The Park-and Loop Routing Problem with Parking Selection

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Solution Method

Computational Results

Conclusion

A study on parking selection in VRP algorithms Motivation

- VRP algorithms presume a single parking spot per customer
- Generally, in VRP softwares, this location is the address of the customer
- **Question 1:** Is this the best we can recommend?
- Question 2: Is it adding a lot of complexity to algorithms to consider other options?

Acknowledgment: Gwenaël Rault @ mapotempo



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Motivation

- 1. There may not be a parking spot in front of each customer
- 2. Assuming there is one, is it always the best?
- 3. Would there be a different route if we had considered other parking spots?
- 4. Why not serving several customers from a parking spot?
- 5. If there is no parking spot, who is choosing?



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Motivations from the litterature

- Unproductive driving while looking for a parking space [Bates et al., 2017]
- Search for parking represents 62% of delivery drivers working time [Allen et al., 2018]
- Fall in driving average speeds in cities and road space reallocated to pedestrians, bicycles and buses [Martinez-Sykora et al., 2020]

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Context of the study

- Last-mile delivery in city centers
- To deliver shops (red locations on the map available as open data)
- Using *loading zones* as potential parking spots (blue locations, also open data)



All maps with leaflet | © OpenStreetMap contributors Data at https://data.nantesmetropole.fr and https://www.data.gouv.fr Solution Method

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Let us presume that :

- A vehicle route starts from the depot, visits a sequence of parking locations, and returns to the depot
- A walking-trip starts from a served parking location, visits a sequence of customers, and returns to the same parking location

The **PLRP-PS** consists of designing vehicle routes and walking-trips to serve all the customers, respecting:

- vehicles capacities & maximum route durations
- trip capacities and a maximum walking distance per driver

and minimizing:

- (i) the number of drivers
- (ii) the sum of driving times, walking times, and parking times

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PLRP-PS Illustration

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Parking and walking in the VRP literature

- Levy and Bodin [1989] location arc routing problem for mail delivery
- Bodin and Levy [2000], Irnich [2008] Park-and-loop (PAL) practice / structure
- Gussmagg-Pfliegl et al. [2011] PAL node-routing problem
- Martinez-Sykora et al. [2020] Traveling Salesman Problem with combination of driving and walking
- Reed et al. [2021] Capacitated Delivery Problem with Parking (CDPP)
- Coindreau et al. [2019] Vehicle Routing Problem with Transportable Resources (VPR-TR)
- Cabrera et al. [2021] Doubly Open Park-and-Loop Routing Problem (DOPLRP)

Also related to VRPs with trucks and trailers, two echelon VRPs, VRPs with drones,...

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Solution methodology

- A simple solution framework: small and large neighborhood search
 A LNS variant inspired by Ropke and Pisinger [2006] and Christiaens and Vanden Berghe [2020]
- Four types of insertion
- Parking selection strategies

$$\begin{array}{c} \hline \end{tildew} \hline \end{tildew}$$

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SLNS operators

Туре	Name	Customer	Parking	Route	Source
Destroy	Random Worst Related String Historical Route	$\begin{array}{l} \boldsymbol{\Sigma}_{small}^{-}, \boldsymbol{\Sigma}_{large}^{-} \\ \boldsymbol{\Sigma}_{small}^{-}, \boldsymbol{\Sigma}_{large}^{-} \\ \boldsymbol{\Sigma}_{small}^{-}, \boldsymbol{\Sigma}_{large}^{-} \\ \boldsymbol{\Sigma}_{small}^{-}, \boldsymbol{\Sigma}_{large}^{-} \\ \boldsymbol{\Sigma}_{small}^{-}, \boldsymbol{\Sigma}_{large}^{-} \end{array}$	$\begin{array}{l} \Sigma^{-}_{large} \\ \Sigma^{-}_{large} \\ \Sigma^{-}_{large} \\ \Sigma^{-}_{large} \\ \Sigma^{-}_{large} \end{array}$	Σ ⁻ large	Ropke and Pisinger [2006] Ropke and Pisinger [2006] Hemmelmayr et al. [2012] Christiaens and Vanden Berghe [2020] Pisinger and Ropke [2007] Hemmelmayr et al. [2012]
Repair	Random Closest Farthest Largest FIFO	$\begin{array}{l} \Sigma_{small}^{+}, \Sigma_{large}^{+} \\ \Sigma_{small}^{+}, \Sigma_{large}^{+} \\ \Sigma_{small}^{+}, \Sigma_{large}^{+} \\ \Sigma_{small}^{+}, \Sigma_{large}^{+} \\ \Sigma_{small}^{+}, \Sigma_{large}^{+} \end{array}$			Christiaens and Vanden Berghe [2020] Christiaens and Vanden Berghe [2020] Christiaens and Vanden Berghe [2020] Christiaens and Vanden Berghe [2020] <i>this paper</i>

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Types of insertions



(a) Insertion in a new route



(c) Insertion in a new walking trip (existing route, served parking location)



(b) Insertion through a new parking location (existing route)



(d) Insertion in an existing walking-trip (existing route, served parking location)

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Parking selection strategies

ONLY for insertion types (a) and (b) (all served parking spots are evaluated)

A parking selection strategy is made of

- A parking selection criterion
- A parking selection method

Two parking selection criteria (from a customer)

- radius-r: walking time to a parking location
- k-nearest: rank wrt the other parking locations

Two parking selection methods

- Filtering
- Sorting

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Parking selection methods Filtering

For each customer, keep only a subset of parking locations



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Parking selection methods

Sorting

- 1. Sort parking locations wrt walking distance
- 2. Stop selecting parking locations based on the parking selection criterion

k-nearest

• After each insertion evaluation, select μ according to $\mathcal{U}(0,1)$ *

• Stop if
$$\mu < p$$
 (with $p = \frac{1}{k}$)

Example: k = 5

i	1	2	3	4	5	6	7	8	9	10
р	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
μ	0.37	0.88	0.09	0.62	0.86	0.71	0.58	0.7	0.58	0.0

with *i* the positions of the parking locations in the sorted list

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Parking selection methods Sorting

r-radius

- After each insertion evaluation, select μ according to $\mathcal{U}(0,1)$
- Stop if $\mu > e^{-\lambda x}$ (with $\lambda = \frac{1}{r}$ and x the walking time to the parking spot)

Example: r = 5 minutes

х	1	1	2	3	7	11	15	16	17	21
$e^{-\lambda x}$	0.9	0.9	0.82	0.74	0.5	0.33	0.22	0.2	0.18	0.12
μ	0.37	0.88	0.09	0.62	0.86	0.71	0.58	0.7	0.58	0.0

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Instances and parameters

Parking locations

352 loading zones locations¹ and 1196 customers locations²



 $^{^{1}} https://www.data.gouv.fr/fr/datasets/aires-de-livraison-du-centre-ville-de-la-ville-de-nantes/$

 $^{^{2}} https://data.nantesmetropole.fr/explore/dataset/244400404_base-sirene-entreprises-nantes-metropole/$

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Instances and parameters

The set of 352 loading zones is considered for every instance

- Parking time is 5 minutes (pt = 5)
- Vehicles can park on customers with no loading zone within 300 meters ($d_{max} = 300$)

Experimentation: five runs per instance Best Known Solution (BKS) ; $\Delta = \frac{z-BKS}{BKS} \times 100$

Best parking selection strategy for the PLRP-PS

Parking se	Parking selection strategy			Max. Δ	Avg. Δ
all parking locations			5	3.12	1.25
		r			
		5	0	38.67	19.22
	filtering	10	0	28.56	15.93
radius-r		15	1	5.45	1.90
i dallab i		5	1	5.35	1.93
	sorting	10	3	5.40	2.11
		15	0	7.64	2.59
		k			
		5	4	3.48	0.88
	filtering	10	13	2.90	0.88
k-nearest		15	3	4.08	1.34
K HEATEST		3	8	3.37	0.81
	sorting	5	6	2.37	0.79
	U	10	7	2.85	0.85

First conclusion

k-nearest is better than radius-r

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Best parking selection strategy for the PLRP-PS sorting or filtering?

filtering-k10					sorting-k5			
n	#Best	$Max\Delta$	AvgΔ	#veh	#Best	$Max\Delta$	AvgΔ	#veh
50	4	0.71	0.17	3.7	6	1.21	0.2	3.7
100	5	1.07	0.31	6.7	5	1.74	0.35	6.7
200	3	2.9	0.72	12.3	7	2.02	0.4	12.3
300	4	1.9	0.84	18.4	6	1.64	0.5	18.4
400	6	2.2	0.48	24.5	4	2.37	0.61	24.5
Avg.	22	2.9	0.5	_	28	2.37	0.41	-

Second conclusion

Filtering and sorting can both give good results but sorting is better

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Validation of the method

	LN	IS	SN	IS	SLNS	
n	#Best	AvgΔ	#Best	AvgΔ	#Best	AvgΔ
50	0	0.98	0	0.95	10	0.00
100	0	3.26	0	2.43	10	0.00
200	0	4.71	0	4.80	10	0.00
300	0	5.10	0	6.01	10	0.00
400	0	6.10	0	7.68	10	0.00
Avg.	0	4.03	0	4.37	10	0.00

Detailed comparison of the LNS strategies per instance size

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Validation of the method

PLRP benchmark [Coindreau et al., 2019]

- Variable Neighborhood Search (VNS) [Coindreau et al., 2019]
- Matheuristic (MH) [Cabrera et al., 2021]³

	VNS		Μ	IH	SLNS		
n	#BKS	Avg. Δ	# BKS	Avg. Δ	# BKS	Avg. Δ	
20	1	4.11	8	0.02	10	0.0	
30	1	3.13	9	0.01	7	0.16	
40	3	1.16	7	0.08	9	0.2	
50	3	1.99	4	0.77	7	0.2	
Total/Avg.	8	2.6	28	0.22	33	0.14	

³https://nicolascabrera.shinyapps.io/VRPTR/

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Managerial insights CVRP vs PLRP vs PLRP-PS(C+LZ)

PLRP-PS(C+LZ)

Vehicles can park at customers and loading zones

The PLRP and PLRP-PS(C+LZ) provide similar results When comparing the PLRP-PS(C+LZ) to the CVRP:

- -16% Driving time
- -72% Parking time

 $\Rightarrow~-35\%$ Sum of driving time, walking time and parking time Vehicles park 3% of the time on delivery areas

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Managerial insights CVRP vs PLRP vs PLRP-PS(LZ)

PLRP-PS(LZ)

Vehicles can park only at loading zones PLRP-PS(LZ) vs CVRP:

- -19% Driving time
- -80% Parking time
- \Rightarrow -30% Sum of driving time, walking time and parking time PLRP-PS(LZ) vs PLRP:
 - +49% Walking time



Managerial insights



Decomposition into driving, parking, and walking time

ntroduction 0000	roduction Problem definition		Solution Method	Compu- 00000	tational Results 00000●00	Conclu 00
		Mar	nagerial ins	sights		
			N			
0.5	50	100	200	300	400	
Average #parking per customer - 0.0 = -0.0 =						Type #LZ #cus

PLRP -

PLRP-PS(C+LZ) -PLRP-PS(LZ) -

PLRP-PS(LZ) -

PLRP-PS(C+LZ)-

PLRP -

- (Z1)S4-BS(LZ)

PLRP-PS(C+LZ)

PLRP -

PLRP-PS(C+LZ) -PLRP-PS(LZ) -

0.0

PLRP -

PLRP -

PLRP-PS(LZ)-

PLRP-PS(C+LZ)

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Managerial insights



Average time per customer decomposed by driving time, parking time, and walking time



Managerial insights



Evolution of the average number of parking instances per customer with respect to parking time

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Main take-away

- Integrating parking selection in VRP heuristics seems simple enough
- Select parking locations based on their ranks wrt customers
- Serving multiple customers from one parking location is efficient

Perspectives

- Stochastic parking times (and walking distance)
- Time windows and synchronization
- SLNS extensions and application to benchmarks

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Thank you!



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