Optimal handover locations for two-echelon routing (presentation of results)

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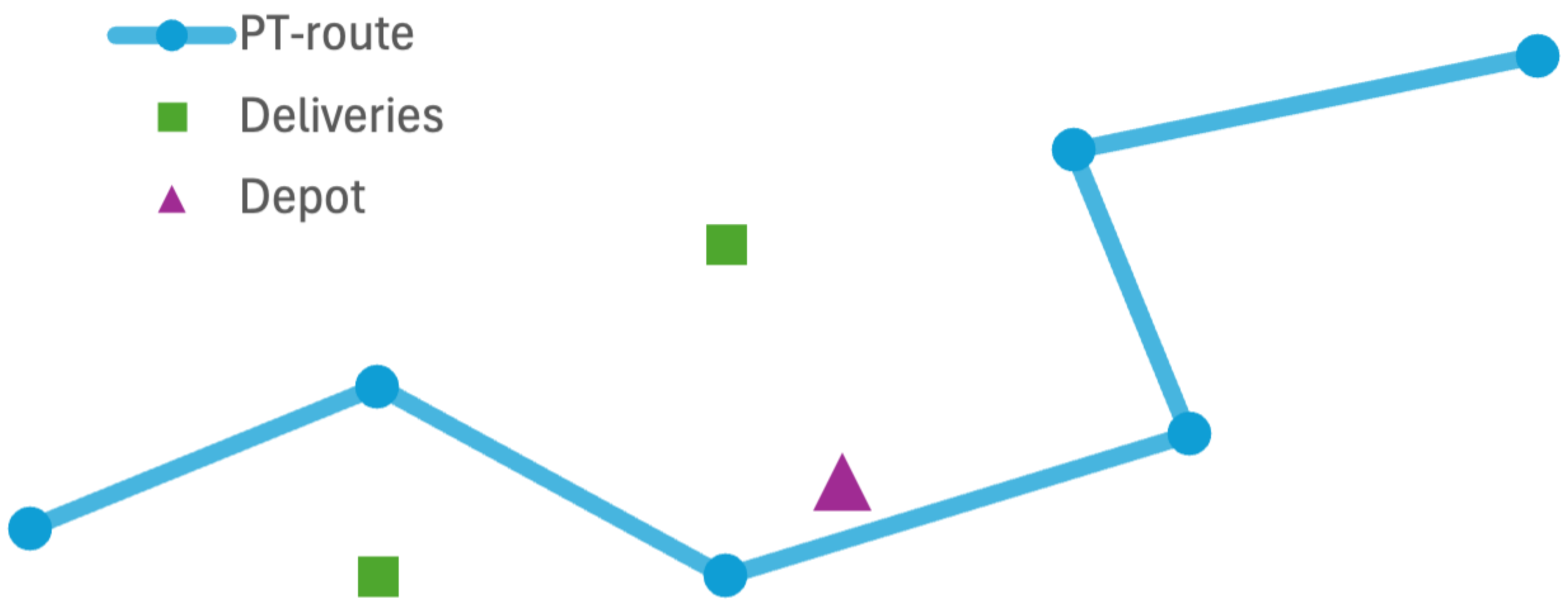
Background

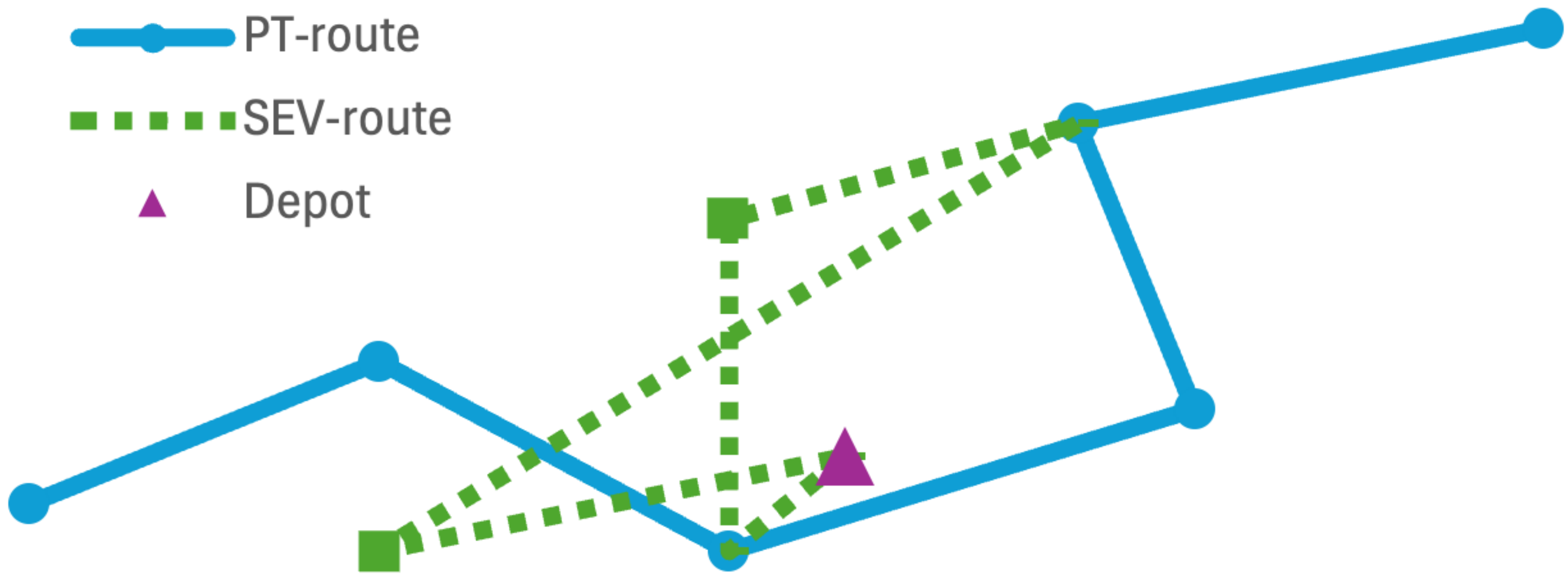
- Need for last mile logistics is rising
- Public transport already exists in metropolitan areas
  - Travels near delivery locations (homes)
- PT-vehicles often have extra space

→ Utilizing PT for package delivery a possible solution

Model

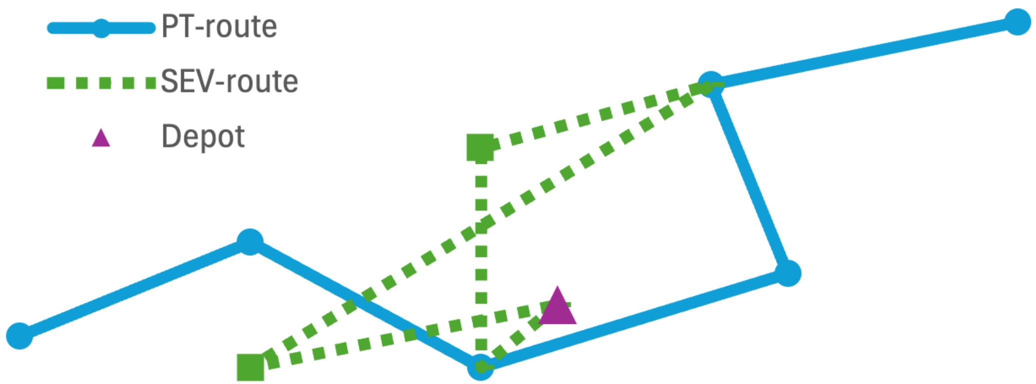


Model



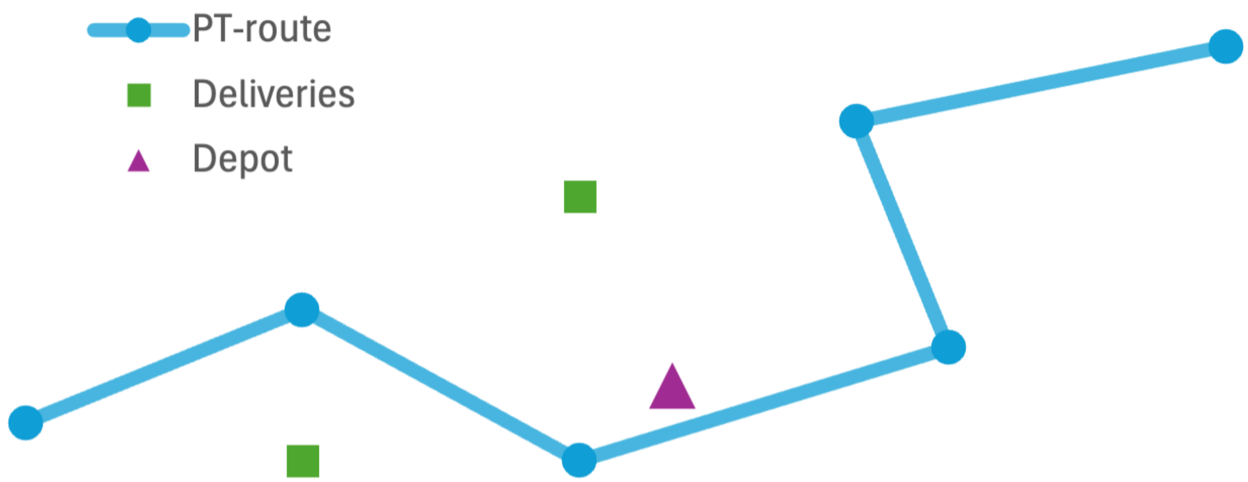
Assumptions and constraints

- Single second echelon vehicle with capacity of 1
- All packages have same demand and all need to be delivered
- SEV and PT need to be synchronized
- Handover takes some additional time
- PT can catch up to schedule between stops



Objective (1/2)

- Find which stops to use as handovers
- Minimize delay for people using public transport



Objective (2/2)

- Objective function:

$$\sum_{s \in S} p(s) \cdot l_s$$

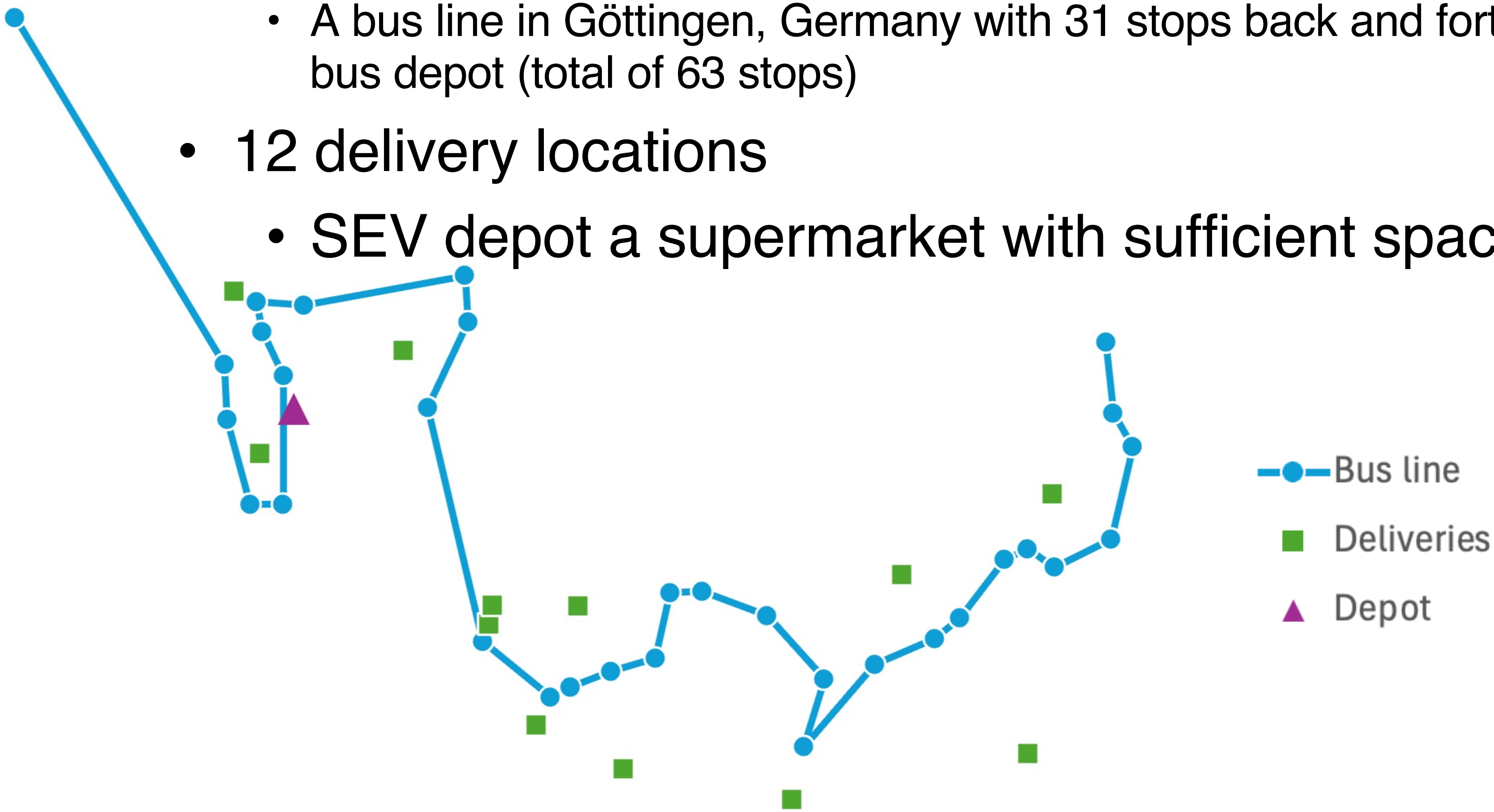
where $l_s = a_{s-1} + w_{s-1} + t_{PT}(s-1, s) - t_{SCH}(s)$

and a_{s-1} models what time PT arrived at previous stop or later of two vehicles in case of handover

- Takes care of synchronization

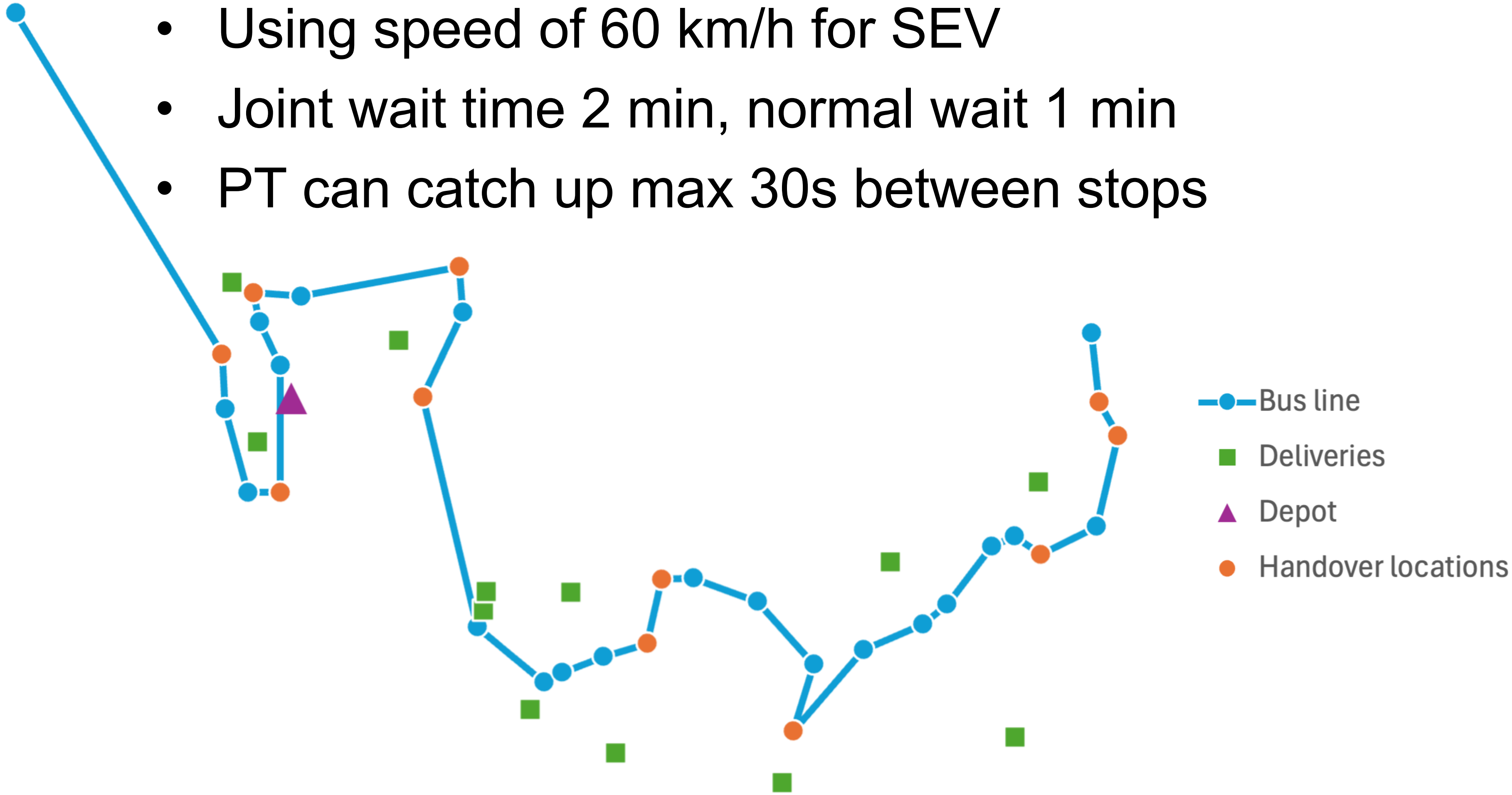
Data

- Line 115 in data set *goevb* from LinTim
    - A bus line in Göttingen, Germany with 31 stops back and forth + bus depot (total of 63 stops)
- 12 delivery locations
    - SEV depot a supermarket with sufficient space



Results

- Using speed of 60 km/h for SEV
- Joint wait time 2 min, normal wait 1 min
- PT can catch up max 30s between stops



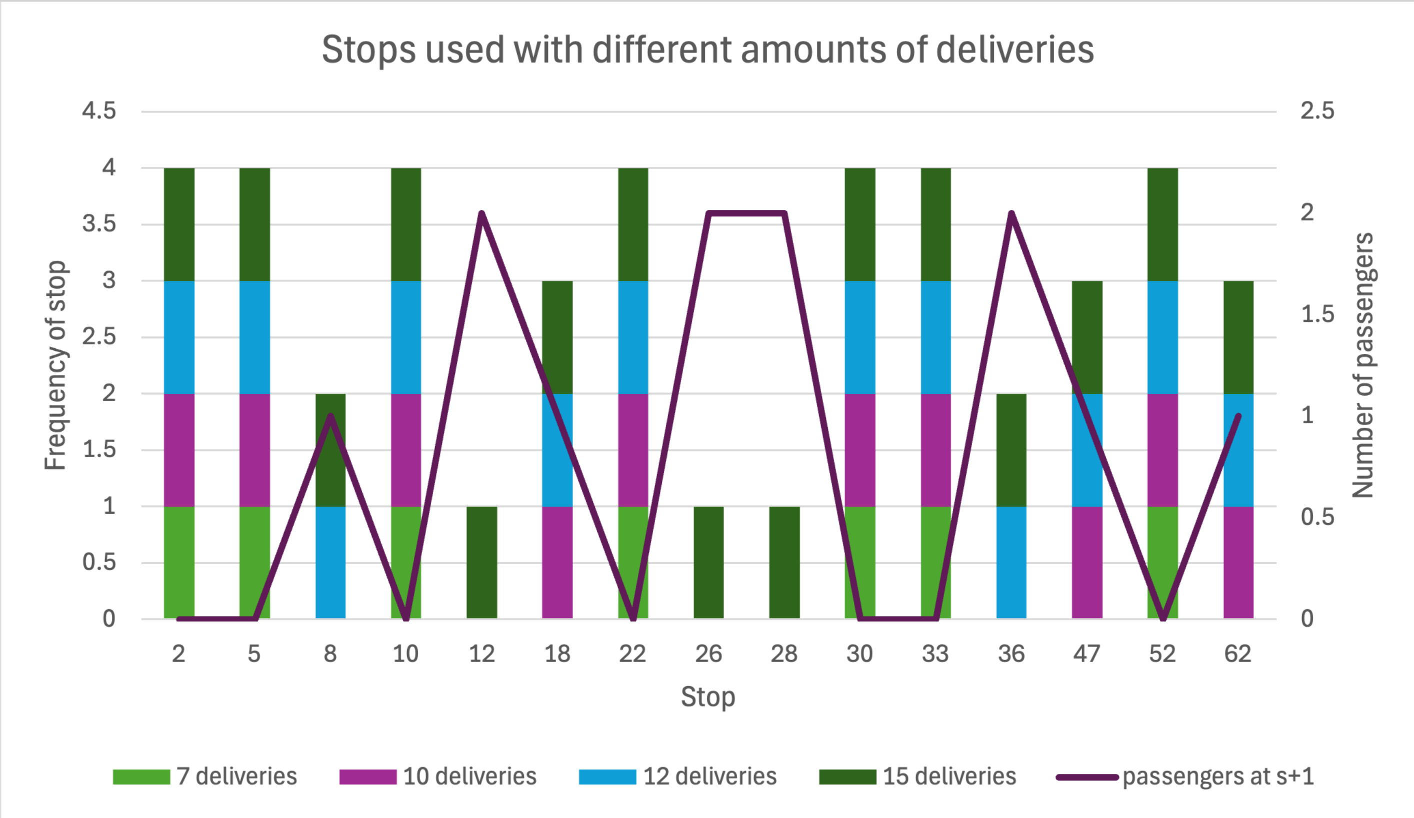
Results of stops with a delay

Stop	Handover before	Lateness	Passengers exiting	Cost
3	1	0.5	0	0
6	1	0.5	0	0
9	1	0.5	1	0.5
11	1	0.5	0	0
19	1	0.5	1	0.5
23	1	0.5	0	0
31	1	0.5	0	0
34	1	0.5	0	0
37	1	0.5	2	1
48	1	0.5	1	0.5
53	1	0.5	0	0
63	1	0.5	1	0.5
TOTAL	12	6.0	5	3.0

Changing speed

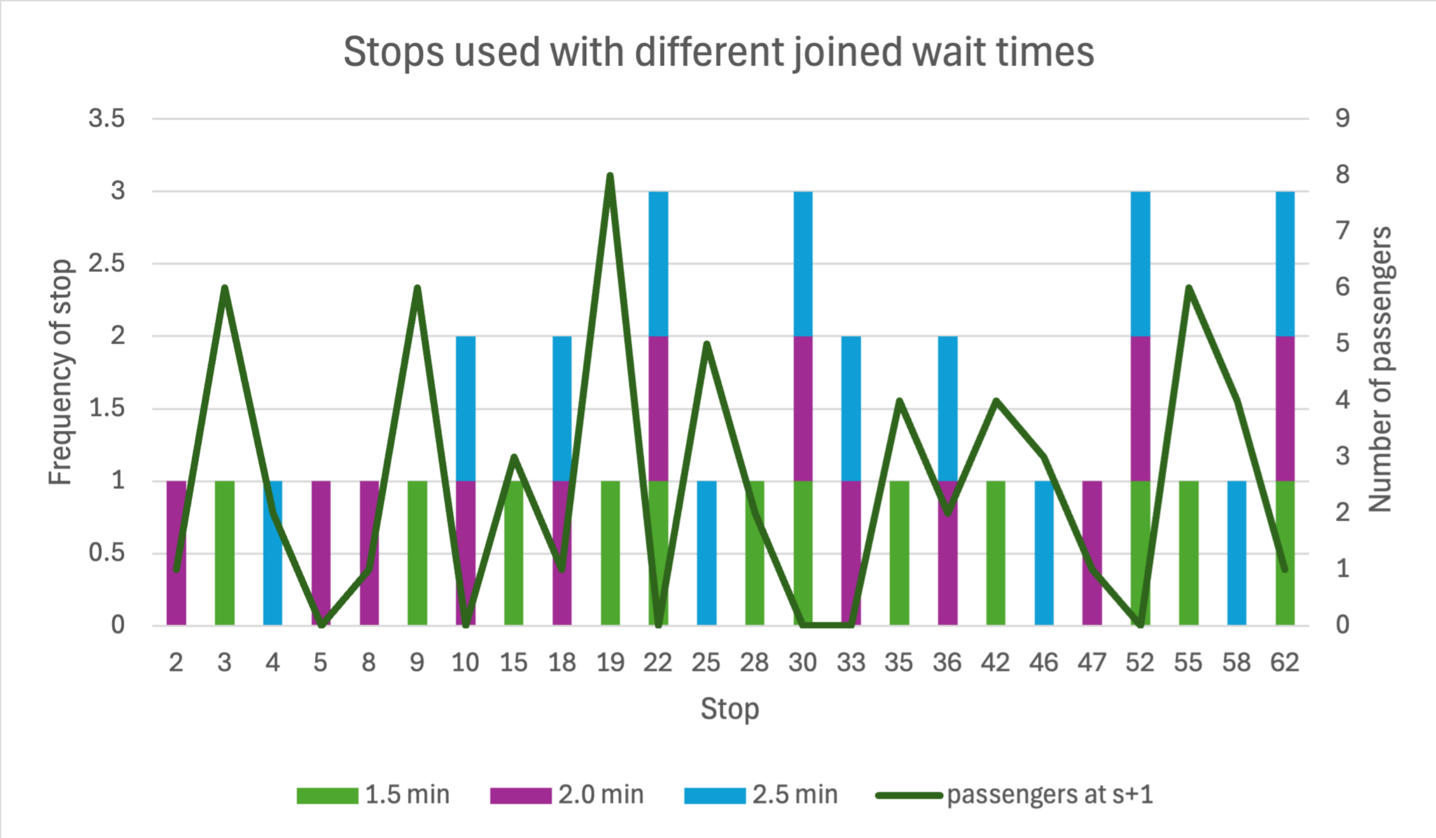
Speed of SEV	15 km/h	30 km/h	60 km/h
Obj.	9	3.5	3

Changing amount of deliveries



Number of stops	7	10	12	15
Obj.	0	1.5	3	6

Changing joined wait time



Joined wait time	1.5 min	2.0 min	2.5 min
Obj.	0	3	42

Conclusions

- Finds very reasonable results even with many deliveries and entire bus line
- Struggles with slower speeds (could not solve with 10 km/h in reasonable time)

- Ideas for future research:
  - Having a larger capacity and/or more second echelon vehices
  - Taking into account differences of time to catch up between stops
  - Taking into account real time information

References

- Schiewe, P., Stinzendörfer, M. (2024). The combined second-echelon vehicle routing problem – Integrating last-mile deliveries into public transport
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- Azcuy, I., Agatz, N., Giesen, R. (2021). Designing integrated urban delivery systems using public transport, *Transportation Research Part E: Logistics and Transportation Review*, 156, 102525
- Data:
  – Stinzendörfer, M., Schiewe, P. (2024). Supplementary material for publication "The combined second echelon routing problem – Models and complexity.
    DOI: 10.5281 / zenodo.13235280. URL: https://doi.org/10.5281/zenodo.13235280

MIP-formulation

$$
\begin{aligned}
\min \quad & \sum_{s\in S} p(s)\cdot l_s && && \text{(1a)}\\
\text{s.t.} \quad & x_{i,j} = 0, && i,j \in D, && \text{(1b)}\\
& \sum_{s\in S} x_{DEP0,s} = 1, && && \text{(1c)}\\
& \sum_{d\in D} x_{d,DEP9} = 1, && && \text{(1d)}\\
& \sum_{v\in V} x_{DEP9,v} = 0, && && \text{(1e)}\\
& \sum_{v\in V} x_{DEP0,v} = 1, && && \text{(1f)}\\
& \sum_{d\in D} x_{s,d} = \sum_{d\in D} x_{d,s} = y_s, && \forall s \in S, && \text{(1g)}\\
& \sum_{v\in V} x_{d,v} = \sum_{v\in V} x_{v,d} = 1, && \forall d \in D, && \text{(1h)}\\
& \sum_{s\in S} y_s = n, && && \text{(1i)}\\
& x_{i,j} + x_{j,i} <= 1 && \forall i,j \in V, && \text{(1j)}
\end{aligned}
$$

$$a_{DEP0} = 0, \tag{1k}$$

$$a_s \geq a_d + t_{SEV}(d, s) - M \cdot x^c_{d,s}, \quad \forall s \in S, \forall d \in D, \tag{1l}$$

$$a_s \geq a_{s-1} + t_{PT}(s-1, s) + w_{s-1}, \quad \forall s \in S, s \geq 2, \tag{1m}$$

$$a_s \geq t_{SCH}(s), \quad \forall s \in S, \tag{1n}$$

$$a_s \geq t_{SEV}(DEP0, s) \cdot x_{DEP0,s} - M \cdot y^c_s, \quad \forall s \in S, \tag{1o}$$

$$a_d \geq a_s + c_2 + t_{SEV}(s, d) - M \cdot x^c_{s,d}, \quad \forall s \in S, \forall d \in D, \tag{1p}$$

$$l_1 = 0, \tag{1q}$$

$$l_s \geq a_{s-1} + w_{s-1} + t_{PT}(s-1, s) - t_{SCH}(s), \quad \forall s \in S, s \geq 2, \tag{1r}$$

$$x^c_{v,w} = 1 - x_{v,w}, \quad \forall v, w \in V, \tag{1s}$$

$$y^c_s = 1 - y_s, \quad \forall v, w \in V, \tag{1t}$$

$$w_s = y^c_s \cdot c_1 + y_s \cdot c_2 \quad \forall s \in S, \tag{1u}$$

$$x_{v,w}, x^c_{v,w} \in \{0, 1\}, \quad \forall v, w \in V, \tag{1v}$$

$$y_s, y^c_s \in \{0, 1\}, \quad \forall s \in S, \tag{1w}$$

$$a_v \geq 0, \quad \forall v \in V, \tag{1x}$$

$$w_s \geq 0, \quad \forall s \in S \tag{1y}$$