Optimizing combined tours – The truck-and-cargo-bike case

Logistics in Operations Research

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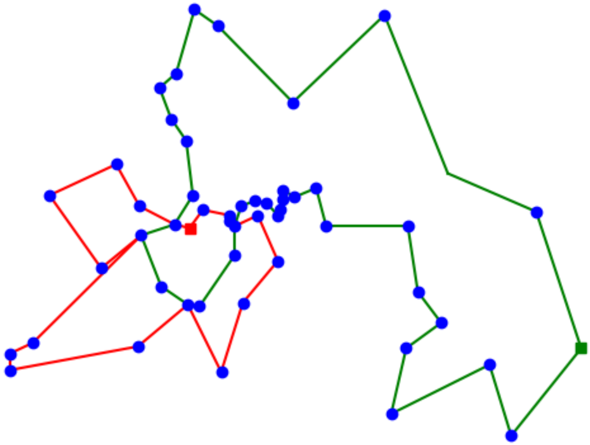
New concepts for last-mile logistics



Truck

- + high capacity
- + fast
- - can't use all streets
- - high emissions

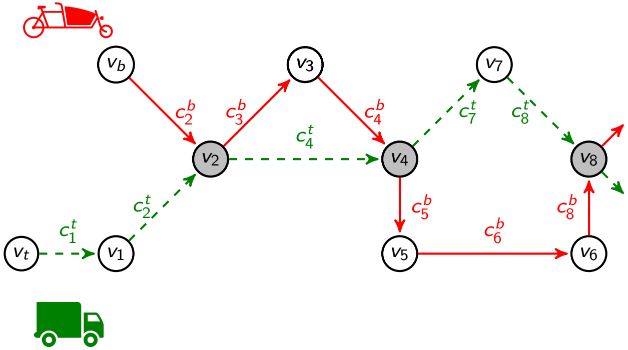
Bike

- - low capacity C_b
- - slower
- + can use bike paths/small streets
- + no emissions

Literature

literature	1st vehicle supplies customers	2nd vehicles per primary vehicle	2nd vehicle type: 2nd vehicle move on network/free	2nd vehicle type: 2nd vehicle can be transported	2nd vehicle type: capacity of 2nd vehicle	flexibility: hand-over location/sync	flexibility: predefined depot/hand-over/assignment
[Murray and Chu, 2015]	yes	1	free	yes	1	customer/yes	yes/no/no
[Agatz et al., 2018]	yes	1	free	yes	1	customer/yes	yes/no/no
[Liu et al., 2020]	yes	1	network	yes	≥ 1	customer/yes	yes/no/no
[Amorosi et al., 2021]	no	≥ 1	free	yes	1	anywhere/yes	yes/no/yes
[Anderluh et al., 2017]	yes	≥ 1	network	no	≥ 1	satellite/yes	yes/yes/yes
[Grangier et al., 2016]	no	≥ 1	network	no	≥ 1	satellite/yes	yes/yes/yes
[Nguyen and Hà, 2023]	yes	≥ 1	free	no	≥ 1	depot/no	yes/-/no
[Boysen et al., 2018]	yes	≥ 1	network	yes	1	customer/yes	yes/no/yes
[Contardo et al., 2012]	no	≥ 1	network	no	≥ 1	satellite/no	set/yes/yes
[Nguyen et al., 2012]	no	≥ 1	network	no	≥ 1	satellite/no	yes/yes/yes
[Hemmelmayr et al., 2012]	no	≥ 1	network	no	≥ 1	satellite/no	yes/yes/yes
[Anderluh et al., 2021]	yes	≥ 1	network	no	≥ 1	satellite/yes	yes/yes/yes
[Li et al., 2021]	no	≥ 1	network	no	≥ 1	satellites/yes	yes/yes/yes
[Li et al., 2022]	yes	1	network	yes	≥ 1	customer/yes	yes/no/set
our approach	**yes**	≥ 1	**network**	**no**	≥ 1	**customer/yes**	**yes/no/no**

Synchronization



$\mathcal{T} = (v_t, v_1, v_2, v_4, v_7, v_8, \dots)$
$\mathcal{B} = (v_b, v_2, v_3, v_4, v_5, v_6, v_8, \dots)$
combined nodes: v_2, v_4, v_8

$$\tilde{c}^b(\mathcal{B}) = c_2^b + \max\{c_3^b + c_4^b, c_4^t\} + \max\{c_5^b + c_6^b + c_8^b, c_7^t + c_8^t\} + \dots$$

$$\tilde{c}^t(\mathcal{T}) = c_1^t + c_2^t + \max\{c_3^b + c_4^b, c_4^t\} + \max\{c_5^b + c_6^b + c_8^b, c_7^t + c_8^t\} + \dots$$

Mixed-integer programming formulation

$$
\begin{aligned}
\min \quad & z && \\
s.t. \quad & d_{v_t}, d_{v_b} \leq z && \\
& t_{v_t}, b_{v_b} = 1 && \\
& 1 \leq t_v + b_v && \forall\, v \in V \\
& \sum_{\substack{w \in V \\ w \neq v}} x^t_{(v,w)} = \sum_{\substack{w \in V \\ w \neq v}} x^t_{(w,v)} = t_v && \forall\, v \in V \\
& \sum_{\substack{w \in V \\ w \neq v}} x^b_{(v,w)} = \sum_{\substack{w \in V \\ w \neq v}} x^b_{(w,v)} = b_v && \forall\, v \in V \\
& x^b_{(v_b,v)} \leq t_v && \forall\, \substack{v \in V \\ v \neq v_b} \\
& \ell_v \leq (1 - t_v) \cdot C_b && \forall\, v \in V \\
& \ell_v + d(w) - \ell_w \leq (1 - x^b_{(v,w)} + t_w) \cdot (C_b + \max_{v \in V}\{d(v)\}) && \forall\, (v, w) \in E \\
& x^t_{(v_t,v)} \cdot c^t(v_t, v) \leq d_v && \forall\, v \in V \\
& x^b_{(v_b,v)} \cdot c^b(v_b, v) \leq d_v && \forall\, v \in V \\
& d_v + c^t(v, w) \leq d_w + (1 - x^t_{(v,w)}) \cdot M && \forall\, \substack{(v,w) \in E \\ v \neq v_t} \\
& d_v + c^b(v, w) \leq d_w + (1 - x^b_{(v,w)}) \cdot M && \forall\, \substack{(v,w) \in E \\ v \neq v_b} \\
& x^t_e, x^b_e, t_v, b_v \in \{0, 1\} && \forall\, e \in E, v \in V \\
& d_v, \ell_v \geq 0 && \forall\, v \in V
\end{aligned}
$$

objective

cover

conservation of flows

bike capacity

subtour elimination

synchronization

Objectives

name	objective	generalized costs	cost type
(tbc_mdp)	delivery period	$c^{DP}(\mathcal{T}, \mathcal{B}) := \max\{\hat{c}^t(\mathcal{T}), \hat{c}^b(\mathcal{B})\}$	synchronized (time-based)
(tbc_mlt)	longest tour	$c^{LT}(\mathcal{T}, \mathcal{B}) := \max\{\tilde{c}^t(\mathcal{T}), \tilde{c}^b(\mathcal{B})\}$	synchronized (time-based)
(tbc_mst)	summed tour durations	$c^{ST}(\mathcal{T}, \mathcal{B}) := \hat{c}^t(\mathcal{T}) + \hat{c}^b(\mathcal{B})$	synchronized (time-based)
(dbc_ws), (dbc_os)	total tour length	$c^{DB}(\mathcal{T}, \mathcal{B}) := c^t(\mathcal{T}) + c^b(\mathcal{B})$	independent (distance-based)

Complexity

Theorem

The combined truck and cargo bike routing problem is

- *NP-hard, even if the truck tour is fixed and the bike capacity is two,*
- *polynomially solvable, if the truck tour is fixed and the bike capacity is one.*

Solution approaches

Clustering-based heuristic

- find clusters
- calculate combined tour between clusters
- calculate combined tour in clusters

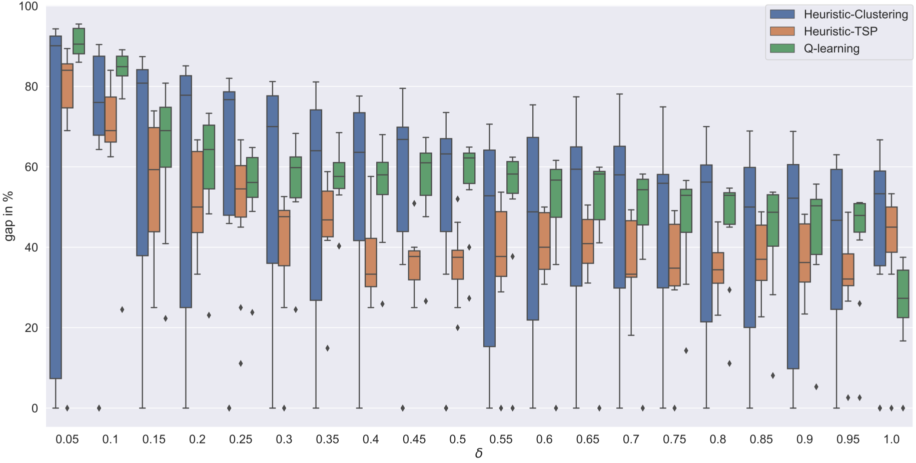
TSP-based heuristic

- start with two TSP tours containing all nodes
- remove nodes from one tour as long as combined tour stays feasible

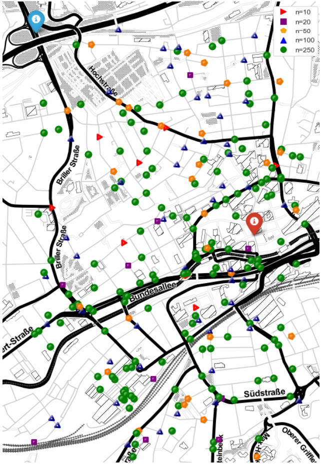
Reinforcement learning

- learn Q-functions for truck and bike
- Q-function approximates extra time needed for adding a node to a tour

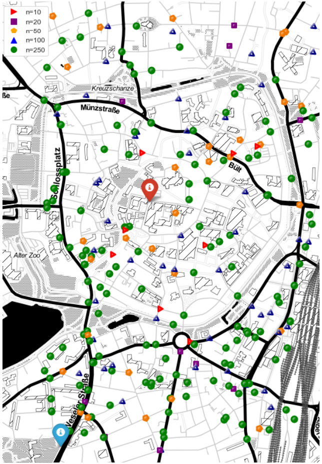
Comparing heuristics – Artificial data set



Experimental evaluation – Real-world data sets

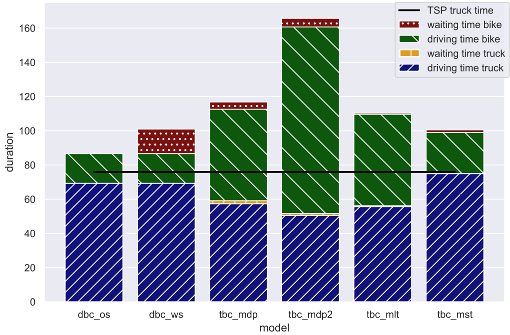


Wuppertal, Germany



Münster, Germany

Comparing objectives – Tour duration



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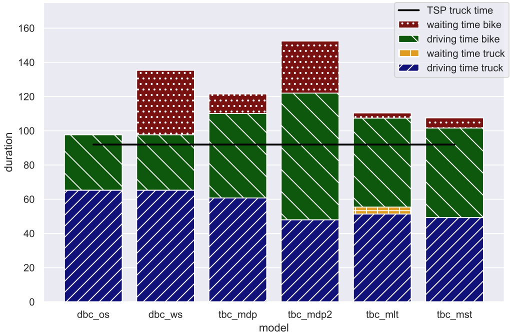

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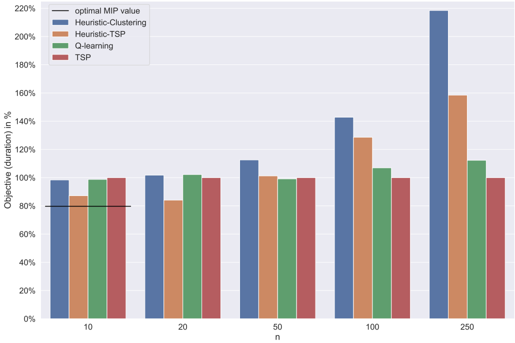
Comparing heuristics – Minimal delivery period



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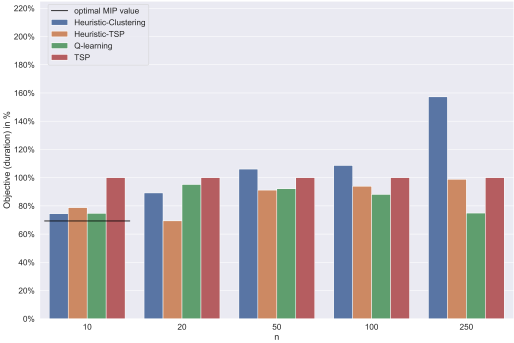

Münster, Germany

Summary and outlook

Summary

- model for combined tours for trucks and cargo bikes
- complexity results
- heuristic solution approaches

Outlook

- exact solution approaches
- cross-sectoral planning with public transport
- approximate value of many secondary vehicles

Kiitos!

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Literature I

Agatz, N., Bouman, P., and Schmidt, M. (2018).
Optimization approaches for the traveling salesman problem with drone.
Transportation Science, 52(4):965–981.

Amorosi, L., Puerto, J., and Valverde, C. (2021).
Coordinating drones with mothership vehicles: The mothership and multiple drones routing problem with graphs.
arXiv preprint arXiv:2109.01447.

Anderluh, A., Hemmelmayr, V. C., and Nolz, P. C. (2017).
Synchronizing vans and cargo bikes in a city distribution network.
Central European Journal of Operations Research, 25(2):345–376.

Literature II

Anderluh, A., Nolz, P. C., Hemmelmayr, V. C., and Crainic, T. G. (2021).
Multi-objective optimization of a two-echelon vehicle routing problem with vehicle synchronization and 'grey zone'customers arising in urban logistics.
European Journal of Operational Research, 289(3):940–958.

Boysen, N., Briskorn, D., Fedtke, S., and Schwerdfeger, S. (2018).
Drone delivery from trucks: Drone scheduling for given truck routes.
Networks, 72(4):506–527.

Contardo, C., Hemmelmayr, V., and Crainic, T. G. (2012).
Lower and upper bounds for the two-echelon capacitated location-routing problem.
Computers & operations research, 39(12):3185–3199.

Literature III

Grangier, P., Gendreau, M., Lehuédé, F., and Rousseau, L.-M. (2016).
An adaptive large neighborhood search for the two-echelon multiple-trip vehicle routing problem with satellite synchronization.
European journal of operational research, 254(1):80–91.

Hemmelmayr, V. C., Cordeau, J.-F., and Crainic, T. G. (2012).
An adaptive large neighborhood search heuristic for two-echelon vehicle routing problems arising in city logistics.
Computers & operations research, 39(12):3215–3228.

Li, H., Wang, H., Chen, J., and Bai, M. (2021).
Two-echelon vehicle routing problem with satellite bi-synchronization.
European Journal of Operational Research, 288(3):775–793.

Literature IV

Li, H., Zhao, J., and Zhan, Z. (2022).
Truck and unmanned vehicle routing problem with time windows: A satellite synchronization perspective.
Journal of Advanced Transportation, 2022.

Liu, Y., Liu, Z., Shi, J., Wu, G., and Pedrycz, W. (2020).
Two-echelon routing problem for parcel delivery by cooperated truck and drone.
IEEE Transactions on Systems, Man, and Cybernetics: Systems, 51(12):7450–7465.

Murray, C. C. and Chu, A. G. (2015).
The flying sidekick traveling salesman problem: Optimization of drone-assisted parcel delivery.
Transportation Research Part C: Emerging Technologies, 54:86–109.

Literature V

Nguyen, M. A. and Hà, M. H. (2023).
The parallel drone scheduling traveling salesman problem with collective drones.
Transportation Science.

Nguyen, V.-P., Prins, C., and Prodhon, C. (2012).
Solving the two-echelon location routing problem by a grasp reinforced by a learning process and path relinking.
European Journal of Operational Research, 216(1):113–126.