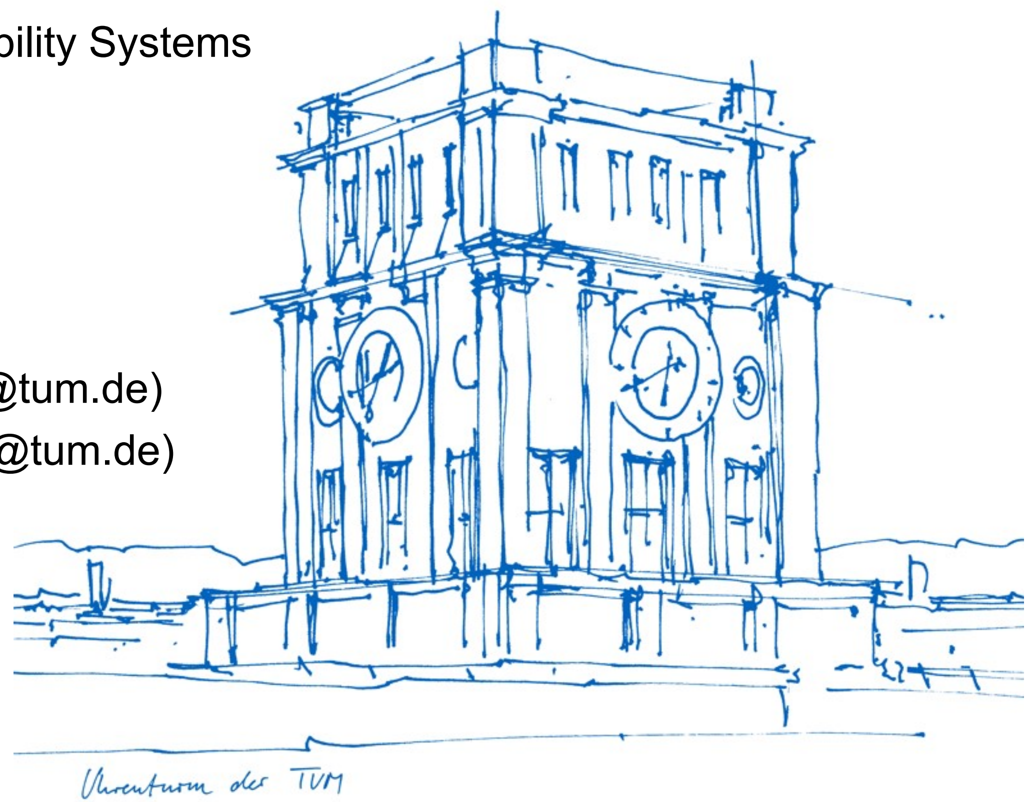
Professorship for Operations and Supply Chain Management
TUM School of Management
Technical University of Munich

Mobility as a Service

Advanced Topics Modeling Future Mobility Systems

Final Presentation



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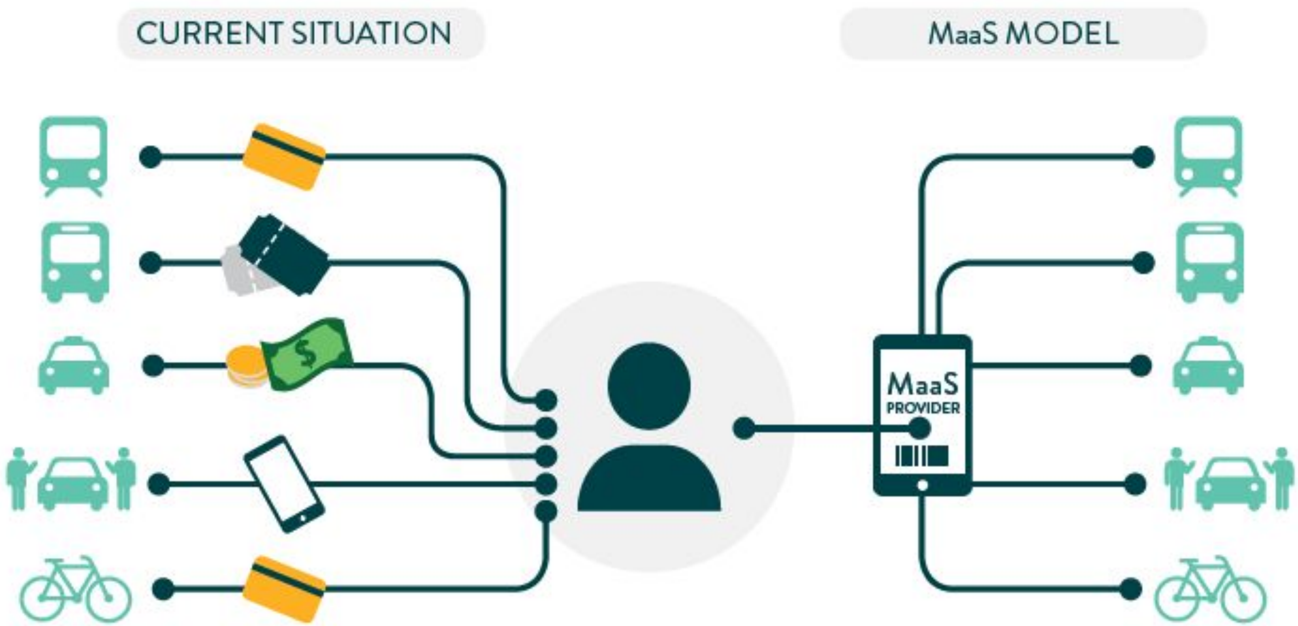
Agenda

- Introduction
- Literature Review
- Methodology
- Results
- Summary & Conclusion
- Lessons Learned / Reflection

Introduction

- "Mobility as a Service" (MaaS) as a new and innovative solution for urban passenger transport services
- MaaS offers more transportation access and convenience to the customers [1]



© UITP – International Association of Public Transport, 2019 [1]

Literature Review | Existing MaaS Provider

- Whim Insights
  - Whim users are more likely to ride public transportation than their counterparts in the Helsinki metropolitan area (63% vs 48%) [2].
  - Whim users are multimodalists, using both bicycles and taxis to solve the first/last mile problem.
  - Public transportation is the backbone of MaaS ecosystem.
  - The MaaS platform seems to succeed in a mode-rich, densely populated urban environment with good connections via public transportation.

Literature Review | Shortest-Path Problem

- Static algorithms for single-source shortest-path[3]

  Compute the shortest-path from a given vertex to all other vertices.

- Most common used of shortest-path algorithms

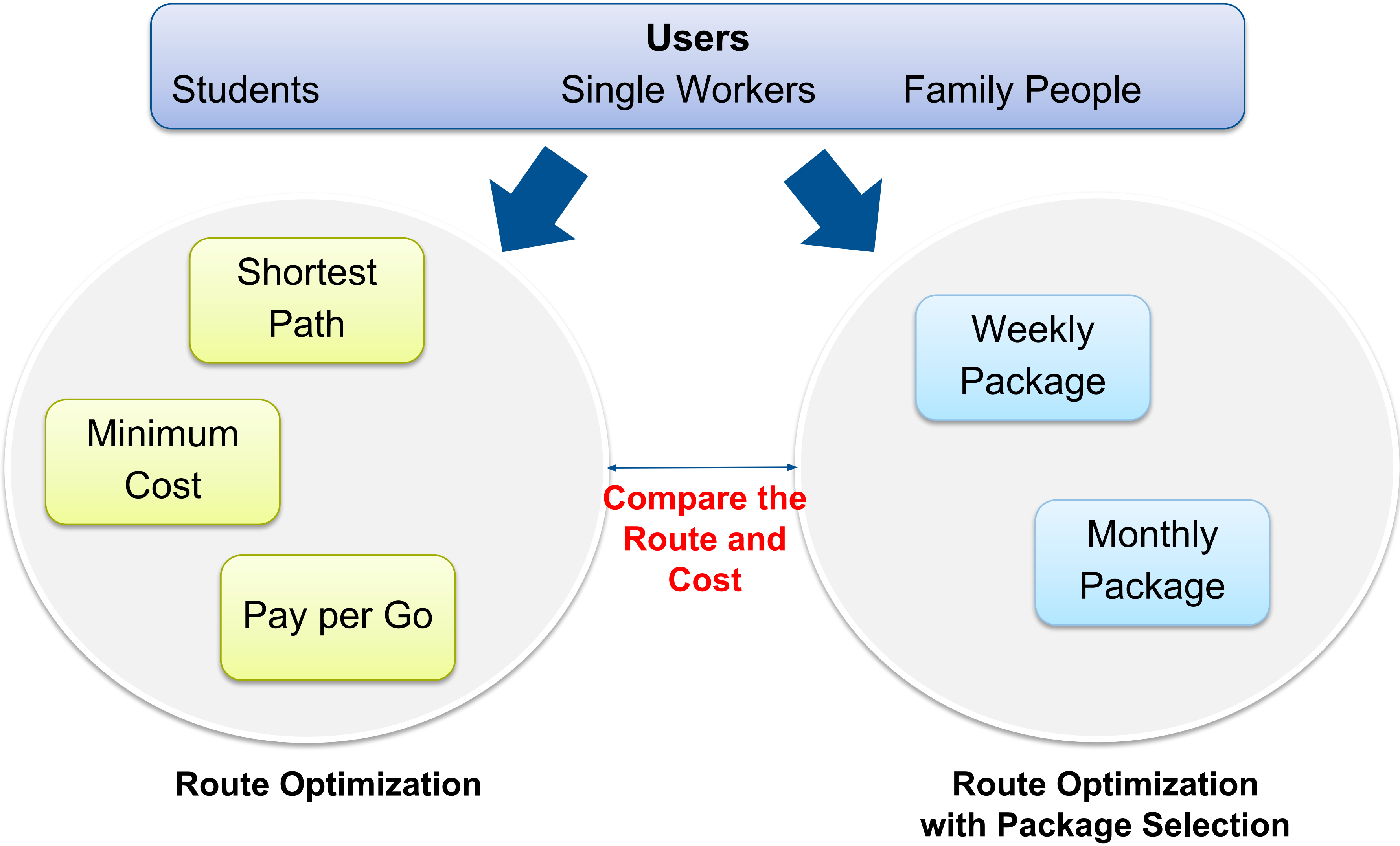
Dijkstra	Bellman-Ford	A*
• Single source shortest-path • Non-negative edge weight	• Single source shortest-path • Can be negative edge weight	• Single pair shortest-path • Using heuristics

Methodology | Objectives

Research Question: How does the users‘ travel behavior change depending on the services provided by MaaS companies?

Route Optimization	Sensitivity Analysis
• Modeling user‘s route choice with and without package selection • Minimizing the costs • Costs consist of monetary value of time and transportation fares • Optimizing the user‘s utility	• Changing the price and service bundles • Identify the changes in user‘s behaviour

Methodology | Problem Description



Methodology | Design of Experiment

- MaaS as combination between public transportation and e-scooter
- The model is tested for Berlin city
- Input data
  - Public transportation schedule & network from GTFS
  - E-scooter random location coordinates (allocated at top 20% main transfer stations)
  - Origin and destination of users
  - Weekly travel pattern of users
  - Walking distance is limited to 1 km, and e-scooter is limited to 5 km
  - Package service bundles

Methodology | Design of Experiment

- Package Service Bundles

Pay-as-you-go	Weekly Package	Monthly Package
Pay the transport fare per usage	6 trips of public transport 20 min	Unlimited public transport 60 min + free unlocked
Public €2.9/trip E-scooter: • unlock €1 • €0.3/min	Price €21/week Over-usage: • E-scooter €0.2/min • Public €2.9/trip	Price €96/month Over-usage: • E-scooter €0.2/min

Methodology | Assumptions

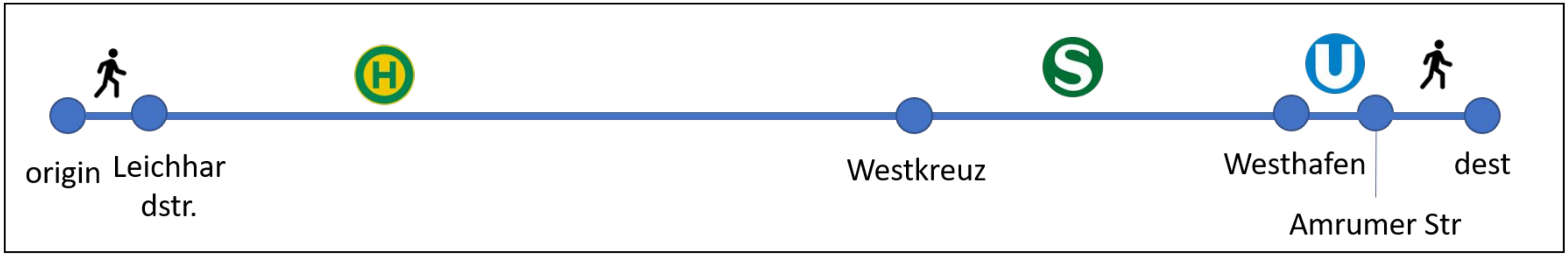
- The network graph is directed and sparse
  $G = (V, A)$ in which $|A| = O(|V|)$
  V is a set of nodes (origin, destination, public transport stations, e-scooters' position)
  A is a set of directed arcs, represent all the available connections between nodes
- The e-scooter has a direct graph for each possible connection

	Nodes	Edges
Public	3,079	14,352
E-scooter	615	200,711

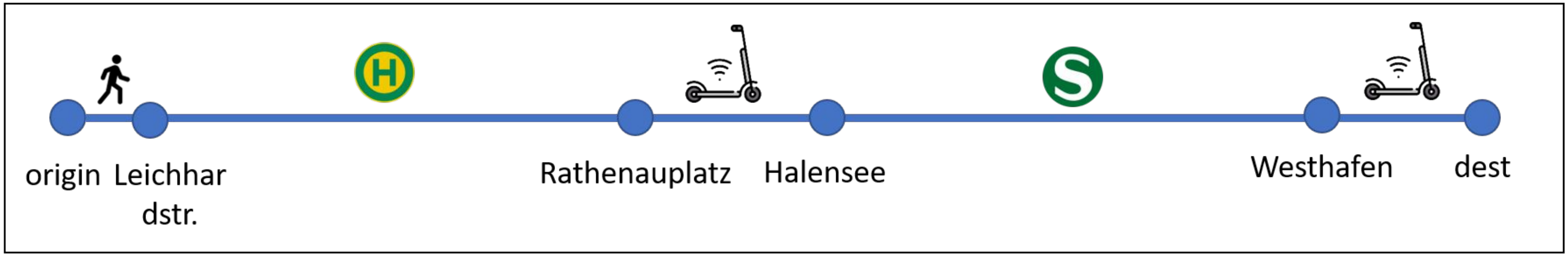
- Euclidian distance for calculating the distance between each node
- Monetary value of time for each user group, based on average yearly income of Berlin in 2018[4] [5]
- The trips are not incorporated with the time schedule of public transportation

Results | Travel Behavior - Worker 1

When PAYG or weekly package is selected (Travel Time: 34 mins):

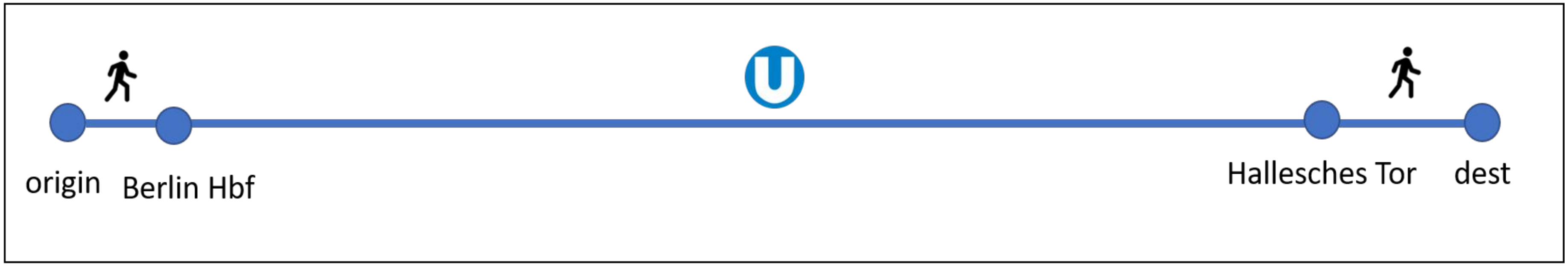


When monthly package is selected (Travel Time: 31 mins):

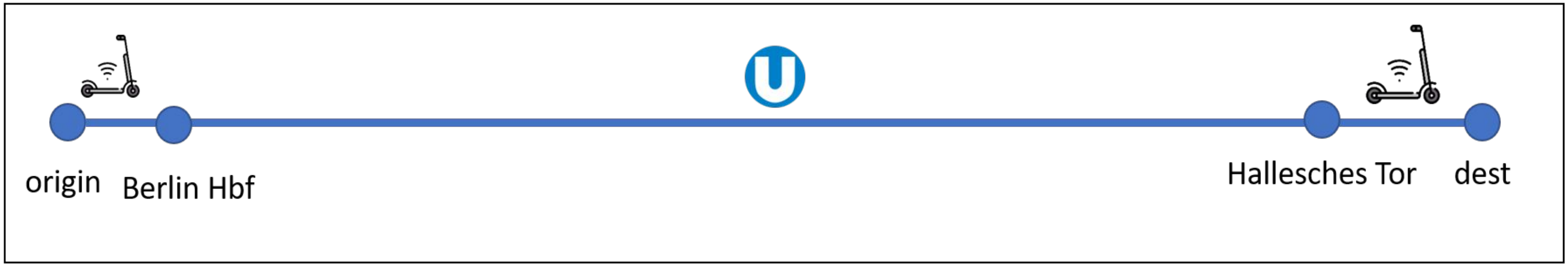


Results | Travel Behavior - Family 2

When PAYG or weekly package is selected (Travel Time: 16 mins):

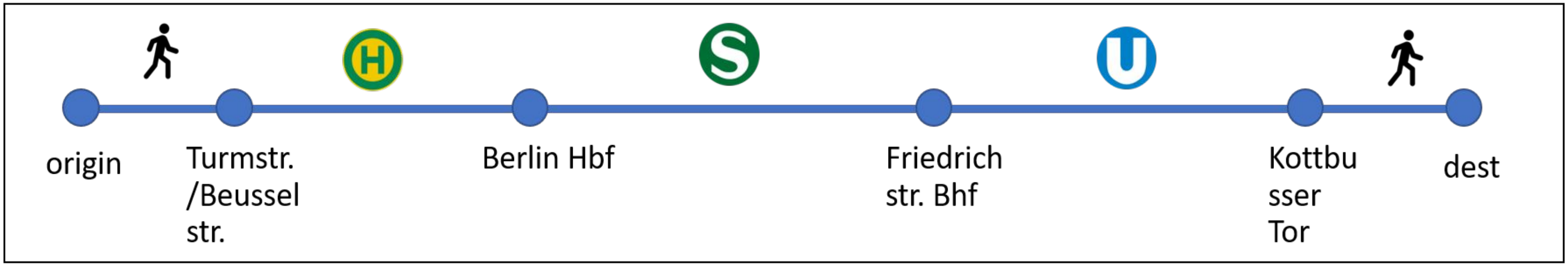


When monthly package is selected (Travel Time: 12 mins):

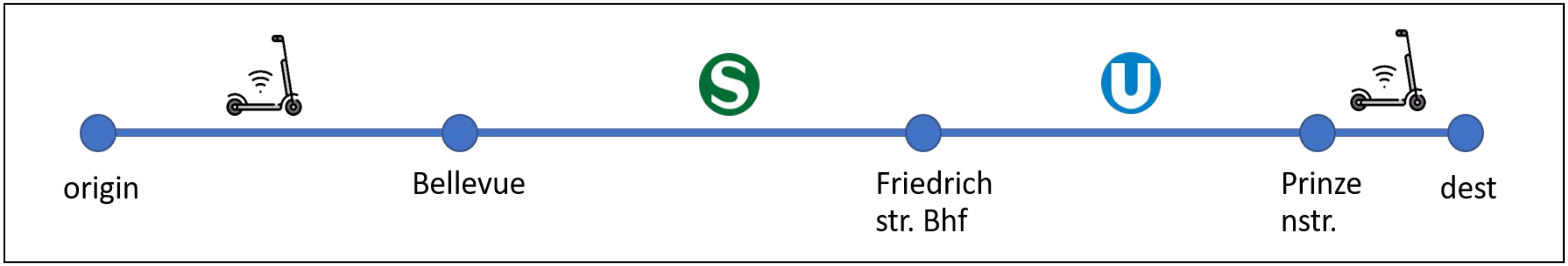


Results | Travel Behavior - Student 3

When PAYG or weekly package is selected (Travel Time: 16.8 mins):



When monthly package is selected (Travel Time: 14.7 mins):



Results | Before Changes

Weekly Package Cost : €34
Unlimited public transport

		Students			Workers			Family		
		1	2	3	1	2	3	1	2	3
PAYG (15)	Week1									
	Week2									
	Week3									
	Week4									
Weekly (1)	Week1									
	Week2									
	Week3									
	Week4									
Monthly (5)										

Weekly package bundle is not attractive compared to PAYG

Results | After Changes

Weekly Package Cost : €21
6 free public transport trips

		Students			Workers			Family		
		1	2	3	1	2	3	1	2	3
PAYG (16)	Week1									
	Week2									
	Week3									
	Week4									
Weekly (4)	Week1									
	Week2									
	Week3									
	Week4									
Monthly (4)										

Family continues to select monthly package due to frequent travel behavior

Summary & Conclusion

- User travel behavior change depending on the package cost and allowances
  - Potential to shift user travel behavior towards more sustainable transport mode through MaaS
  - Package service bundles can be used as a mobility management tool to promote MaaS and attract more customers[1]
- Possible further improvements :
  - Use time-dependant model
  - Add another transport mode, e.g. taxis
  - Broader scope (increase number of users, bigger area coverage)
  - Comparison with existing BVG packages
  - Use the road distance instead of Euclidian distance

Lessons Learned / Reflection

- Limited literature on MaaS from operational perspective
- Long computation time
  - We use Intel® Core™ i5-8250 CPU @ 1.60 GHz 1.80 GHz, RAM 8GB
  - Monthly package selection has the longest computation time, with average 20 mins per user
- Pre-computing of sparse network
  - It took 16 hours to run the model, we used only 1 out of 4 cores. It could have been faster through higher cores usage

References

[1] International Association of Public Transport. (2019). *Mobility as a Service Report April 2019.*

[2] Ramboll. (2019). *Whimpact: Insights from the world’s first Mobility-as-a-Service (MaaS) system.*

[3] A. Madkour, F. Rehman, W. Aref, and A. Rahman. A Survey of Shortest-Path Algorithms, 2017.

[4] (2019) ‘Berliner liegen mit 42.525 Euro beim Gehalt auf Platz neun in Deutschland‘, *B.Z.*, 6 February. Retrieved from http://www.bz-berlin.de (Accessed: 22 January 2020).

[5] (2019) ‘Gehalt Werkstudent in Berlin‘, *Berufsstart*. Retrieved from https://www.berufsstart.de (Accessed: 22 January 2020).

Thank You!

Questions?

Mathematical Model

$$min \sum_{m \in M} \sum_{ij \in A^M} R_{ijm}[(v_u.t_{ijm}) + (c_m.t_{ijm}) + ul_m] \;\; + X * f_m$$

R_{ijm}	Optimum route between node i and node j using transport mode *m*
X	BInary Variable to check if public transport is used in the route or not

<u>Constraints</u>

At most one link is used to arrive at node j

$$\sum_{m \in M} \sum_{hj \in A^M} R_{hjm} \leq 1 \qquad \forall_{j \in V}$$

At most one link is used to leave node j

$$\sum_{m \in M} \sum_{jk \in A^M} R_{jkm} \leq 1 \qquad \forall_{j \in V}$$

User must arrive and leave the node j (except origin & destination)

$$\sum_{m \in M} \sum_{hj \in A^M} R_{hjm} - \sum_{m \in M} \sum_{jk \in A^M} R_{jkm} = 0 \qquad \forall_{j \in V \setminus j:}$$

Origin must have link with exactly one other node j

$$\sum_{m \in M} \sum_{j \in V} R_{ojm} - \sum_{m \in M} \sum_{j \in V} R_{jom} = 1$$

Destination must have link with exactly one other node j

$$\sum_{m \in M} \sum_{j \in V} R_{jdm} - \sum_{m \in M} \sum_{j \in V} R_{djm} = 1$$

Constraint to check if public transport is used in the trip

$$\sum_{ij \in A^M} R_{ijm} \leq M.X$$

M = Public

$$\sum_{ij \in A^M} R_{ijm} \geq M.(X-1)$$

Binary constraint

$$R_{ijm} \in \{0, 1\} \qquad \forall_{ij \in A^M} \quad \forall_{m \in M}$$

Mathematical Model | Route Optimization with Weekly Package

$$min\ z_w = \sum_{s\in S}\sum_{m\in M}\sum_{ij\in A^N} R_{sijmw}[(v.t_{ijm}) + ul_m] + c_m.O_{mw} + PC$$

R_{sijmw}	Optimum route between node i and node j using transport mode *m* for trip *s* in week *w*
O_{mw}	Over-usage of each transport mode *m* in week *w*

Constraints

At most one link is used to arrive at node j

$$\sum_{m\in M}\sum_{hj\in A^N} R_{shjmw} \leq 1 \qquad \forall_{j\in V}, \forall_{s\in S}, \forall_{w\in W}$$

At most one link is used to leave node j

$$\sum_{m\in M}\sum_{jk\in A^N} R_{sjkmw} \leq 1 \qquad \forall_{j\in V}, \forall_{s\in S}, \forall_{w\in W}$$

User must arrive and leave the node j (except origin & destination)

$$\sum_{m\in M}\sum_{hj\in A^N} R_{shjmw} - \sum_{m\in M}\sum_{jk\in A^N} R_{sjkmw} = 0 \qquad \forall_{j\in V}, \forall_{s\in S}, \forall_{w\in W}$$

Origin must have link with exactly one other node j

$$\sum_{m\in M}\sum_{j\in V} R_{sojmw} - \sum_{m\in M}\sum_{j\in V} R_{sjomw} = 1 \qquad \forall_{s\in S}, \forall_{w\in W}$$

Destination must have link with exactly one other node j

$$\sum_{m\in M}\sum_{j\in V} R_{sjdmw} - \sum_{m\in M}\sum_{j\in V} R_{sdjmw} = 1 \qquad \forall_{s\in S}, \forall_{w\in W}$$

Over-usage of each transport mode

$$\sum_{s\in S}\sum_{ij\in A^N} R_{sijmw}.t_{ijm} \leq e_m + O_{mw} \qquad \forall_{m\in\{scooter,taxi\}}\ \forall_{w\in W}$$

Binary constraint

$$R_{sijmw} \in \{0,1\} \qquad \forall_{s\in S}, \forall_{m\in M}, \forall_{ij\in A^N}, \forall_{w\in W}$$

$$O_{mw} \geq 0 \qquad \forall_{m\in\{scooter,taxi\}}, \forall_{w\in W}$$