Verdus congress 2014

Sustainable multimodal passenger transportation networks: scientific results
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Aim of SRMT project

Search for optimal design of metropolitan passenger transportation network

Criteria: sustainability

- Accessibility: less traffic congestion/delays, multimodal transport chains, alternative modes/routes, reliability: predictable trip times
- Social: use of urban space by vehicles, equity
- Environment: less (fossil) energy consumption, air pollution and noise

→ Multi-objective network performance evaluation
Multimodal passenger transportation network
## Optimization approaches

<table>
<thead>
<tr>
<th>Single objective optimization</th>
<th>Combined single objective optimization</th>
<th>Multi objective optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 optimal solution for each objective, within constraints</td>
<td>1 optimal solution within constraints</td>
<td>A set of possibly optimal solutions (Pareto set)</td>
</tr>
<tr>
<td>Problem: Multiple re-run, No comparison of objective values and generalized costs &amp; benefits</td>
<td>Problem: Multiple re-run, complex weighting and conversion of objective values into (monetary) costs</td>
<td>Clear Pareto frontiers No weighting nor conversion of objective values required, easy sensitivity analyses</td>
</tr>
</tbody>
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Multi-objective optimization

- A Pareto set of solutions instead of one single solution

SO result for Travel time

RED dominates BLUE

Weighted result (using tangent line)

SO result for CO₂ emissions

Pareto set after MO optimization

○ = not dominated
● = dominated

Total travel time →
Network design problem: bi-level optimization

Upper level:
Minimization of system objectives (costs) concerning sustainability

Lower level:
User equilibrium problem: multimodal assignment for a given travel demand

Network state
 Loads, speeds

SRMT P1:
What land use patterns are expected, given the type of networks proposed?

SRMT P4:
How can such a multimodal passenger transport network be correctly modelled?

SRMT P2:
How can such a transition take place?

SRMT P5:
Does infrastructure capacity cope with the predicted transport demand and supply (higher frequencies, new stations)?
Decision variables

- Park & Ride candidate locations
- Frequency of train lines
- Frequency of bus lines
- New railway (transfer) station candidate locations
- New express train station candidate locations

Case study Northwing Randstad 2030
→ Decision space contains $7 \times 10^9$ possible solutions
- Calculation time of 1 solution (running the lower level): 6 min
Objective functions (selected)

1. Accessibility: total travel time
2. Use of urban space by parking: car trips to and from zones
3. Operating deficit of PT (cost – revenue) and cost of park and ride
4. Climate impact: total CO$_2$ emissions for car and PT vehicles
Optimization algorithms

- Multi objective genetic algorithm NSGA-II widely used
  - Fitness based on
    - Pareto ranking: dominance relation
    - Crowding distance: prefer solutions in less crowded areas
  - Deb, 2002
- Improvement by applying $\epsilon$-NSGAII
  - $\epsilon$-dominance to detect large progress over little progress: restart if no large progress is made
  - Restarts with adaptive population sizes to accelerate search in the initial stage of the algorithm
Findings:
Faster optimization algorithm $\varepsilon$-NSGAII

Findings:
Influence of randomness in genetic algorithms

- The differences in the attained objective values are not big among the runs: neither within runs with the same parameters nor between runs with different parameter settings.
- The decisions to be taken are substantially different in different outcomes of the optimization algorithm, so the advised decisions are influenced by the randomness of the algorithm.
  - More knowledge is needed on the sensitivity of decision variables with respect to the objective values.

Influence of demand uncertainty

Realistic predictions for possible futures:

- Base scenario: 2030 demand prediction (WLO GE)
- Low growth scenario: 2020 demand prediction (WLO GE)
- TOD growth scenario: developments of new dwellings and jobs only take place near train stations, instead of spread out over the whole area

→ Do optimized transportation networks using one demand forecast still perform Pareto optimal under a different demand forecast?
Findings:
Influence of demand uncertainty

- A majority of the solutions does not perform Pareto optimal any more if assessed using a different transportation demand
- However, the loss in objective function values is small
- In the context of policy measures that promote multimodal trip making, the measures that are optimal in one future situation, are near optimal in a different future situation
- Demand uncertainty only causes slightly more differences in decision variables than differences caused by the random nature of the used optimization heuristic
- The resulting decision variables are insensitive for transportation demand

Brands, van Berkum, Wismans (2014), OPT-I conference, 4-6 June 2014, Kos, Greece
Optimization results
Post optimization analysis: Constraint to one objective
Post optimization analysis:
Compromise between two objectives
Improvements reached

- 1% difference to be made in total travel time, compared to current network
- 1.5% difference to be made in $\text{CO}_2$ emissions, compared to current network
- Much larger improvements possible for CO2 emissions by more radical policies, for example road pricing or decrease of road capacity
Conclusions / recommendations

- Multi-objective optimization is technically feasible and can be applied to real life case studies
- Methodological experiments did not reveal large shortcomings of the method
- Post optimization analysis of results enables more insight for decision makers
- Interactive decision support tool should be developed to make better use of the Pareto sets
References


