extending the search to include article titles, abstract and keywords the number of returned articles increases to 8,907 (resp. 11,377). This data was extracted on 14 Dec 2020.

There is undoubtedly interest in this domain. There is not an increase in the number of papers every year (see Table 1 and Figure 1), but the trend line demonstrates an overall increase. The number of papers may now be levelling off, but we know that there is often a lag in the data, so later years are subject to change.

Table 1 provides this data year-on-year, with a summary for papers before 2001. Figure 1 shows one of these dimensions (Web of Science, by Topic) in a graphical form.

3. Variants

We have taken Mendoza et al. (2014) as our primary reference for the VRP datasets and variants. The authors maintain a website where the datasets can be downloaded[1]. On the VRP-REP website, they define 48 variants of the VRP problem. In addition, we also accessed other papers as/when we found additional datasets.

In Table 2 we attempt to summarise these variants, along with a brief description. Despite expanding the search beyond VRP-REP, we have less variants that are listed on their website. This is because we have combined some to just the main category. For example, many variants have a main category and then there is another category "*with Time Windows*" – along with many other prefixes.

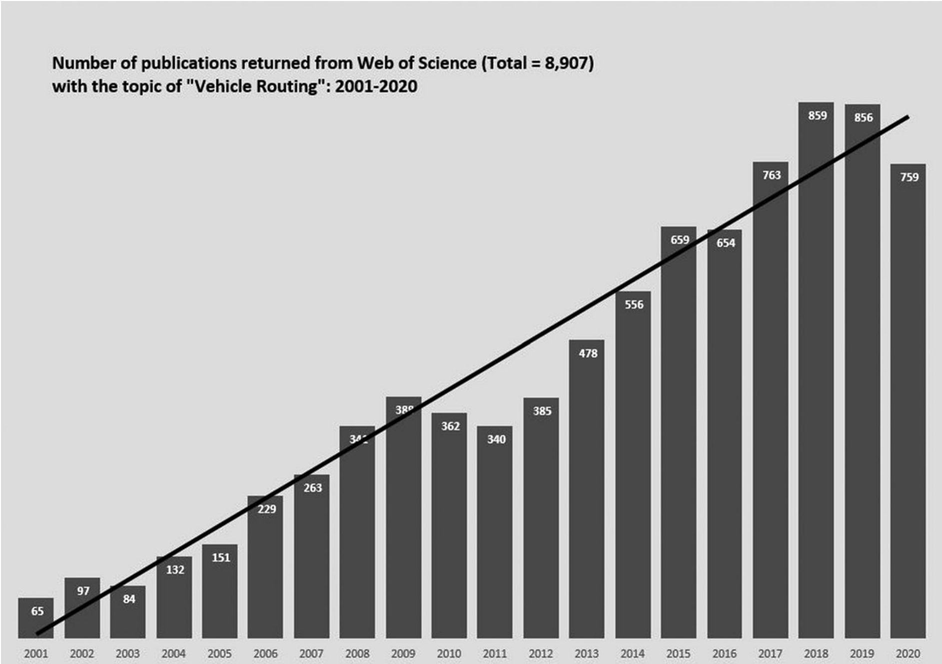

Figure 1. Number of papers papers with a Topic of" Vehicle Routing", 2001–2020, showing a trend line.

Table 2. Vehicle routing variants, drawn from VRP-REP.

#	Variant	Description)
1	ACVRP	Asymmetric Capacitated Vehicle Routing Problem
2	CARP-TP	Capacitated Arc Routing Problem with Turn Penalties
3	ColSVRP	Collaborative Selective Vehicle Routing Problem
4	conMCVRP	Consistent Multi-Compartment Vehicle Routing Problem
5	ConVRP	Consistent Vehicle Routing Problem
6	COP	Clustered Orienteering Problem
7	CTTRP	Capacitated Truck-and-Trailer Routing Problem
8	CVRP	Capacitated Vehicle Routing Problem
9	CVTSP	Carrier-Vehicle Traveling Salesman Problem
10	DARP	Dial a Ride Problem
11	DVRP	Dynamic Vehicle Routing Problem
12	E-VRP	Electric Vehicle Routing Problem
13	GenConVRP	Generalized Consistent Vehicle Routing Problem
14	G-VRP	Green Vehicle Routing Problem
15	H2E-FTW	Heterogeneous Electric Fleet Routing Problem with Time Windows and Recharging Stations
16	MCGRP-TP	Mixed Capacitated General Routing Problem with Turn Penalties
17	MC-VRPSD	Multicompartment Vehicle Routing Problem with Stochastic Demands
18	MDPVRP	Multi-Depot Periodic Vehicle Routing Problem
19	MD-TEVRP-DO	Multi-Depot Two-Echelon Vehicle Routing Problem with Delivery Options
20	MDVRP	Multiple Depot Vehicle Routing Problem
21	MOGenConVRP	Multi-objective Generalized Consistent Vehicle Routing Problem
22	MOSPP	Multi-Objective Shortest Path Problem,
23	MTMDVRP	Multi-Trip Multi-Depot Vehicle Routing Problem
24	PDP	Pickup and Delivery Problem
25	POP	Probabilistic Orienteering Problem
26	PRP	Pollution Routing Problem
27	PTP	Prisoner Transportation Problem
28	PVRP	Periodic Vehicle Routing Problem
29	SBVRP	Swap-body Vehicle Routing Problem
30	TBRD	Truck-Based Robots with Depots
31	TOP	Team Orienteering Problem
32	TRSP	Technician Routing and Scheduling Problem
33	TSPPDDL	Travelling Salesman Problem with Pickup, Delivery and Draught Limits
34	TWAVRP	Time Window Assignment Vehicle Routing Problem
35	VRP	Vehicle Routing Problem
36	VRPB	Vehicle Routing Problem With Backhauls
37	VRPCD	Vehicle Pouting Problem with Cross-Docking
38	VRPFT	Vehicle Routing Problem with Floating Targets
39	VRPSD	Vehicle Routing Problem with Stochastic Demands
40	VRP-SL	Vehicle Routing Problem with Service Level Constraints
41	VRPTW	Vehicle Routing Problem with Time Windows

We did not want to list every possible variant but just provide the main ones so that the reader has some idea of the large number of variants that exist, noting that then we are unable to provide every single (even main)category due to the wide variety that exists.

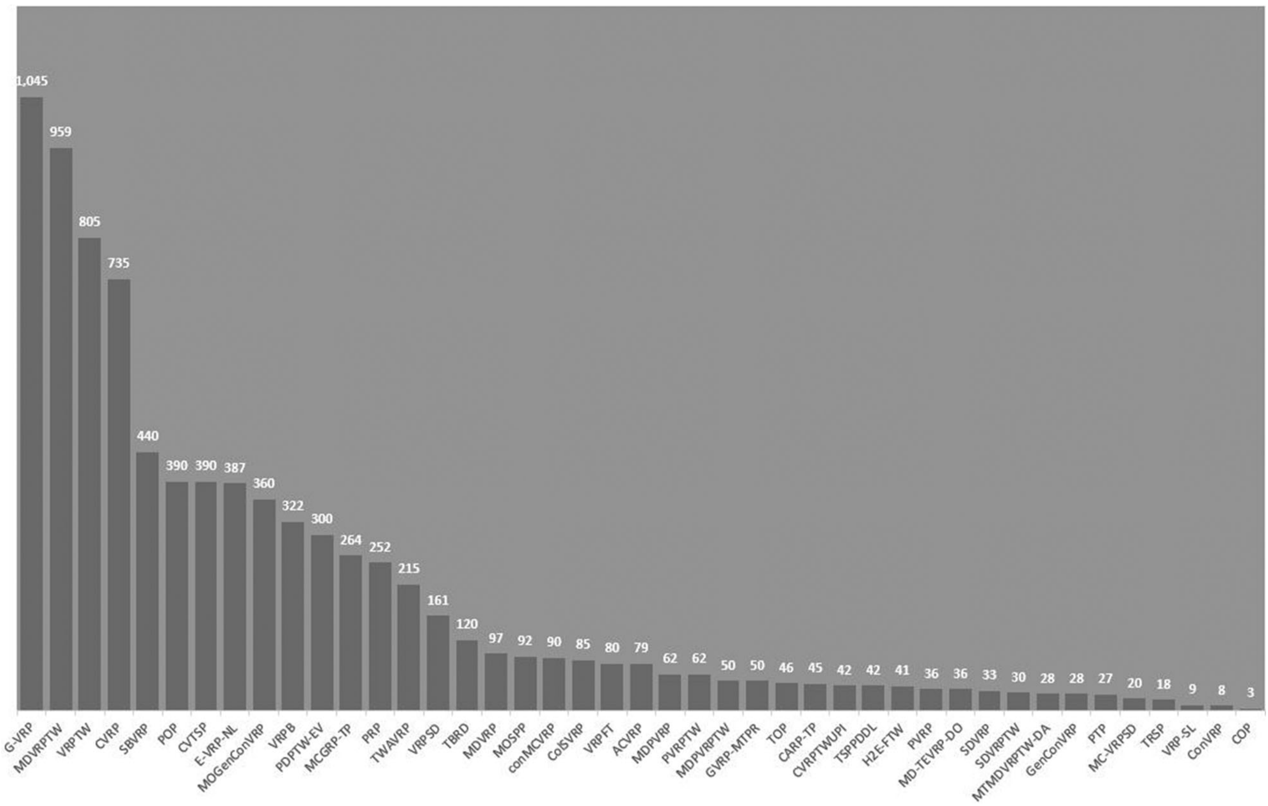

Figure 2. Number of VRP instances by variant. Data extracted from the VRP-REP website.

Other researchers have provided taxonomies of the VRP (Eksioglu et al., 2009) and lists of VRP variants, for example, Braekers et al. (2016), Rincon-Garcia et al. (2018) and more recently Vidal et al. (2020).

Figure 2 shows the number of instances for each VRP variant that has been identified in the scientific literature. The variants with the most instances are G-VRP (Green Vehicle Routing Problem) – 1,045; MDVRPTW (Multi-Depot Vehicle Routing Problem with Time Windows) – 959; VRPTW (Vehicle Routing Problem with Time Windows) – 805; CVRP (Capacitated Vehicle Routing Problem) – 735 and SBVRP (Swap-body Vehicle Routing Problem) – 440.

Of course, the number of instance variants that are available to other researchers is dictated by other researchers and what they are prepared to make available. For example, 924 of the Green VRP instances are due to (Andelmin & Bartolini, 2017), with the other 121 instances being attributed to two other papers (Christofides et al., 1979a; Golden et al., 1998) and one other paper which we were unable to find from the information provided on the VRP-REP website.

Apart from above-mentioned variants, the concept of the VRP has also been integrated with other problems, such the VRP with cross-docking (VRPCD) Gunawan et al. (2020), Lee et al. (2006), Yu et al. (2016). Grangier et al. (2017), Urtasun and Montero (2019), Wen et al. (2009) extended the problem by considering time windows (VRPCDTW). Widjaja et al. (2020) introduced the Vehicle routing problem with reverse cross-docking (VRP-RCD).

4. Vehicle routing datasets

In this section we define all the datasets that form part of this survey.

Our primary source was the VRP-REP listing of datasets. In addition, we searched for other papers, sourced datasets via citations in papers that form part of this survey and received personal recommendations from colleagues who read the first draft of this paper.

Table 3 summarises the papers that contain datasets.

We recognise that the list will be incomplete due to the number of papers that have been written on Vehicle Routing (see Section 2), but we believe that it provides access to many VRP datasets and provides researchers with a good foundation when starting work in this area.

4.1. VRP-REP

In their VeRoLog presentation (Mendoza et al., 2014) the authors state that new VRP instances are being generated faster than ever and there is not one place on the Internet where these are all brought together. Moreover, the data is stored in different formats, which makes it time consuming for researchers to access, possibly requiring many different (programming) functions to access the

Table 3. Vehicle routing datasets. Those with shown with a VRP-REP ID were taken from the VRP-REP website. Others were identified as part of our research when writing this paper.

#	Year	VRP-REP ID	Citation	Variant
1	1959		Dantzig and Ramser (1959)	CVRP
2	1964		Clarke and Wright (1964)	CVRP
3	1967		Gaskell (1967)	CVRP
4	1967		Hayes (1967)	CVRP
5	1969	2014-0010	Christofides and Eilon (1969)	CVRP
6	1969	2017-0031	Christofides and Eilon (1969)	MDVRP
7	1971		Eilon et al. (1971a)	CVRP
8	1971		Eilon et al. (1971b)	CVRP
9	1979	2014-0002	Christofides et al. (1979a)	CVRP
10	1979	2017-0027	Christofides et al. (1979a)	G-VRP
11	1981		Christofides et al. (1981b)	CVRP
12	1981		Christofides et al. (1981a)	VRP
13	1984		Golden et al. (1984)	VRP
14	1986		Laporte et al. (1986)	CVRP
15	1987	2014-0012	Solomon (1987)	VRPTW
16	1987	2014-0013	Solomon (1987)	VRPTW
17	1987	2014-0014	Solomon (1987)	VRPTW
18	1987	2014-0015	Solomon (1987)	VRPTW
19	1987	2014-0016	Solomon (1987)	VRPTW
20	1987	2014-0017	Solomon (1987)	VRPTW
21	1993		Taillard (1993)	VRP
22	1994	2014-0011	Fisher (1994)	CVRP
23	1994	2017-0002	Fischetti et al. (1994)	ACVRP
24	1994		Noon et al. (1994)	VRP
25	1994		Fischetti et al. (1994)	CVRP
26	1994		Gendreau et al. (1994)	CVRP
27	1995	2014-0000	Augerat (1995)	CVRP
28	1995	2014-0001	Augerat (1995)	CVRP
29	1995	2014-0003	Christofides et al. (1979a)	CVRP
30	1995	2014-0009	Augerat (1995)	CVRP
31	1995		Hadjiconstantinou et al. (1995)	VRP
32	1995		Russell (1995)	VRPTW
33	1997	2017-0009	Cordeau et al. (1997)	PVRP
34	1997	2017-0010	Cordeau et al. (1997)	MDVRP
35	1997	2017-0015	Cordeau et al. (1997)	SDVRP
36	1998	2014-0004	Golden et al. (1998)	CVRP
37	1998	2017-0028	Golden et al. (1998)	G-VRP
38	1999	2014-0018	Gehring and Homberger (1999)	VRPTW
39	1999	2014-0019	Gehring and Homberger (1999)	VRPTW
40	1999	2014-0020	Gehring and Homberger (1999)	VRPTW
41	1999	2014-0021	Gehring and Homberger (1999)	VRPTW
42	1999	2014-0022	Gehring and Homberger (1999)	VRPTW
43	1999	2014-0023	Gehring and Homberger (1999)	VRPTW
44	1999	2016-0011	Toth and Vigo (1999)	VRPB
45	2001	2017-0011	Cordeau et al. (2001)	PVRPTW
46	2001	2017-0012	Cordeau et al. (2001)	MDVRPTW
47	2001	2017-0016	Cordeau et al. (2001)	SDVRPTW
48	2001		Li and Lim (2001)	PDPTW
49	2005	2014-0005	Li et al. (2005)	CVRP
50	2006		Lee et al. (2006)	VRPCD
51	2006		Gendreau et al. (2006)	CVRP
52	2007	2014-0007	Christiansen and Lysgaard (2007)	VRPSD
53	2007	2017-0020	Archetti et al. (2007)	TOP
54	2009	2015-0000	Groër et al. (2009)	ConVRP
55	2009	2015-0001	Groër et al. (2009)	ConVRP
56	2009	2017-0018	Pirkwieser and Raidl (2009)	PVRPTW
57	2009		Wen et al. (2009)	VRPCD
58	2009		Tarantilis et al. (2009)	CVRP
59	2009		Bräysy et al. (2009)	VRPTW
60	2010	2014-0006	Mendoza et al. (2010)	MC-VRPSD
61	2012	2017-0007	Demir et al. (2012)	PRP
62	2012	2017-0008	Vidal et al. (2012)	MDPVRP
63	2012	2020-0012	Erdoğan and Miller-Hooks (2012)	G-VRP
64	2012		Ma et al. (2012)	VRPTW
65	2013	2014-0024	Pillac et al. (2013b)	TRSP
66	2013	2017-0013	Vidal et al. (2013b)	MDVRPTW
67	2013	2017-0014	Vidal et al. (2013b)	PVRPTW
68	2013	2017-0017	Vidal et al. (2013b)	SDVRPTW
69	2014	2014-0025	De Smet (2014)	CVRP
70	2014	2015-0002	Kovacs et al. (2014)	ConVRP
71	2014	2016-0002	PTV Group (2014)	SBVRP
72	2014	2017-0001a	De Smet (2014)	ACVRP
73	2014	2017-0001b	De Smet (2014)	CVRP
74	2014	2017-0001c	De Smet (2014)	MDVRP
75	2014	2017-0001d	De Smet (2014)	VRPTW
76	2014	2017-0019	Vidal et al. (2014)	MDPVRPTW

(*continued*)

Table 3. Continued.

#	Year	VRP-REP ID	Citation	Variant
77	2014	2017-0021	Angelelli et al. (2014)	COP
78	2014	2018-0004	Felipe et al. (2014)	GVRP-MTPR
79	2014		Morais et al. (2014)	VRPCD
80	2015	2015-0003	Kovacs et al. (2015)	GenConVRP
81	2015	2015-0004	Kovacs et al. (2015)	MOGenConVRP
82	2015	2015-0005	Gromicho et al. (2015)	CVRPTWUPI
83	2015	2016-0005	Gromicho et al. (2015)	VRPB
84	2015	2017-0005	Kramer et al. (2015)	PRP
85	2016	2014-0008a	Mendoza et al. (2016)	VRPSD
86	2016	2014-0008 b	Mendoza et al. (2016)	VRPSD
87	2016	2014-0008c	Mendoza et al. (2016)	VRPSD
88	2016	2014-0008d	Mendoza et al. (2016)	VRPSD
89	2016	2016-0000	Thomopulos and Vigo (2016)	CVRP
90	2016	2016-0016	Thomopulos and Vigo (2016)	CVRP
91	2016	2016-0017	N/A	MTMDVRPTW-DA
92	2016	2017-0023	Defryn et al. (2016)	ColSVRP
93	2016	2017-0024	Defryn et al. (2016)	ColSVRP
94	2016	2017-0025	Defryn et al. (2016)	ColSVRP
95	2016	2020-0013	Koç and Karaoglan (2016)	G-VRP
96	2017	2016-0003	Absi et al. (2017)	SBVRP
97	2017	2016-0015	Andelmin and Bartolini (2017)	G-VRP
98	2017	2016-0019	Uchoa et al. (2017)	CVRP
99	2017	2016-0020	Montoya et al. (2017)	E-VRP-NL
100	2017	2017-0003	Vidal (2017)	CARP-TP
101	2017	2017-0004	Vidal (2017)	MCGRP-TP
102	2017	2017-0022	Angelelli et al. (2017)	POP
103	2017		Zhang et al. (2017)	VRPTW
104	2017		Zachariadis et al. (2017)	VRP
105	2017		Yang et al. (2017)	DVRPTW
106	2017		Gajpal et al. (2017)	GVRP
107	2018	2016-0006	Gambella et al. (2018a)	CVTSP
108	2018	2016-0009	Malaguti et al. (2018)	TSPPDDL
109	2018	2016-0012	Gambella et al. (2018b)	VRPFT
110	2018	2016-0013	Gambella et al. (2018b)	VRPFT
111	2018	2017-0006	Bulhões et al. (2018)	VRP-SL
112	2018	2017-0026	Zhou et al. (2018)	MD-TEVRP-DO
113	2018	2018-0002	Dalmeijer and Spliet (2018)	TWAVRP
114	2018	2020-0009	Tellez et al. (2018)	FSM-DARP-RC
115	2018		Ouaddi et al. (2018)	DVRP
116	2018		Abdulkader et al. (2018)	CVRP
117	2019	2017-0029	Hiermann et al. (2019)	H2E-FTW
118	2019	2018-0003	Letchford and Salazar-González (2019)	CVRP
119	2019	2018-0005	Martins et al. (2019)	conMCVRP
120	2019		Nikolopoulou et al. (2019)	VRPCD
121	2020	2019-0003	Queiroga et al. (2020)	VRPB
122	2020	2020-0001	Christiaens et al. (2020)	PTP
123	2020	2018-0006	Bartolini and Schneider (2020)	CTTRP
124	2020	2020-0008	N/A	MDVRPTW
125	2020	2020-0014	N/A	MDVRPTW
126		2018-0001	N/A	MOSPP
127		2019-0001a	N/A	G-VRP
128		2019-0001 b	N/A	PDPTW-EV
129		2019-0001c	N/A	VRPTW
130		2020-0004	N/A	TWAVRP
131		2020-0005	N/A	TBRD

various formats in which the data is held. We hope that this paper provides a check point which can be used by future researchers to compare against the number of datasets that are subsequently introduced.

The tool that has been developed (VRP-REP) is an open-data platform of VRP-datasets, along with a set of tools to support VRP research.

At the time of analysis (17 Dec 2020) VRP-REP holds 100 datasets, comprising 8,683 instances. These datasets have been downloaded 25,614 times. Table 3 shows the VRP-REP instances. The table is sorted by year but the VRP-REP instances can be identified as as we have shown their identifier.

If you are interested in Vehicle Routing research, the VRP-REP tool is a valuable resource in not only locating the various datasets that are available, but in checking the solutions that are generated.

4.2. Other datasets

In addition to the datasets on the VRP-REP website, we identified several other datasets. They are shown in Table 3 (those without a VRP-REP ID). We briefly comment on these below, but refer the reader to the relevant paper(s) for more details.

The original VRP paper Dantzig and Ramser (1959) contained a small instance, which the authors worked through as they described their algorithm. The instance was a variant of CVRP.

In Eilon et al. (1971a) ten instances are provided. These are not new instances, but, usefully, the data is provided. Instance #1 comes from Hayes (1967), instance #2 comes from Dantzig and Ramser (1959), instances #3 to #5 and #7 comes from Gaskell (1967), instance #6 comes from Clarke and Wright (1964) (we note that Eilon et al. (1971a) provides a slightly incorrect reference), and instances #8 to #10 comes from Eilon et al. (1971b).

In 1981, two papers were published by the same authors. Christofides et al. (1981b) considered the VRP, with their test instances ranging in size from 15, 20, 25, …, 50, with each problem size having five instances generated, giving a total of 40 instances. Christofides et al. (1981a) presents 10 CVRP instances. These are a mix of example problems, given by the authors, and instances drawn from Eilon et al. (1971a, 1971b).

Taillard (1993) studies VRP, drawing on Christofides et al. (1979a), for fourteen of the problems it reports. It introduces one new instance, which has 385 cities, based on the canton of Vaud in Switzerland. The paper describes how the instance was generated.

Noon et al. (1994) presents 14 problems, which are a combination of instances drawn from the literature and a real-world problem. The instance data is provided.

Gendreau et al. (1994) proposed a tabu search heuristic to address the CVRP. They utilised fourteen problems drawn from Christofides et al. (1979b). This paper did not propose any new instances, but they do give details of the solutions they generated, which is not often done. We also note this paper as other papers have cited it as using the instances from this paper.

Hadjiconstantinou et al. (1995) took three of its test problems from Eilon et al. (1971a,b), modifying them to provide ten instances. Another fifteen problems were randomly generated. The authors described the procedures they used.

Rochat and Taillard (1995) studied both VRP and VRPTW. They use instances drawn from various sources, these being Christofides et al. (1979a), Fisher (1994), Taillard (1993).

Russell (1995) addressed the VRPTW, using Solomon's dataset, comprising 56 instances (Solomon, 1987). Four additional real-world problems were introduced, which are based on regional fast food delivery. The first dataset has 249 customers and is based on the dataset reported by Baker and Schaffer (1986). Two problems (denoted D249 and E249) were derived by adjusting the vehicle capacity. Two additional problems (D417 and E417) are based on a fast food routing application in the United States.

Laporte et al. (1986) presented 30 problems, which were randomly generated. The same generation procedure was used by Fischetti et al. (1994), generating 63 instances.

Li and Lim (2001) introduced 65 new instances for the Pick up and Delivery Problem with Time Windows (PDPTW), using Solomon (1987) as a basis for the new datasets.

Gendreau et al. (2006) considers the CVRP, together with three-dimensional loading. They derived 27 Euclidean instances from Toth and Vigo (2002), with some modifications, which are described. Five real-world problems (from an Italian bedroom furniture manufacturer) are discussed, which combine CVRP and three-dimensional packing. The details of the instances are not provided, therefore other researchers will not be able to use this dataset.

For the VRPCD instances, Lee et al. (2006) introduced randomly generated instances with sizes of 10, 30 and 50 nodes, each with 30 instances, given a total of 90 instances. Wen et al. (2009) introduced 36 new instances for the VRPCD which are classified as small instances, comprising 20 pairs of nodes and 25 large instances, comprising 30, 50, 100, 150 and 200 pairs of nodes. The datasets were provided by the Danish consultancy Transvision.

Tarantilis et al. (2009) considers the CVRP with three-dimensional loading constraints. in the paper they utilised 27 benchmark instances from Gendreau et al. (2006), as well as introducing 12 new instances. Details of how the new instances were generated are provided.

Ma et al. (2012) considers a variant of VRPTW. They are unable to use the real-world instances from their collaborative partner. Instead they create 56 test instances based on those from Solomon (1987). The only difference is the addition of a link capacity constraint.

Golden et al. (1984) uses 20 VRP instances, which are actually drawn from Christofides and Eilon (1969) and Clarke and Wright (1964) but, usefully data is provided in the appendix.

Bräysy et al. (2009) introduced 600 new VRPTW instances and also drew on instances presented in Liu and Shen (1999), which reported results from 168 sample problems and 20 other benchmarking problems.

Morais et al. (2014) addresses the VRP with cross docking. They use instances from Wen et al. (2009), but as these instances are all solved, they introduce a new set of 16 instances. These new instances are drawn from Gehring and Homberger (1999), which are challenging VRPTW instances

The Green VRP (GVRP) is considered in Gajpal et al. (2017). Their experiments draw on fourteen CVRP benchmark instances from Christofides et al. (1979a), Christofides and Eilon (1969) and Fisher (1994), with modifications to make them suitable for the problem being addressed in the current paper. The paper proposes a new set of 108 instances.

Zhang et al. (2017)) studies a CRPTW, with pallet loading constraints. Their benchmarks instances are generated from two previous papers (Gendreau et al., 1994; Solomon, 1987)

Zachariadis et al. (2017) addresses three variants of the vehicle routing problem, all of which include two-dimensional loading constraints.

Yang et al. (2017) considers a Dynamic VRP with Time Windows (DVRPTW). The data for a case study is presented, which is based on the benchmarks of Solomon (1987). As well as studying the benchmark problems, the authors also worked with Trigon, a Dutch security company. They carried out a practical experiment where two teams of five drivers were employed, with one team following a baseline algorithm and another team following the algorithm presented in the paper.

Abdulkader et al. (2018) studies a variant of the VRP where a retail stores are served from a distribution centre by a fleet of vehicles. The problem is termed *VRP in omni-channel retail distribution* and no benchmark instances exist for this problem. Therefore, the paper generates problem instances, with an explanation as to how this is carried out. Twenty small and sixty larger instances are generated.

Ouaddi et al. (2018) focusses on the DVRP. They present 21 instances, which are drawn from Christofides et al. (1979a), Fisher (1994) and Rochat and Taillard (1995), making some adjustments to meet their requirements. The changes they make are detailed in the paper.

Nikolopoulou et al. (2019) considers VRPCD, using the datasets from Wen et al. (2009) and Morais et al. (2014). They also introduced 188 new instances for VRPCD, deriving them from Li and Lim (2001).

5. Future datasets

In this section we suggest what future datasets might be worthy of consideration by the scientific community. The datasets that are reported in this paper have been useful and some are still a valuable resource for scientific research. However, it would be useful for the scientific community to review the VRP datasets that it has available and consider deriving a range of datasets that are applicable to the challenges that the world faces now, and in the foreseeable future.

As an example of why new datasets are required, many of the datasets assume that customers are separated by a straight line, with an x and y coordinate provided so that the straight line distance is easily calculated. Most real world problems cannot assume this. Not only is the distance between two customers not a straight line but the distance between customer a and customer b is not the same as the distance between cusomer b and customer a (i.e. it is not a symmetric VRP, but an asymmetric VRP). It is okay to define a symmetric VRP, whether based on straight line distances, or not, but it should be recognised that this would be an academic problem and may not be useful in the real world. These academic problems are still important in enabling algorithm comparison but may not be useful beyond the scientific community.

We present a number of ideas that the community may want to consider in deriving new datasets. Of course, the suggestions are open to extension, as well as new proposals being proposed.

In defining these datasets the researchers that propose them might want to adhere to the Good Laboratory Practice for optimization research in (Kendall et al., 2016). With regard to datasets, we would encourage that authors are particularly minded to consider recommendations 4 to 13. If this is done from the outset it will provide a solid foundation for future researchers.

5.1. Standard datasets

The majority of the datasets that have been introduced into the scientific literature have been done so on a case by cases basis. These datasets have been invaluable in advancing the VRP scientific literature and have provided a way to compare different algorithms as they were executed against the same benchmark instances.

We would suggest that the time is right to produce a set of benchmark datasets that address each of the problem variants, possibly drawing on the list in Table 2. It would be important that each variant is precisely defined. Each variant could then have a recognised set of instances that could be categorised in different ways. A suggestion would be at least three categories, i) easy, medium, hard and challenging, where the challenging ones are envisioned not to be solvable to optimality for some time, ii) those where the optimal solution is known and those that are yet to be solved (some of the instances could be created in a such a way that the optimal solution is known at the outset) and iii) instances that are dynamic and/or stochastic as this is how the real world operates and the complete problem may not been known at the outset, and is gradually revealed.

The problem may also change over time, reflecting changing traffic conditions, breakdowns and changes to the planned schedule; amongst others.

Researchers who are interested in introducing new datasets area are also referred to the recent paper of Vidal et al. (2020) who discuss emerging vehicle routing variants and also note that it may not be possible to use one objective and they list seven other objectives/constraints that could be considered, these being profitability, service quality, equity, consistency, simplicity, reliability and external factors.

5.2. Real world problems

Rincon-Garcia et al. (2018) focused on Computerised Vehicle Routing and Scheduling (CVRS). They noted that only 11% of companies with less than 10 vehicles and 17% of companies with more than 10 vehicles utilised a computerised routing system. A survey was conducted, only calling on those companies that employed a CVRS. The survey found that the most important areas that should be addressed by a CVRS were improvements to route optimisation, minimising the impact of congestion and accuracy with regard to vehicle restriction to certain zones and times. Unfortunately, the sample size was limited (19), but we believe that the areas that were highlighted are representative of those that are important to commercial operators.

It would be useful for the community to have a range of real world problems that have been contributed by the commercial sector that serve as benchmark datasets. Indeed, it would be important to engage the commercial sector when defining benchmark datasets which they would find useful.

It is unlikely that these problems will be single objective, as real world problems are often multi-objective and measured in terms of the Pareto front that is obtained. It will take some work to specify how best to evaluate the datasets in this area so that research papers can be compared in a fair, unambiguous way. To achieve this is likely to require a comprehensive description, a robust data source and an evaluation protocol (Kendall et al., 2016).

5.3. Sustainable development goals

To quote from the United Nations "*The Sustainable Development Goals (SDGs) are the blueprint to achieve a better and more sustainable future for all. They address the global challenges we face, including those related to poverty, inequality, climate change, environmental degradation, peace and justice. The 17 Goals are all interconnected, and in order to leave no one behind, it is important that we achieve them all by 2030.*" The 17 SDGs were adopted under the Paris Agreement in 2015.

Many VRP papers align themselves to at least one SDG, for example by making reference to climate change (Goal 13: Climate Action) and how minimising distances will reduce carbon emissions. However, that is often as far as it goes and there is no strong relationship to the SDG, or the targets that have been set.

Each of the 17 SDGs has a specific target, which it hopes achieve by 2030. Moreover, there are frequent updates to the progress of each of these targets. For example, Goal 13 has the goal to "*The Paris Agreement, adopted in 2015, aims to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below two degrees Celsius above preindustrial levels. The agreement also aims to strengthen the ability of countries to deal with the impacts of climate change, through appropriate financial flows, a new technology framework and an enhanced capacity building framework.*" There are another five goals which include focusing on strengthening resilience to climate change, integrate climate change into national policies and improving education.

It would be useful for the scientific community to look at each of the SDGs and decide which ones VRP research can sensibly contribute to and then devise datasets which are targeted at the SDG's goals, in such a way that they can be measured. It is not sufficient to say that minimising the distance traveled will result in a reduction of carbon emissions, without some way of objectively measuring this. It is challenging to design such datasets, but if the scientific community can do this and the benchmarks can demonstrably be shown to contribute to SDG targets, it would motivate the community to work on these problems.

6. Conclusion

The datasets for the Vehicle Routing Problem (VRP), since its introduction in 1959 (Dantzig & Ramser, 1959), have served the community well and the advances made in this important domain have been largely due to having common benchmarks which have enabled algorithm comparison. However, with the introduction of new VRP variants and an ever changing world, it provides the VRP community the opportunity to introduce new datasets that are relevant to the problems that we face today. It would be beneficial if any newly introduced datasets underwent peer review (recommendation 5 in Kendall et al. (2016)).

If the VRP community has oversight of the datasets that are formally recognised within the scientific literature, it would add value to the domain as we strive to develop ever better solution methodologies for VRPs.

Note

1. http://www.vrp-rep.org/, last accessed 14 Dec 2020

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ORCID

Aldy Gunawan http://orcid.org/0000-0003-0697-8619
Graham Kendall http://orcid.org/0000-0003-2006-5103
Hsin-Vonn Seow http://orcid.org/0000-0002-6877-8498
Lai Soon Lee http://orcid.org/0000-0002-6270-1414

References

Abdulkader, M., Gajpal, Y., & ElMekkawy, T. Y. (2018). Vehicle routing problem in omni-channel retailing distribution systems. *International Journal of Production Economics*, *196*, 43–55. https://doi.org/10.1016/j.ijpe.2017.11.011

Absi, N., Cattaruzza, D., Feillet, D., & Housseman, S. (2017). A relax-and-repair heuristic for the swap-body vehicle routing problem. *Annals of Operations Research*, *253*(2), 957–978. https://doi.org/10.1007/s10479-015-2098-8

Adewumi, A. O., & Adeleke, O. J. (2018). A survey of recent advances in vehicle routing problems. *International Journal of System Assurance Engineering and Management*, *9*(1), 155–172. https://doi.org/10.1007/s13198-016-0493-4

Andelmin, J., & Bartolini, E. (2017). An exact algorithm for the green vehicle routing problem. *Transportation Science*, *51*(4), 1288–1303. https://doi.org/10.1287/trsc.2016.0734

Angelelli, E., Archetti, C., Filippi, C., & Vindigni, M. (2017). The probabilistic orienteering problem. *Computers & Operations Research*, *81*, 269–281. https://doi.org/10.1016/j.cor.2016.12.025

Angelelli, E., Archetti, C., & Vindigni, M. (2014). The clustered orienteering problem. *European Journal of Operational Research*, *238*(2), 404–414. https://doi.org/10.1016/j.ejor.2014.04.006

Archetti, C., Hertz, A., & Speranza, M. G. (2007). Metaheuristics for the team orienteering problem. *Journal of Heuristics*, *13*(1), 49–76. https://doi.org/10.1007/s10732-006-9004-0

Archetti, C., & Speranza, M. (2008). The split delivery vehicle routing problem: A survey. In B. Golden, S. Raghavan, & E. Wasil (Eds.), *Vehicle routing problem: Latest advances and new challanges, volume 43 of operations research computer science interfaces* (pp. 103–122). Springer.

Archetti, C., & Speranza, M. G. (2012). Vehicle routing problems with split deliveries. *International Transactions in Operational Research*, *19*(1–2), 3–22. https://doi.org/10.1111/j.1475-3995.2011.00811.x

Augerat, P. (1995). *Approche polyédrale du problème de tournées de véhicules* [PhD thesis]. Institut National Polytechnique de Grenoble.

Baker, E. K., & Schaffer, J. R. (1986). Solution improvement heuristics for the vehicle routing and scheduling problem with time window constraints. *American Journal of Mathematical and Management Sciences*, *6*(3–4), 261–300. https://doi.org/10.1080/01966324.1986.10737197

Baldacci, R., Toth, P., & Vigo, D. (2007). Recent advances in vehicle routing exact algorithms. *4OR*, *5*(4), 269–298. https://doi.org/10.1007/s10288-007-0063-3

Bartolini, E., & Schneider, M. (2020). A two-commodity flow formulation for the capacitated truck-and-trailer routing problem. *Discrete Applied Mathematics*, *275*, 3–18. https://doi.org/10.1016/j.dam.2018.07.033

Bellmore, M., & Nemhauser, G. (1968). Travelling salesman problem: A survey. *Operations Research*, *16*(3), 538–558. https://doi.org/10.1287/opre.16.3.538

Braekers, K., Ramaekers, K., & Van Nieuwenhuyse, I. (2016). The vehicle routing problem: State of the art classification and review. *Computers & Industrial Engineering*, *99*, 300–313. https://doi.org/10.1016/j.cie.2015.12.007

Braysy, I., & Gendreau, M. (2005a). Vehicle routing problem with time windows, part 1: Route construction and local search algorithms. *Transportation Science*, *39*(1), 104–118. https://doi.org/10.1287/trsc.1030.0056

Braysy, I., & Gendreau, M. (2005b). Vehicle routing problem with time windows. *Transportation Science*, *39*(1), 119–139. https://doi.org/10.1287/trsc.1030.0057

Bräysy, O., Dullaert, W., & Gendreau, M. (2004). Evolutionary algorithms for the vehicle routing problem with time windows. *Journal of Heuristics*, *10*(6), 587–611. https://doi.org/10.1007/s10732-005-5431-6

Bräysy, O., Porkka, P. P., Dullaert, W., Repoussis, P. P., & Tarantilis, C. D. (2009). A well-scalable metaheuristic for the fleet size and mix vehicle routing problem with time windows. *Expert Systems with Applications*, *36*(4), 8460–8475. https://doi.org/10.1016/j.eswa.2008.10.040

Bulhões, T., Hà, M. H., Martinelli, R., & Vidal, T. (2018). The vehicle routing problem with service level constraints. *European Journal of Operational Research*, *265*(2), 544–558. https://doi.org/10.1016/j.ejor.2017.08.027

Caceres-Cruz, J., Arias, P., Guimarans, D., Riera, D., & Juan, A. A. (2015). Rich vehicle routing problem. *ACM Computing Surveys*, *47*(2), 1–28. https://doi.org/10.1145/2666003

Cattaruzza, D., Absi, N., & Feillet, D. (2018). Vehicle routing problems with multiple trips. *Annals of Operations Research*, *271*(1), 127–159. https://doi.org/10.1007/s10479-018-2988-7

Cattaruzza, D., Absi, N., Feillet, D., & Gonzalez-Feliu, J. (2017). Vehicle routing problems for city logistics. *EURO Journal on Transportation and Logistics*, *6*(1), 51–79. https://doi.org/10.1007/s13676-014-0074-0

Christiaens, J., Çalik, H., Wauters, T., Chirayil Chandrasekharan, R., & Vanden Berghe, G. (2020). The prisoner transportation problem. *European Journal of Operational Research*, *284*(3), 1058–1073. https://doi.org/10.1016/j.ejor.2020.01.027

Christiansen, C. H., & Lysgaard, J. (2007). A branch-and-price algorithm for the capacitated arc routing problem with stochastic demands. *Operations Research Letters*, *35*(6), 773–781. https://doi.org/10.1016/j.orl.2006.12.009

Christofides, N., & Eilon, S. (1969). An algorithm for the vehicle dispatching problems. *Journal of the Operational Research Society*, *20*(3), 309–318. https://doi.org/10.1057/jors.1969.75

Christofides, N., Mingozzi, A., & Toth, P. (1981a). Exact algorithms for the vehicle routing problem, based on spanning tree and shortest path relaxations. *Mathematical Programming*, *20*(1), 255–282. https://doi.org/10.1007/BF01589353

Christofides, N., Mingozzi, A., & Toth, P. (1981b). Space state relaxation procedures for the computation of bounds to routing problems. *Networks*, *11*(2), 145–164. https://doi.org/10.1002/net.3230110207

Christofides, N., Mingozzi, A., & Toth, P. (1979a). The vehicle routing problem. In N. Christofides, A. Mingozzi, P. Toth, & C. Sandi (Eds.), *Combinatorial optimization* (pp. 315–338).Wiley. Chapter 11.

Christofides, N., Mingozzi, A., Toth, P., & Sandi, C. (Eds.). (1979b). *Combinatorial optimization*. John Wiley & Sons.

Clarke, G., & Wright, J. (1964). Scheduling of vehicles from a central depot to a number of delivery points. *Operations Research*, *12*(4), 568–581. https://doi.org/10.1287/opre.12.4.568

Cordeau, J.-F., Gendreau, M., & Laporte, G. (1997). A tabu search heuristic for periodic and multi-depot vehicle routing problems. *Networks*, *30*(2), 105–119. https://doi.org/10.1002/(SICI)1097-0037(199709)30:2<105::AID-NET5>3.0.CO;2-G

Cordeau, J.-F., Laporte, G., & Mercier, A. (2001). A unified tabu search heuristic for vehicle routing problems with time windows. *Journal of the Operational Research Society*, *52*(8), 928–936. https://doi.org/10.1057/palgrave.jors.2601163

Costa, L., Contardo, C., & Desaulniers, G. (2019). Exact branch-price-and-cut algorithms for vehicle routing. *Transportation Science*, *53*(4), 946–985. https://doi.org/10.1287/trsc.2018.0878

Dalmeijer, K., & Spliet, R. (2018). A branch-and-cut algorithm for the time window assignment vehicle routing problem. *Computers & Operations Research*, *89*, 140–152. https://doi.org/10.1016/j.cor.2017.08.015

Dantzig, G. B., & Ramser, J. H. (1959). The truck dispatching problem. *Management Science*, *6*(1), 80–91. https://doi.org/10.1287/mnsc.6.1.80

De Smet, G. (2014). *Vehicle routing with real road distances - optaplanner blog*. https://www.optaplanner.org/blog/2014/09/02/VehicleRoutingWithRealRoadDistances.html.

Defryn, C., Sörensen, K., & Cornelissens, T. (2016). The selective vehicle routing problem in a collaborative environment. *European Journal of Operational Research*, *250*(2), 400–411. https://doi.org/10.1016/j.ejor.2015.09.059

Demir, E., Bektaş, T., & Laporte, G. (2012). An adaptive large neighborhood search heuristic for the pollution-routing problem. *European Journal of Operational Research*, *223*(2), 346–359. https://doi.org/10.1016/j.ejor.2012.06.044

Drexl, M. (2012). Synchronization in vehicle routing-A survey of VRPs with multiple synchronization constraints. *Transportation Science*, *46*(3), 297–316. https://doi.org/10.1287/trsc.1110.0400

Eilon, S., Watson-Gandy, C., & Christofides, N. (Eds.). (1971a). *Distribution management, mathematical modeling and practical analysis* (pp. 181–203). Vehicle Scheduling. Chapter 9.

Eilon, S., Watson-Gandy, C., & Christofides, N. (Eds.). (1971b). *Distribution management, mathematical modeling and practical analysis, Chapter 4: Multu-depot location for deterministic demand* (pp. 58–91).London.

Eksioglu, B., Vural, A. V., & Reisman, A. (2009). The vehicle routing problem: A taxonomic review. *Computers & Industrial Engineering*, *57*(4), 1472–1483. https://doi.org/10.1016/j.cie.2009.05.009

Elshaer, R., & Awad, H. (2020). A taxonomic review of metaheuristic algorithms for solving the vehicle routing problem and its variants. *Computers & Industrial Engineering*, *140*, 106242. https://doi.org/10.1016/j.cie.2019.106242

Erdelic, T., & Caric, T. (2019). A survey on the electric vehicle routing problem: Variants and solution approaches. *Journal of Advanced Transportation*, *2019*, 5075671. https://doi.org/10.1155/2019/5075671

Erdoğan, S., & Miller-Hooks, E. (2012). A green vehicle routing problem. *Transportation Research Part E: Logistics and Transportation Review*, *48*(1), 100–114. https://doi.org/10.1016/j.tre.2011.08.001

Felipe, Á., Ortuño, M. T., Righini, G., & Tirado, G. (2014). A heuristic approach for the green vehicle routing problem with multiple technologies and partial recharges. *Transportation Research Part E: Logistics and Transportation Review*, *71*, 111–128. https://doi.org/10.1016/j.tre.2014.09.003

Fischetti, M., Toth, P., & Vigo, D. (1994). A branch-and-bound algorithm for the capacitated vehicle routing problem on directed graphs. *Operations Research*, *42*(5), 846–859. https://doi.org/10.1287/opre.42.5.846

Fisher, M. L. (1994). Optimal solution of vehicle routing problems using minimum k-trees. *Operations Research*, *42*(4), 626–642. https://doi.org/10.1287/opre.42.4.626

Gajpal, Y., Abdulkader, M. M. S., Zhang, S., & Appadoo, S. S. (2017). Optimizing garbage collection vehicle routing problem with alternative fuel-powered vehicles. *Optimization*, *66*(11), 1851–1862. https://doi.org/10.1080/02331934.2017.1349126

Gambella, C., Lodi, A., & Vigo, D. (2018a). Exact solutions for the carrier-vehicle traveling salesman problem. *Transportation Science*, *52*(2), 320–330. https://doi.org/10.1287/trsc.2017.0771

Gambella, C., Naoum-Sawaya, J., & Ghaddar, B. (2018b). The vehicle routing problem with floating targets: Formulation and solution approaches. *INFORMS Journal on Computing*, *30*(3), 554–569. https://doi.org/10.1287/ijoc.2017.0800

Gansterer, M., & Hartl, R. F. (2018). Collaborative vehicle routing: A survey. *European Journal of Operational Research*, *268*(1), 1–12. https://doi.org/10.1016/j.ejor.2017.10.023

Gansterer, M., & Hartl, R. F. (2020). Shared resources in collaborative vehicle routing. *TOP*, *28*(1), 1–20. https://doi.org/10.1007/s11750-020-00541-6

Gaskell, T. J. (1967). Bases for vehicle fleet scheduling. *Journal of the Operational Research Society*, *18*(3), 281–295. https://doi.org/10.1057/jors.1967.44

Gehring, H., & Homberger, J. (1999). A parallel hybrid evolutionary metaheuristic for the vehicle routing problem with time windows. In K. Miettinen, M. Makela, & J. Toivanen (Eds.), *Proceeding of EUROGEN99 - Short Course on Evolutionary Algorithms in Engineering and Computer Science* (pp. 57–64). University of Jyväskylä.

Gendreau, M., Hertz, A., & Laporte, G. (1994). A tabu search heuristic for the vehicle routing problem. *Management Science*, *40*(10), 1276–1290. https://doi.org/10.1287/mnsc.40.10.1276

Gendreau, M., Iori, M., Laporte, G., & Martello, S. (2006). A tabu search algorithm for a routing and container loading problem. *Transportation Science*, *40*(3), 342–350. https://doi.org/10.1287/trsc.1050.0145

Golden, B., Assad, A., Levy, L., & Gheysens, F. (1984). The fleet size and mix vehicle routing problem. *Computers & Operations Research*, *11*(1), 49–66. https://doi.org/10.1016/0305-0548(84)90007-8

Golden, B. L., Wasil, E. A., Kelly, J. P., & Chao, I.-M. (1998). The impact of metaheuristics on solving the vehicle routing problem: algorithms, problem sets, and computational results. In Teodor G.Crainic, & Gilbert Laporte (Eds.), *Fleet management and logistics* (pp. 33–56). Springer.

Grangier, P., Gendreau, M., Lehuédé, F., & Rousseau, L. M. (2017). A matheuristic based on large neighborhood search for the vehicle routing problem with cross-docking. *Computers & Operations Research*, *84*, 116–126. https://doi.org/10.1016/j.cor.2017.03.004

Groër, C., Golden, B., & Wasil, E. (2009). The consistent vehicle routing problem. *Manufacturing & Service Operations Management*, *11*(4), 630–643. https://doi.org/10.1287/msom.1080.0243

Gromicho, J. A. S., Haneyah, S., & Kok, L. (2015). Solving a real-life VRP with inter-route and intra-route challenges. Available at SSRN.

Gunawan, A., Widjaja, A. T., Vansteenwegen, P., & Yu, V. F. (2020). Adaptive large neighborhood search for vehicle routing problem with cross-docking. In *2020 The IEEE World Congress on Computational Intelligence (IEEE WCCI)*. IEEE.

Hadjiconstantinou, E., Christofides, N., & Mingozzi, A. (1995). A new exact algorithm for the vehicle routing problem based on q-paths and k-shortest paths relaxations. *Annals of Operations Research*, *61*(1), 21–43. https://doi.org/10.1007/BF02098280

Hashimoto, H., Yagiura, M., Imahori, S., & Ibaraki, T. (2013). Recent progress of local search in handling the time window constraints of the vehicle routing problem. *Annals of Operations Research*, *204*(1), 171–187. https://doi.org/10.1007/s10479-012-1264-5

Hayes, R. (1967). *The delivery problem* [PhD thesis]. Carnegie Institute of Technology.

Hiermann, G., Hartl, R. F., Puchinger, J., & Vidal, T. (2019). Routing a mix of conventional, plug-in hybrid, and electric vehicles. *European Journal of Operational Research*, *272*(1), 235– 248. https://doi.org/10.1016/j.ejor.2018.06.025

Ilin, V., Simic, D., Tepic, J., Stojic, G., & Saulic, N. (2015). A survey of hybrid artificial intelligence algorithms for dynamic vehicle routing problem. In *Lecture notes in artificial intelligence* (Vol. 9121, pp. 644–655).

Jaillet, P., & Wagner, M. (2008). Online vehicle routing problems: A survey. In B. Golden, S. Raghavan, & E. Wasil (Eds.), *Vehicle routing problem: Latest advances and new challenges, volume 43 of operations research computer science interfaces* (pp. 221–237). Springer.

Jozefowiez, N., Semet, F., & Talbi, E. (2008). Multi-objective vehicle routing problems. *European Journal of Operational Research*, *189*(2), 293–309. https://doi.org/10.1016/j.ejor.2007.05.055

Karakatic, S., & Podgorelec, V. (2015). A survey of genetic algorithms for solving multi depot vehicle routing problem. *Applied Soft Computing*, *27*, 519–532. https://doi.org/10.1016/j.asoc.2014.11.005

Kendall, G., Bai, R., Błazewicz, J., De Causmaecker, P., Gendreau, M., John, R., Li, J., McCollum, B., Pesch, E., Qu, R., Sabar, N., Berghe, G. V., & Yee, A. (2016). Good laboratory practice for optimization research. *Journal of the Operational Research Society*, *67*(4), 676–689. https://doi.org/10.1057/jors.2015.77

Kim, G., Ong, Y. S., Heng, C. K., Tan, P. S., & Zhang, N. A. (2015). City vehicle routing problem (City VRP): A review. *IEEE Transactions on Intelligent Transportation Systems*, *16*(4), 1654–1666. https://doi.org/10.1109/TITS.2015.2395536

Koç, Ç., Bektaş, T., Jabali, O., & Laporte, G. (2016). Thirty years of heterogeneous vehicle routing. *European Journal of Operational Research*, *249*(1), 1–21. https://doi.org/10.1016/j.ejor.2015.07.020

Koç, Ç., & Karaoglan, I. (2016). The green vehicle routing problem: A heuristic based exact solution approach. *Applied Soft Computing*, *39*, 154–164. https://doi.org/10.1016/j.asoc.2015.10.064

Koç, Ç., & Laporte, G. (2018). Vehicle routing with backhauls: Review and research perspectives. *Computers & Operations Research*, *91*, 79–91. https://doi.org/10.1016/j.cor.2017.11.003

Koç, Ç., Laporte, G., & Tükenmez, İ. (2020). A review on vehicle routing with simultaneous pickup and delivery. *Computers & Operations Research*, *122*, 104987. https://doi.org/10.1016/j.cor.2020.104987

Kovacs, A. A., Golden, B. L., Hartl, R., & Parragh, S. (2015). The generalized consistent vehicle routing problem. *Transportation Science*, *49*(4), 796–816. https://doi.org/10.1287/trsc.2014.0529

Kovacs, A. A., Parragh, S., & Hartl, R. (2014). A template-based adaptive large neighborhood search for the consistent vehicle routing problem. *Networks*, *63*(1), 60–81. https://doi.org/10.1002/net.21522

Kramer, R., Subramanian, A., Vidal, T., d A. F., & Cabral, L. (2015). A matheuristic approach for the pollution-routing problem. *European Journal of Operational Research*, *243*(2), 523–539. https://doi.org/10.1016/j.ejor.2014.12.009

Labadie, N., & Prodhon, C. (2014). A survey on multi-criteria analysis in logistics: focus on vehicle routing problems. In L. Benyoucef, J. C. Hennet, & M. K. Tiwari (Eds.), *Applications of multi-criteria and game theory approaches: Manufacturing and logistics* (pp. 3–29). Springer Series in Advanced Manufacturing.

Laporte, G. (2009). Fifty years of vehicle routing. *Transportation Science*, *43*(4), 408–416. https://doi.org/10.1287/trsc.1090.0301

Laporte, G., Mercure, H., & Nobert, Y. (1986). An exact algorithm for the asymmetrical capacitated vehicle routing problem. *Networks*, *16*(1), 33–46. https://doi.org/10.1002/net.3230160104

Lee, Y. H., Jung, J. W., & Lee, K. M. (2006). Vehicle routing scheduling for cross-docking in the supply chain. *Computers & Industrial Engineering*, *51*(2), 247–256. https://doi.org/10.1016/j.cie.2006.02.006

Letchford, A. N., & Salazar-González, J.-J. (2019). The capacitated vehicle routing problem: Stronger bounds in pseudo-polynomial time. *European Journal of Operational Research*, *272*(1), 24–31. https://doi.org/10.1016/j.ejor.2018.06.002

Li, F., Golden, B., & Wasil, E. (2005). Very large-scale vehicle routing: New test problems, algorithms, and

results. *Computers & Operations Research*, *32*(5), 1165–1179. https://doi.org/10.1016/j.cor.2003.10.002
Lin, C., Choy, K. L., Ho, G. T. S., Chung, S. H., & Lam, H. Y. (2014). Survey of green vehicle routing problem: Past and future trends. *Expert Systems with Applications*, *41(4)*, 1118–1138. https://doi.org/10.1016/j.eswa.2013.07.107
Liu, F.-H., & Shen, S.-Y. (1999). The fleet size and mix vehicle routing problem with time windows. *Journal of the Operational Research Society*, *50*(7), 721–732. https://doi.org/10.1057/palgrave.jors.2600763
Li, H., & Lim, A. (2001). *A metaheuristic for the pickup and delivery problem with time windows* [Paper presentation]. 13th IEEE International Conference on Tools with Artificial Intelligence (pp. 160–167). ICTAI. https://doi.org/10.1109/ICTAI.2001.974461
Ma, H., Cheang, B., Lim, A., Zhang, L., & Zhu, Y. (2012). An investigation into the vehicle routing problem with time windows and link capacity constraints. *Omega*, *40*(3), 336–347. https://doi.org/10.1016/j.omega.2011.08.003
Malaguti, E., Martello, S., & Santini, A. (2018). The traveling salesman problem with pickups, deliveries, and draft limits. *Omega*, *74*, 50–58. https://doi.org/10.1016/j.omega.2017.01.005
Martins, S., Ostermeier, M., Amorim, P., Hübner, A., & Almada-Lobo, B. (2019). Product-oriented time window assignment for a multi-compartment vehicle routing problem. *European Journal of Operational Research*, *276*(3), 893–909. https://doi.org/10.1016/j.ejor.2019.01.053
Masutti, T. A. S., & de Castro, L. N. (2017). Bee-inspired algorithms applied to vehicle routing problems: A survey and a proposal. *Mathematical Problems in Engineering*, *2017*, 1–20. https://doi.org/10.1155/2017/3046830
Matl, P., Hartl, R. F., & Vidal, T. (2018). Workload equity in vehicle routing problems: A survey and analysis. *Transportation Science*, *52*(2), 239–260. https://doi.org/10.1287/trsc.2017.0744
Mendoza, J. E., Castanier, B., Guéret, C., Medaglia, A. L., & Velasco, N. (2010). A memetic algorithm for the multi-compartment vehicle routing problem with stochastic demands. *Computers & Operations Research*, *37*(11), 1886–1898. https://doi.org/10.1016/j.cor.2009.06.015
Mendoza, J. E., Rousseau, L.-M., & Villegas, J. G. (2016). A hybrid metaheuristic for the vehicle routing problem with stochastic demand and duration constraints. *Journal of Heuristics*, *22*(4), 539–566. https://doi.org/10.1007/s10732-015-9281-6
Mendoza, J., Guéret, C., Hoskins, M., Lobit, H., Pillac, V., Vidal, T., & Vigo, D. (2014). VRP-REP: The vehicle routing community repository. In *3rd meeting of the EURO Working Group on Vehicle Routing and Logistics Optimization (VeRoLog)*, Norway.
Mole, R. (1979). Survey ogf local delivery vehicle routing methodology. *Journal of the Operational Research Society*, *30*(3), 245–252. https://doi.org/10.1057/jors.1979.46
Montoya, A., Guéret, C., Mendoza, J. E., & Villegas, J. G. (2017). The electric vehicle routing problem with nonlinear charging function. *Transportation Research Part B: Methodological*, *103*, 87–110. https://doi.org/10.1016/j.trb.2017.02.004
Morais, V., Mateus, G. R., & Noronha, T. F. (2014). Iterated local search heuristics for the vehicle routing problem with cross-docking. *Expert Systems with Applications*, *41*(16), 7495–7506. https://doi.org/10.1016/j.eswa.2014.06.010
Nikolopoulou, A. I., Repoussis, P. P., Tarantilis, C. D., & Zachariadi, E. E. (2019). Adaptive memory programming for the many-to-many vehicle routing problem with cross-docking. *Operational Research*, *19*(1), 1–38. https://doi.org/10.1007/s12351-016-0278-1
Noon, C. E., Mittenthal, J., & Pillai, R. (1994). A TSSP + 1 decomposition strategy for the vehicle routing problem. *European Journal of Operational Research*, *79*(3), 524–536. https://doi.org/10.1016/0377-2217(94)90063-9
Ouaddi, K., Benadada, Y., & Mhada, F.-Z. (2018). Ant colony system for dynamic vehicle routing problem with overtime. *International Journal of Advanced Computer Science and Applications*, *9*(6), 306–315. https://doi.org/10.14569/IJACSA.2018.090644
Perrier, N., Langevin, A., & Campbell, J. F. (2007a). A survey of models and algorithms for winter road maintenance. Part III: Vehicle routing and depot location for spreading. *Computers & Operations Research*, *34*(1), 211–257. https://doi.org/10.1016/j.cor.2005.05.007
Perrier, N., Langevin, A., & Campbell, J. F. (2007b). A survey of models and algorithms for winter road maintenance. Part IV: Vehicle routing and fleet sizing for plowing and snow disposal. *Computers & Operations Research*, *34*(1), 258–294. https://doi.org/10.1016/j.cor.2005.05.008
Pillac, V., Gendreau, M., Gueret, C., & Medaglia, A. L. (2013a). A review of dynamic vehicle routing problems. *European Journal of Operational Research*, *225*(1), 1–11. https://doi.org/10.1016/j.ejor.2012.08.015
Pillac, V., Guéret, C., & Medaglia, A. L. (2013b). A parallel matheuristic for the technician routing and scheduling problem. *Optimization Letters*, *7*(7), 1525–1535. https://doi.org/10.1007/s11590-012-0567-4
Pirkwieser, S., & Raidl, G. R. (2009). Multiple variable neighborhood search enriched with ilp techniques for the periodic vehicle routing problem with time windows. In M. J. Blesa, C. Blum, L. Di Gaspero, A. Roli, M. Sampels, & A. Schaerf (Eds.), *Hybrid metaheuristics* (pp. 45–59).Springer Berlin Heidelberg.
PTV Group. (2014). *Verolog solver challenge 2014*. http://www.vrp-rep.org/references/item/ptv-2014.html.
Queiroga, E., Frota, Y., Sadykov, R., Subramanian, A., Uchoa, E., & Vidal, T. (2020). On the exact solution of vehicle routing problems with backhauls. *European Journal of Operational Research*, *287*(1), 76–89. https://doi.org/10.1016/j.ejor.2020.04.047
Rincon-Garcia, N., Waterson, B. J., & Cherrett, T. J. (2018). Requirements from vehicle routing software: Perspectives from literature, developers and the freight industry. *Transport Reviews*, *38*(1), 117–138. https://doi.org/10.1080/01441647.2017.1297869
Ritzinger, U., Puchinger, J., & Hartl, R. F. (2016). A survey on dynamic and stochastic vehicle routing problems. *International Journal of Production Research*, *54*(1), 215–231. https://doi.org/10.1080/00207543.2015.1043403
Rochat, Y., & Taillard, E. D. (1995). Probabilistic diversification and intensification in local search for vehicle routing. *Journal of Heuristics*, *1*(1), 147–167. https://doi.org/10.1007/BF02430370
Russell, R. A. (1995). Hybrid heuristics for the vehicle routing problem with time windows. *Transportation Science*, *29*(2), 156–166. https://doi.org/10.1287/trsc.29.2.156

Schiffer, M., Schneider, M., Walther, G., & Laporte, G. (2019). Vehicle routing and location routing with intermediate stops: A review. *Transportation Science*, *53*(2), 319–343. https://doi.org/10.1287/trsc.2018.0836

Solomon, M. M. (1987). Algorithms for the vehicle routing and scheduling with time windows constraints. *Operations Research*, *35*(2), 254–265. https://doi.org/10.1287/opre.35.2.254

Taillard, E. (1993). Parallel iterative search methods for vehicle routing problems. *Networks*, *23*(8), 661–673. https://doi.org/10.1002/net.3230230804

Tarantilis, C. D., Zachariadis, E. E., & Kiranoudis, C. T. (2009). A hybrid metaheuristic algorithm for the integrated vehicle routing and three-dimensional container-loading problem. *IEEE Transactions on Intelligent Transportation Systems*, *10*(2), 255–271. https://doi.org/10.1109/TITS.2009.2020187

Tellez, O., Vercraene, S., Lehuédé, F., Péton, O., & Monteiro, T. (2018). The fleet size and mix dial-a-ride problem with reconfigurable vehicle capacity. *Transportation Research Part C: Emerging Technologies*, *91*, 99–123. https://doi.org/10.1016/j.trc.2018.03.020

Thomopulos, D., & Vigo, D. (2016). *Verolog members*. http://www.vrp-rep.org/datasets/item/2016-0016.html.

Toth, P., & Vigo, D. (1999). A heuristic algorithm for the symmetric and asymmetric vehicle routing problems with backhauls. *European Journal of Operational Research*, *113*(3), 528–543. https://doi.org/10.1016/S0377-2217(98)00086-1

Toth, P., & Vigo, D. (Eds.). (2002). *The vehicle routing problem*. SIAM Monographs on Discrete Mathematics and Applications.

Uchoa, E., Pecin, D., Pessoa, A., Poggi, M., Vidal, T., & Subramanian, A. (2017). New benchmark instances for the capacitated vehicle routing problem. *European Journal of Operational Research*, *257*(3), 845–858. https://doi.org/10.1016/j.ejor.2016.08.012

Urtasun, J. M., & Montero, E. (2019). *An study of operator design under an adaptive approach for solving the cross-docks vehicle routing problem* [Paper presentation]. 2019 IEEE Congress on Evolutionary Computation (CEC) (pp. 2098–2105). IEEE. https://doi.org/10.1109/CEC.2019.8790019

Vidal, T. (2017). Node, edge, arc routing and turn penalties: Multiple problems-one neighborhood extension. *Operations Research*, *65*(4), 992–1010. https://doi.org/10.1287/opre.2017.1595

Vidal, T., Crainic, T. G., Gendreau, M., Lahrichi, N., & Rei, W. (2012). A hybrid genetic algorithm for multidepot and periodic vehicle routing problems. *Operations Research*, *60*(3), 611–624. https://doi.org/10.1287/opre.1120.1048

Vidal, T., Crainic, T. G., Gendreau, M., & Prins, C. (2013b). A hybrid genetic algorithm with adaptive diversity management for a large class of vehicle routing problems with time-windows. *Computers & Operations Research*, *40*(1), 475–489. https://doi.org/10.1016/j.cor.2012.07.018

Vidal, T., Crainic, T. G., Gendreau, M., & Prins, C. (2014). A unified solution framework for multi-attribute vehicle routing problems. *European Journal of Operational Research*, *234*(3), 658–673. https://doi.org/10.1016/j.ejor.2013.09.045

Vidal, T., Crainic, T., Gendreau, M., & Prins, C. (2013a). Heuristics for multi-attribute vehicle routing problems: A survey and synthesis. *European Journal of Operational Research*, *231*(1), 1–21. https://doi.org/10.1016/j.ejor.2013.02.053

Vidal, T., Laporte, G., & Matl, P. (2020). A concise guide to existing and emerging vehicle routing problem variants. *European Journal of Operational Research*, *286*(2), 401–416. https://doi.org/10.1016/j.ejor.2019.10.010

Wang, X., & Wasil, E. (2021). On the road to better routes: Five decades of published research on the vehicle routing problem. *Networks*, *77*(1), 66–87. https://doi.org/10.1002/net.21942

Wen, M., Larsen, J., Clausen, J., Cordeau, J. F., & Laporte, G. (2009). Vehicle routing with cross-docking. *Journal of the Operational Research Society*, *60*(12), 1708–1718. https://doi.org/10.1057/jors.2008.108

Widjaja, A. T., Gunawan, A., Jodiawan, P., & Yu, V. F. (2020). Incorporating a reverse logistics scheme in a vehicle routing problem with cross-docking. In *2020 IEEE 7th International Conference on Industrial Engineering and Applications (ICIEA 2020)*. IEEE.

Yang, Z., van Osta, J.-P., van Veen, B., van Krevelen, R., van Klaveren, R., Stam, A., Kok, J., Bäck, T., & Emmerich, M. (2017). Dynamic vehicle routing with time windows in theory and practice. *Natural Computing*, *16*(1), 119–134. https://doi.org/10.1007/s11047-016-9550-9

Yu, V. F., Jewpanya, P., & Redi, A. A. N. P. (2016). Open vehicle routing problem with cross-docking. *Computers & Industrial Engineering*, *94*, 6–17. https://doi.org/10.1016/j.cie.2016.01.018

Zachariadis, E. E., Tarantilis, C., & Kiranoudis, C. (2017). Vehicle routing strategies for pick-up and delivery service under two dimensional loading constraints. *Operational Research*, *17*(1), 115–143. https://doi.org/10.1007/s12351-015-0218-5

Zhang, D., Cai, S., Ye, F., Si, Y.-W., & Nguyen, T. T. (2017). A hybrid algorithm for a vehicle routing problem with realistic constraints. *Information Sciences*, *394–395*, 167–182. https://doi.org/10.1016/j.ins.2017.02.028

Zhou, L., Baldacci, R., Vigo, D., & Wang, X. (2018). A multi-depot two-echelon vehicle routing problem with delivery options arising in the last mile distribution. *European Journal of Operational Research*, *265*(2), 765–778. https://doi.org/10.1016/j.ejor.2017.08.011