Modelling multi-modal transport planning

Challenges and ideas for the SynphOnie project

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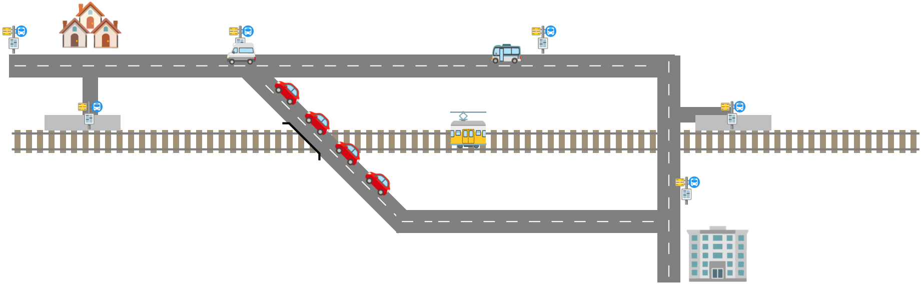
RPTU | OPT Optimization Research Group

Multi-modal transport



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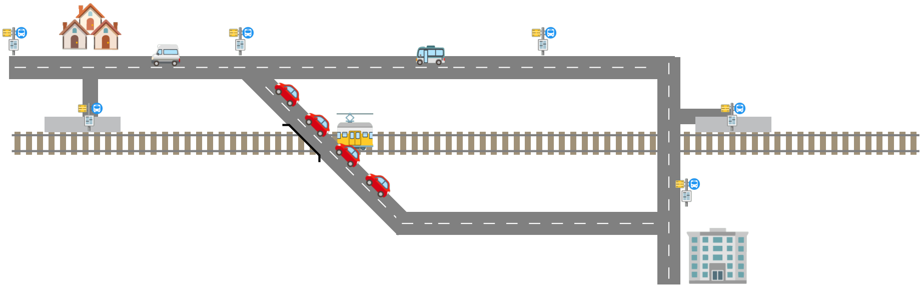

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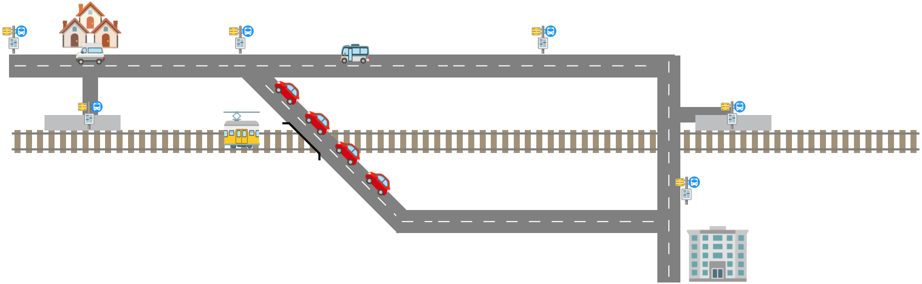

The SynphOnie project

SynphOnie

Synergien aus **ph**ysikalischen und verkehrsplanerischen Modellen zur multikriteriellen **O**ptimierung multimodaler **n**achfrageor**ie**ntierter Verkehre

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The SynphOnie project
Profile

SynphOnie	
Participants	› Department for Transportation Planning and Traffic Engineering, University of Stuttgart › Optimization Division, Fraunhofer ITWM › Optimization Group, RPTU Kaiserslautern-Landau › Optimization Group, University of Passau
Project Partners	› Verkehrsverbund Rhein-Neckar › Verkehrs- und Tarifverbund Stuttgart › PTV Planung Transport Verkehr GmbH
Duration	3 years
Funding	Federal Ministry of Education and Research (BMBF)

The SynphOnie project
Goals

Develop methods for planning public transport that take account of

- the interplay of different transport modes (subway, bus, demand-responsive transport (DRT), private transport)
- capacities and congestion effects
- (selfish) decisions of travellers ($\rightsquigarrow$ global equilibrium constraints)
- multiple objectives (cost, travel time, environmental impact)

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Desired result: Diverse Pareto solutions, each specifying lines, timetables, DRT areas and numbers of vehicles...

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Challenge: Already with a single objective and no congestion effects, the integrated planning of lines and timetables cannot be solved exactly in acceptable time.

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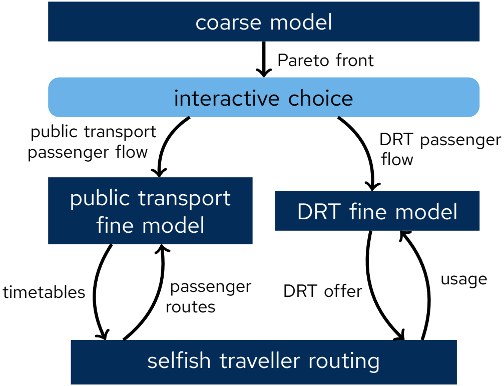
Ideas

- Use abstract **coarse model** that allows for approximate multi-criteria optimization taking into account the global equilibrium constraints.
- Use **fine models** for the different modes or planning aspects (e.g. computation of passenger equilibrium) that can be solved exactly or heuristically.

How to combine these models?
Some first ideas



- The coarse model offers different trade-offs for the objective functions.
- The fine models iteratively compute a solution and a corresponding traveller equilibrium.

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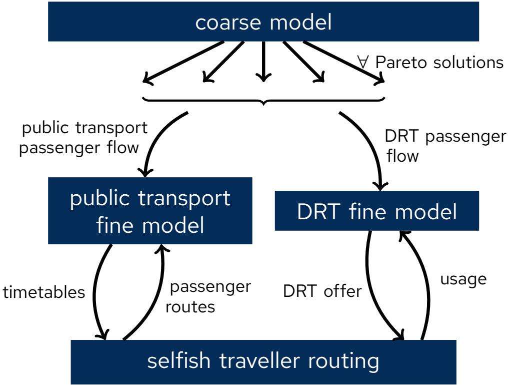

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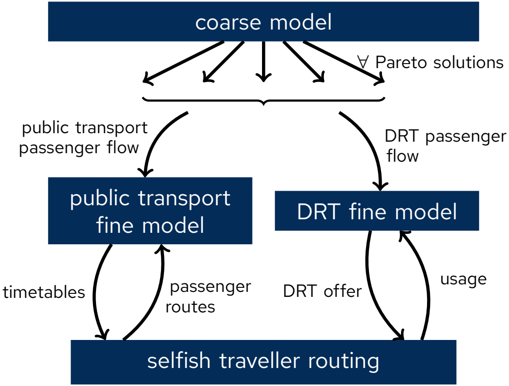

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Danger: During the iterations the solution can diverge from the solution chosen initially by the user.

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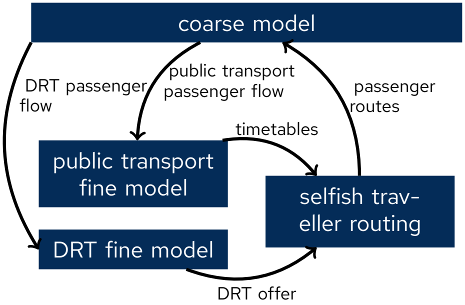

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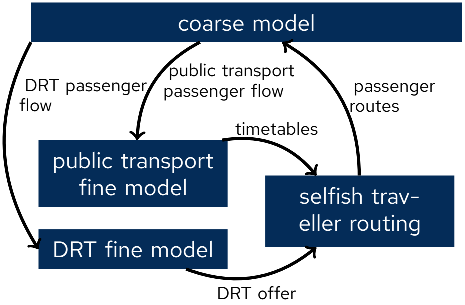

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Danger: Fitting the model parameters for one Pareto solution need not fit the other Pareto solutions.

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- Aggregate geographic regions.
- Ignore line courses, timetables etc.

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Ambitious goal: Combine selfish behaviour and multiple planning objectives.

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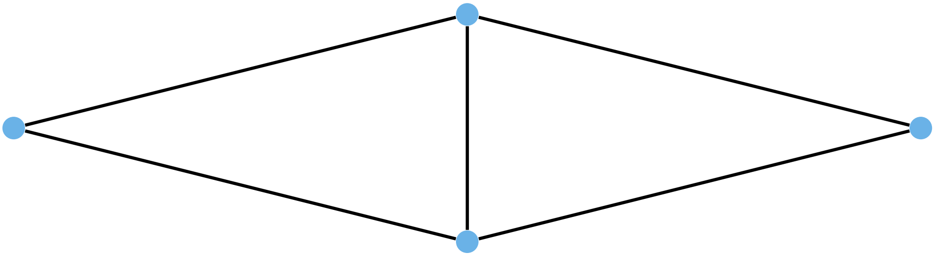
A multi-objective multi-commodity flow network design model

Basic idea

- OD-pairs are multiple commodities in a network flow model on a non-simple digraph (V, A) with each arc connects two locations with a specific mode.



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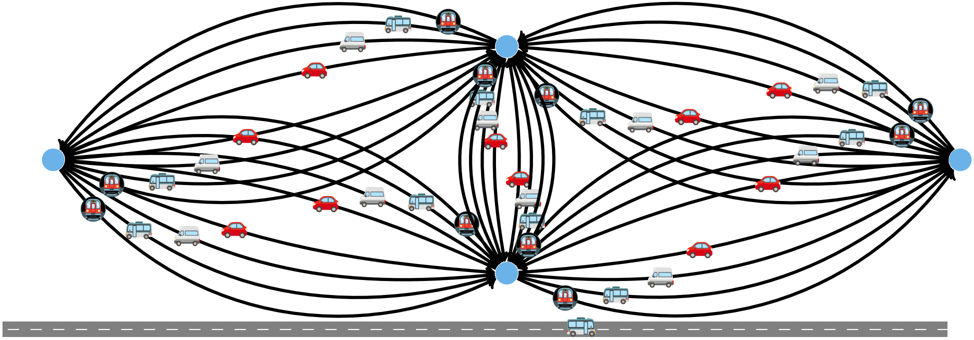

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A multi-objective multi-commodity flow network design model

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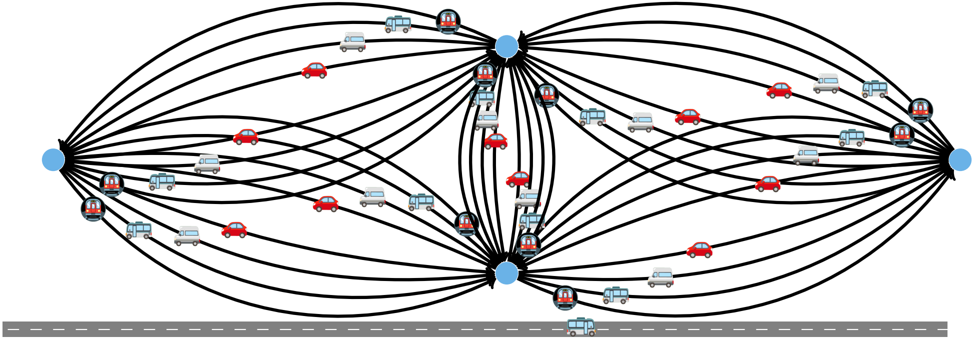
- For a flow x, all objective functions are of the form $f(x) = \sum_{a \in A} f_a(x_a)$, where x_a is the total flow on arc a.



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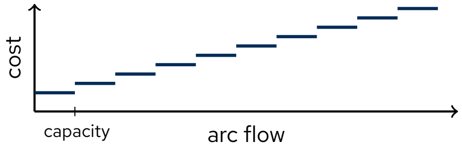
Objective functions

Operator’s cost and environmental impact



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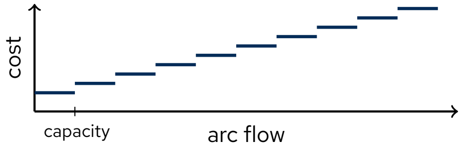

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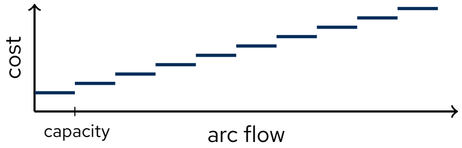

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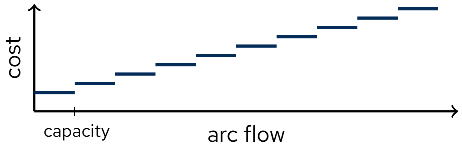

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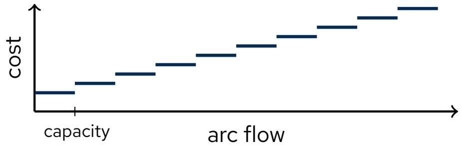

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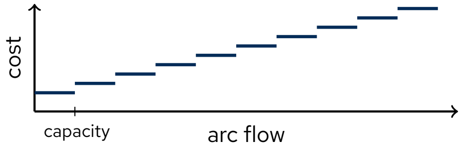

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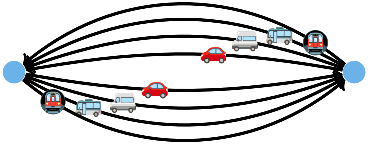
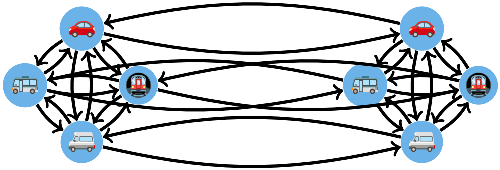
- Due to congestion also depends on number of vehicles of other transport modes.
- The **cost** and **environmental impact** also depend on the driving times.

Further model aspects

- Mode changes should be penalized. ⇝ Copy each node for each mode and add transfer arcs.





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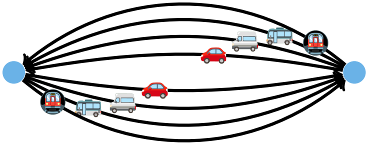

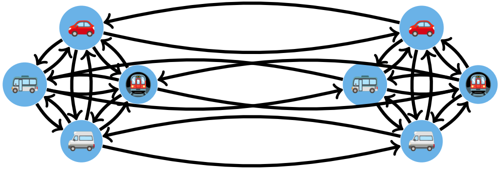

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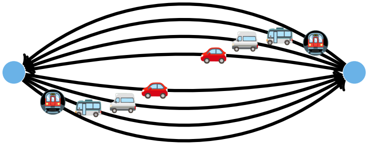

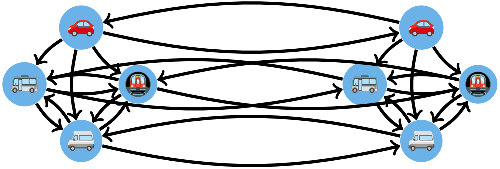

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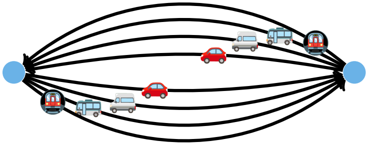

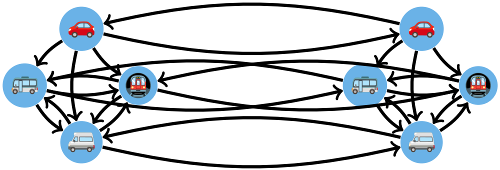

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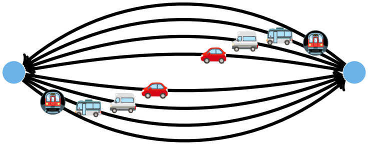

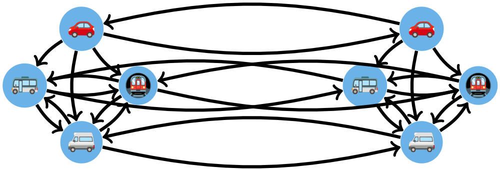

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- The congestion may change over time.

Challenges

Selfish behavior of travellers

- For a fixed network design, the travellers will form an **equilibrium**
  - Wardrop equilibrium
  - Logit equilibrium
- The network designer aims to minimize **multiple objectives** subject to anticipated traveller's response.

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Related work

- Gairing, Harks, & Klimm (2017): network designer minimizes weighted sum of total travel time and cost.
- Harks & Schedel (2021): multiple operators want to maximize their profits.
- Mordukhovich (2009), ...: general multi-objective problems with equilibrium constraints

Challenges

Demand-responsive transport on a fine level

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Related Work

- Steiner & Irnich (2020), Calabrò et al. (2021) …: General models for integrated planning of fixed and demand-responsive transportation
- Tian, Lin, & Wang (2021): 2-stage line planning where additional vehicles can be assigned to lines in second stage
- An & Lo (2016): 2-stage model for transit network design with flexible services
- Pu & Zhan (2021): 2-stage model for railway line-planning with line plan rescheduling
- …

Thank you!

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