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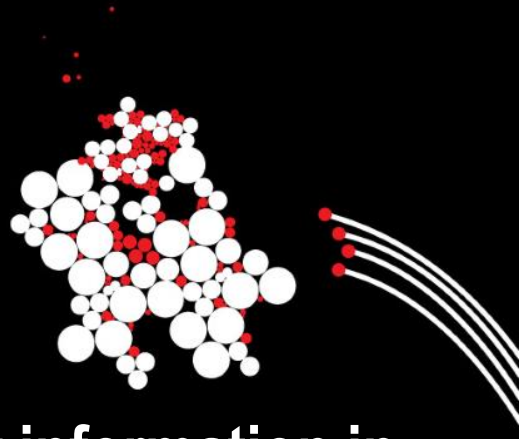

The Pareto set as decision support information in multimodal passenger transportation network design

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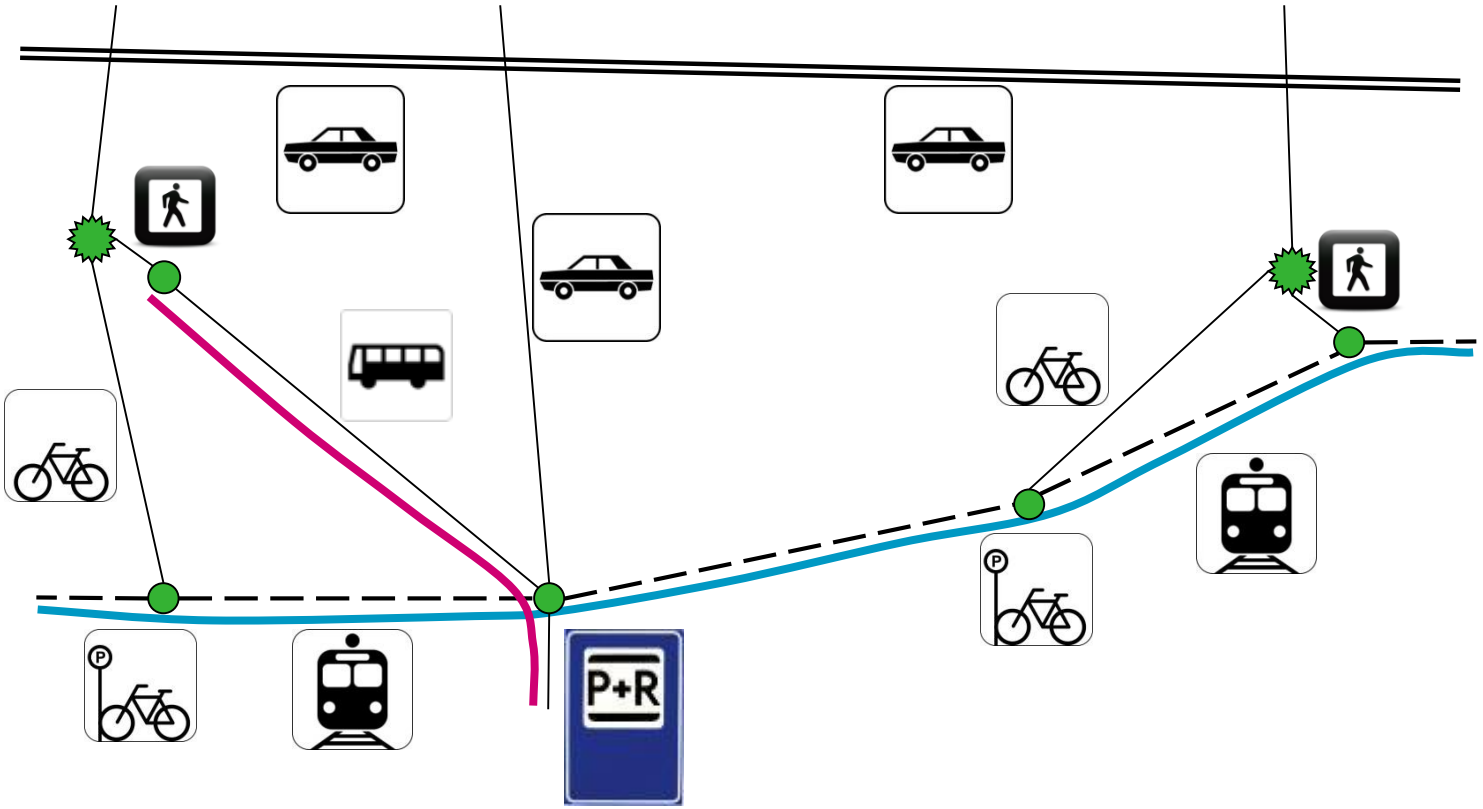
NWO
Netherlands Organisation for Scientific Research

Background

- How to improve the passenger transportation network?
- What to improve: sustainability
  - → multi-objective is necessary for multiple aspects of sustainability
- How to improve: multimodal network improvements
- Optimisation: search for the best possible combination of measures
- → A lot of output
- Methods are needed to visualise and analyse the Pareto set

Multimodal passenger transportation network

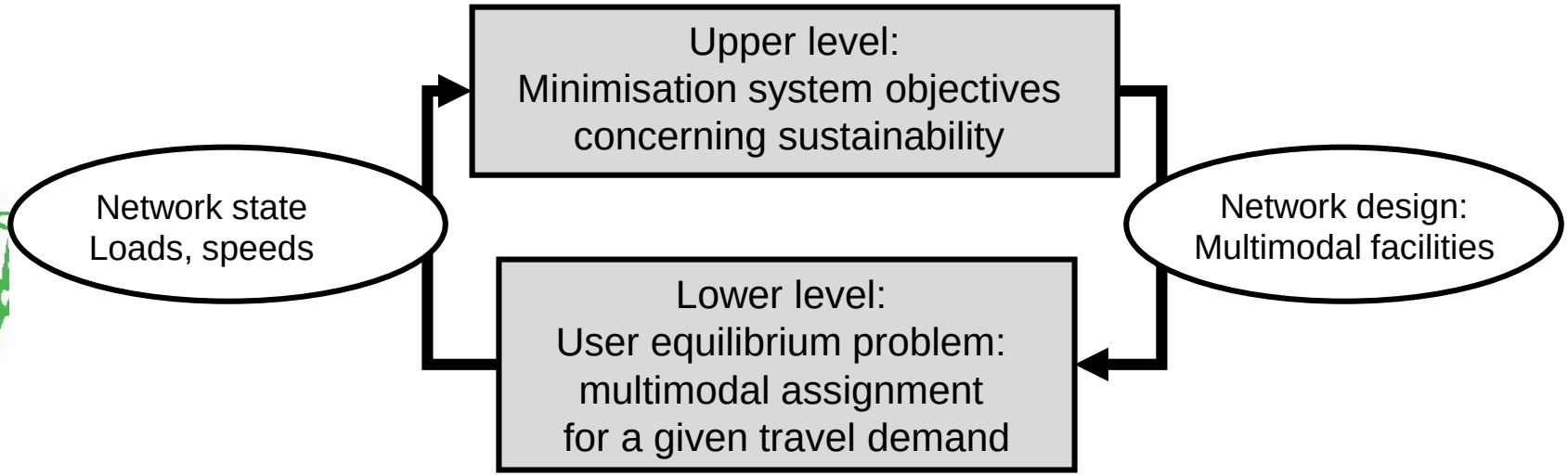


Objective functions to be optimised

Aspects of sustainability:

1. Accessibility: total travel time
2. Use of urban space by parking: car trips to and from urban areas
3. Operating deficit of public transportation (cost – revenue) and cost of park and ride
4. Climate impact: total CO_2 emissions for car and public transport vehicles

Network design problem: bi-level optimisation



Case study: Metropolitan region of Amsterdam in 2030

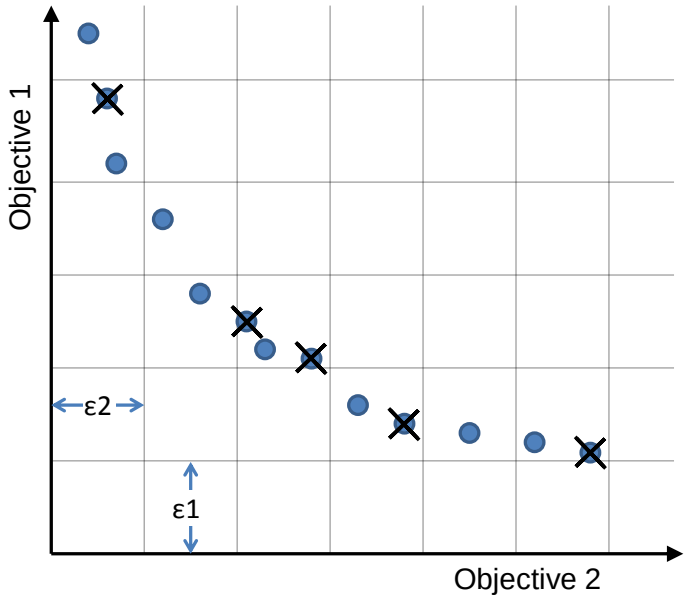
37 decision variables

- 7 candidate locations for Park and Ride
- Frequency of 12 train lines
- Frequency of 8 bus lines
- 6 candidate locations for train stations
- 3 candidate locations for express train stations
- 1 possible tram line extension
- → Decision space contains 7E13 possible solutions

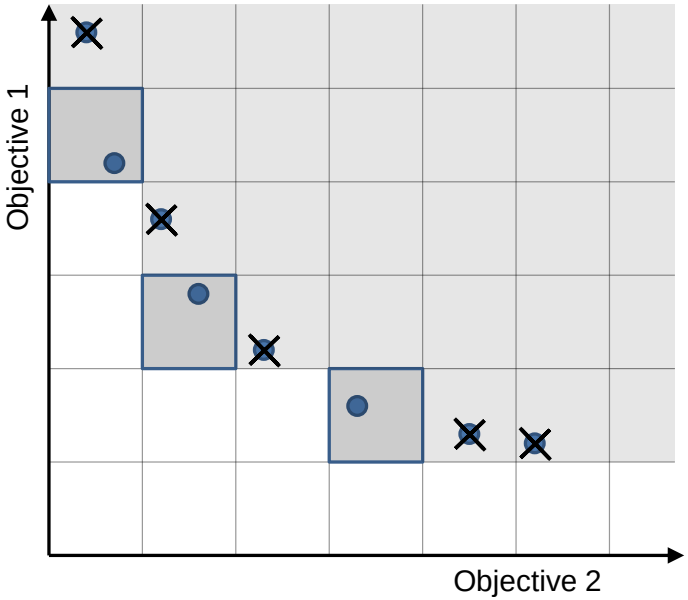
- Calculation time of 1 solution (running the lower level): 6 minutes

Solution algorithm: ε-NSGAII

- Extension of well known genetic algorithm NSGAII
- ε-dominance to detect large progress over little progress
- No waste of calculation time when only little progress is made

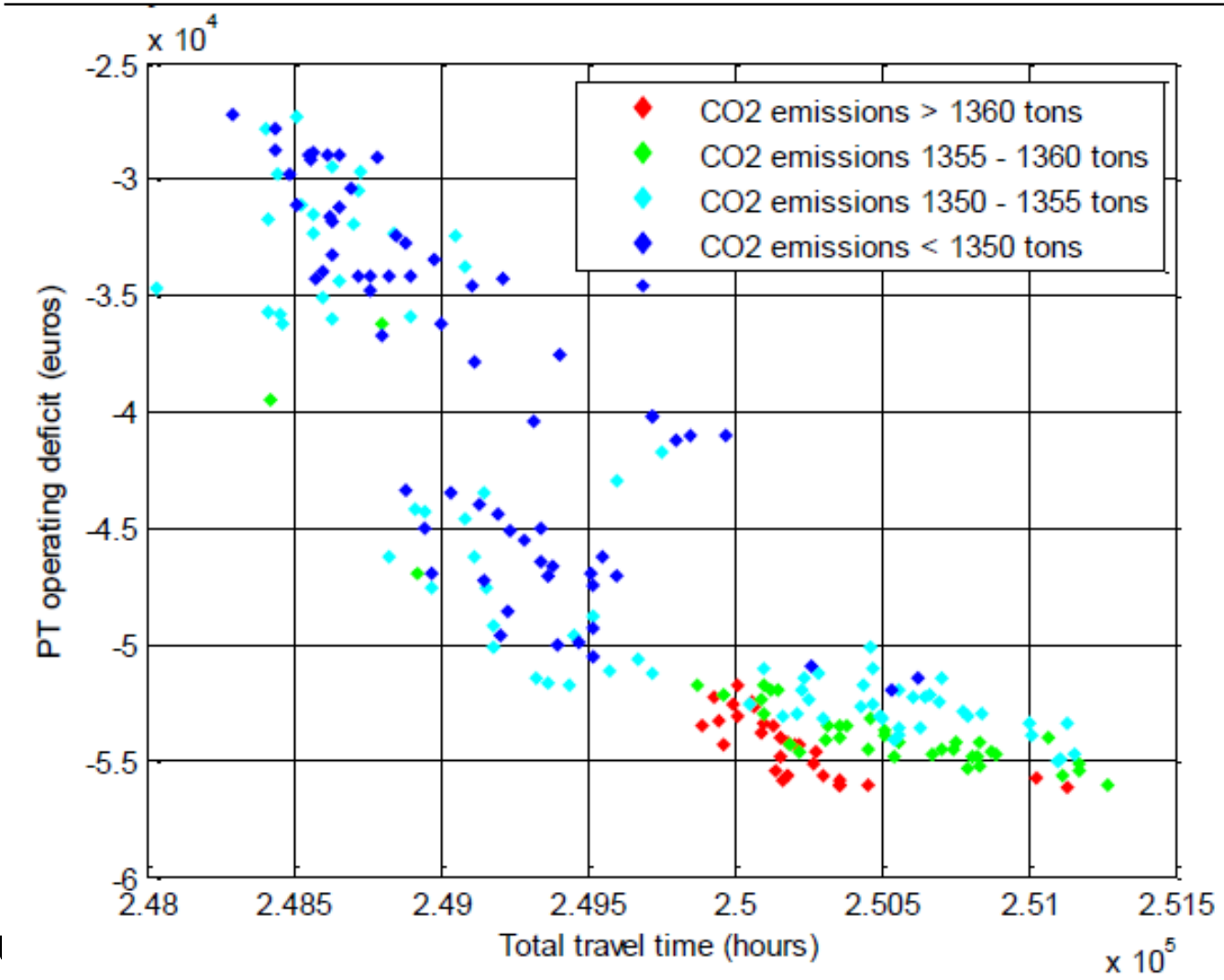


Step 1

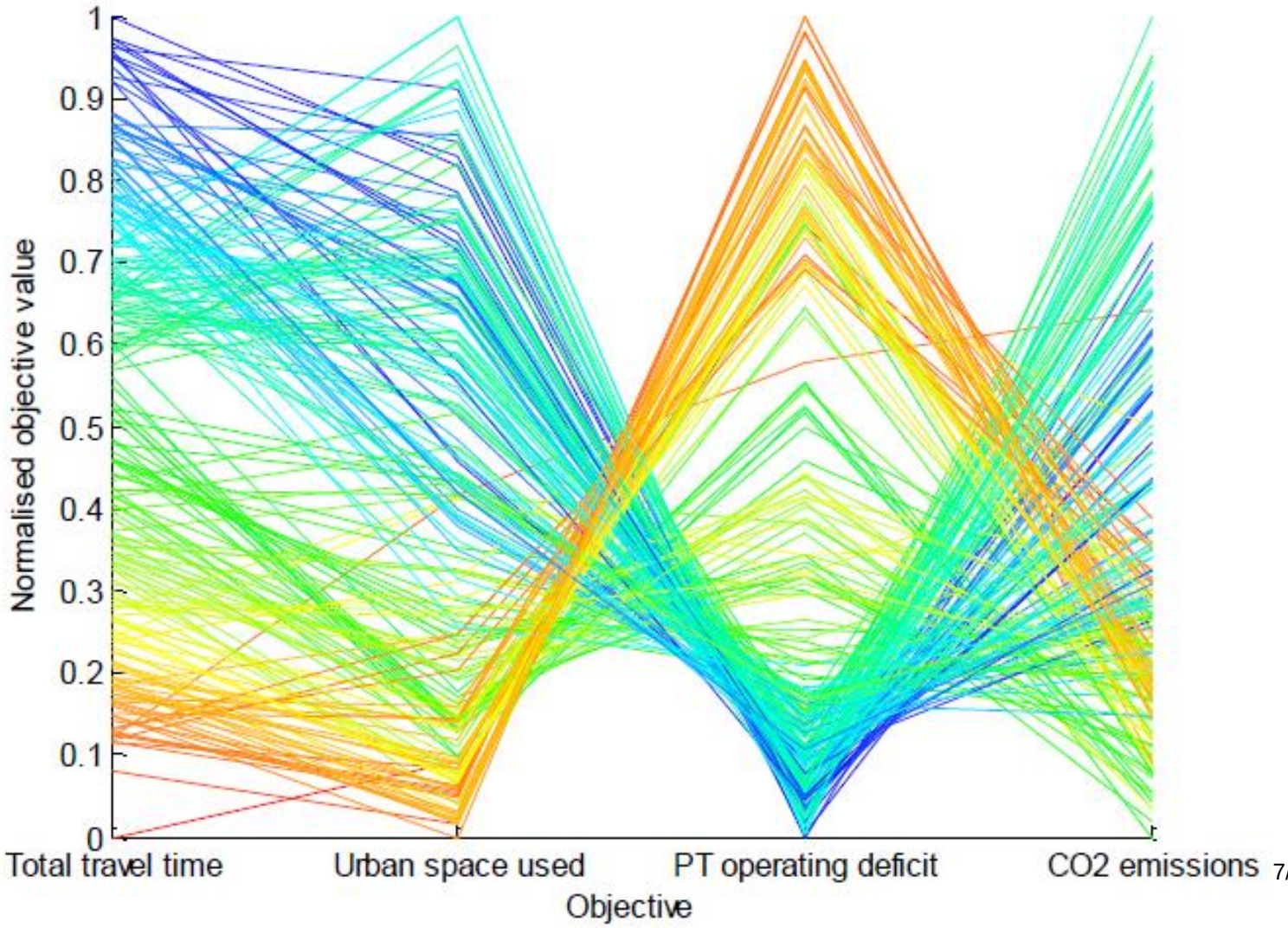


Step 2

Visualisation of the Pareto set: scatter plot



Visualisation of the Pareto set: parallel coordinate plot

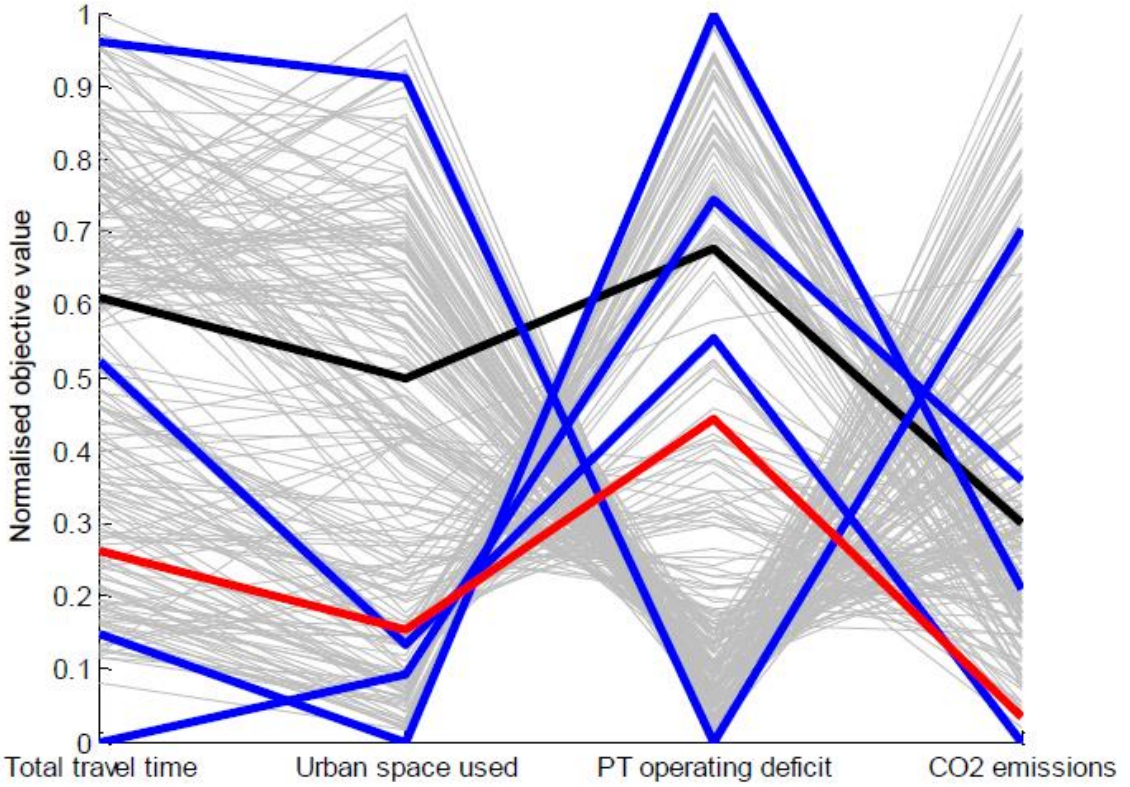


Best value per objective

Black: base situation

Blue: individually optimal solutions

Red: best simultaneous improvement for all four objectives: 0.4% w.r.t. base



Base situation	250007	68720	-36594	1352
Minimum	248034	67659	-56203	1346
Improvement w.r.t. base	-0.79%	-1.54%	-6.19%	-0.45%

Resolution of measures

- Selected measures all related to multimodal trip making
- Small relative improvements, but considerable absolute improvements
- Every AM peak
  - 4000 hours of travel time
  - 2000 parked cars
  - 12 tons of CO_2 emissions
    - Equivalent to the daily direct CO_2 emissions of 500 Dutch households

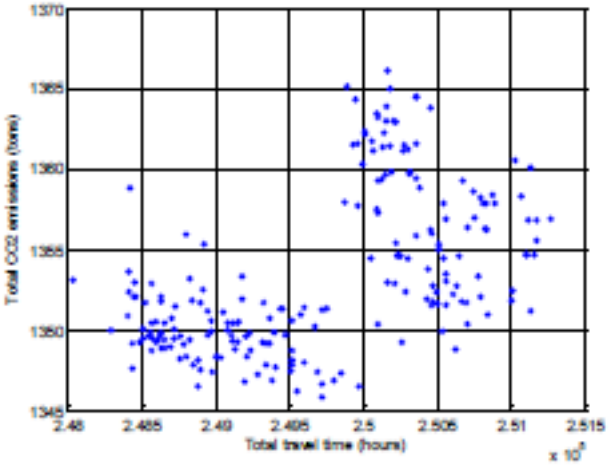
Relations between objectives

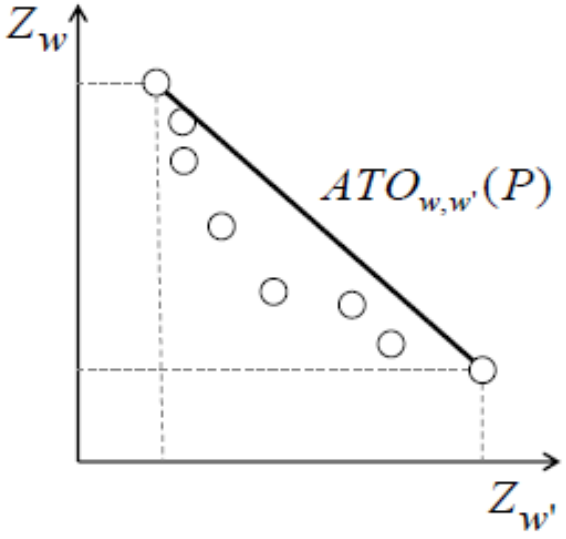
- Correlation between objectives

	TTT	USU	OpD	CE
Total travel time (TTT)	1.00	0.79	-0.87	0.53
Urban space used (USU)	0.79	1.00	-0.87	0.84
Operating deficit (OpD)	-0.87	-0.87	1.00	-0.62
CO_2 emissions (CE)	0.53	0.84	-0.62	1.00

Relations between objectives

- Average trade-off values





$w \setminus w'$	TTT (hours)	USU (# of cars)	OpD (euros)	CE (kilos)
TTT (hours)		-2.44	-0.144	-0.232
USU (# of cars)	-0.411		-0.067	-0.0661
OpD (euros)	-6.94	-14.9		-1.12
CE (kilos)	-4.31	-15.1	-0.89	

Relations between decision variables and objectives

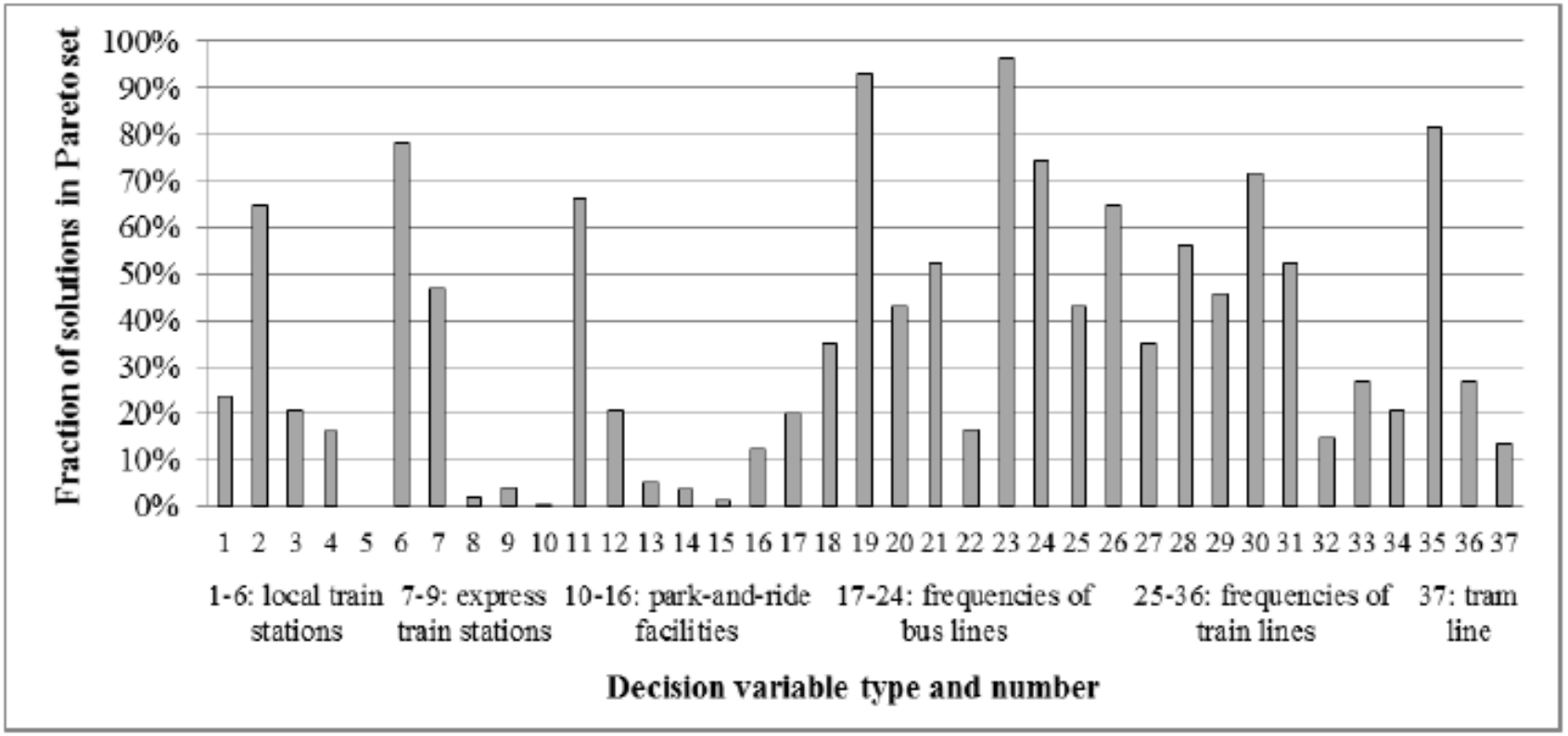
- Correlation between types of decision variables and objectives

	TTT	USU	OpD	CE
Train stations	-0.50	-0.63	0.57	-0.41
Express train stations	0.32	0.23	-0.30	-0.04
P&R facilities	-0.43	-0.36	0.47	-0.16
Bus frequencies	-0.71	-0.80	0.77	-0.57
Train frequencies	-0.85	-0.93	0.96	-0.78

- Correlation between types of decision variables

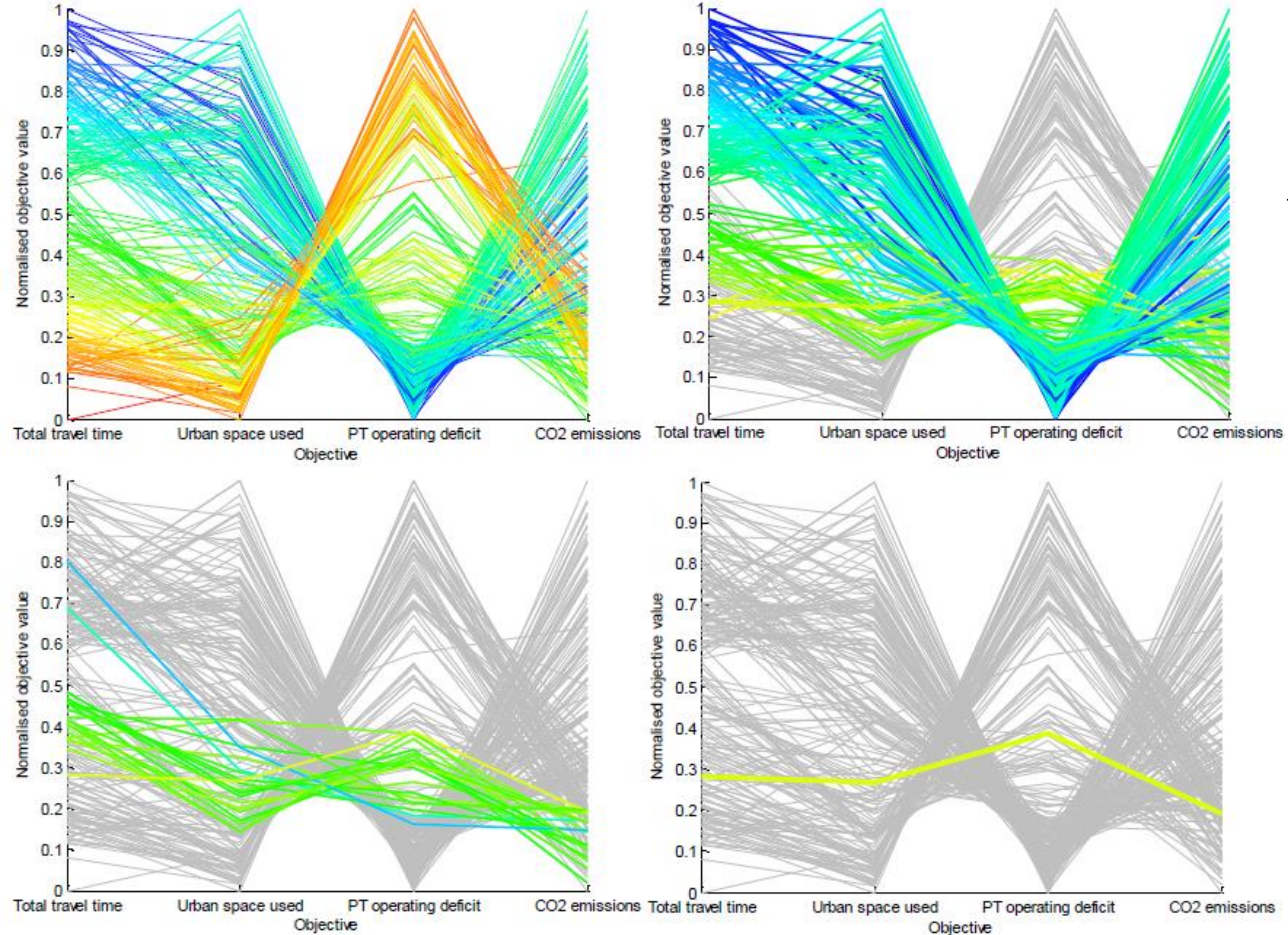
	Train stations	Express train stations	P&R facilities	Bus frequencies	Train frequencies
Train stations	1.00	-0.12	0.25	0.52	0.55
Express train stations	-0.12	1.00	-0.19	-0.21	-0.25
P&R facilities	0.25	-0.19	1.00	0.30	0.42
Bus frequencies	0.52	-0.21	0.30	1.00	0.73
Train frequencies	0.55	-0.25	0.42	0.73	1.00

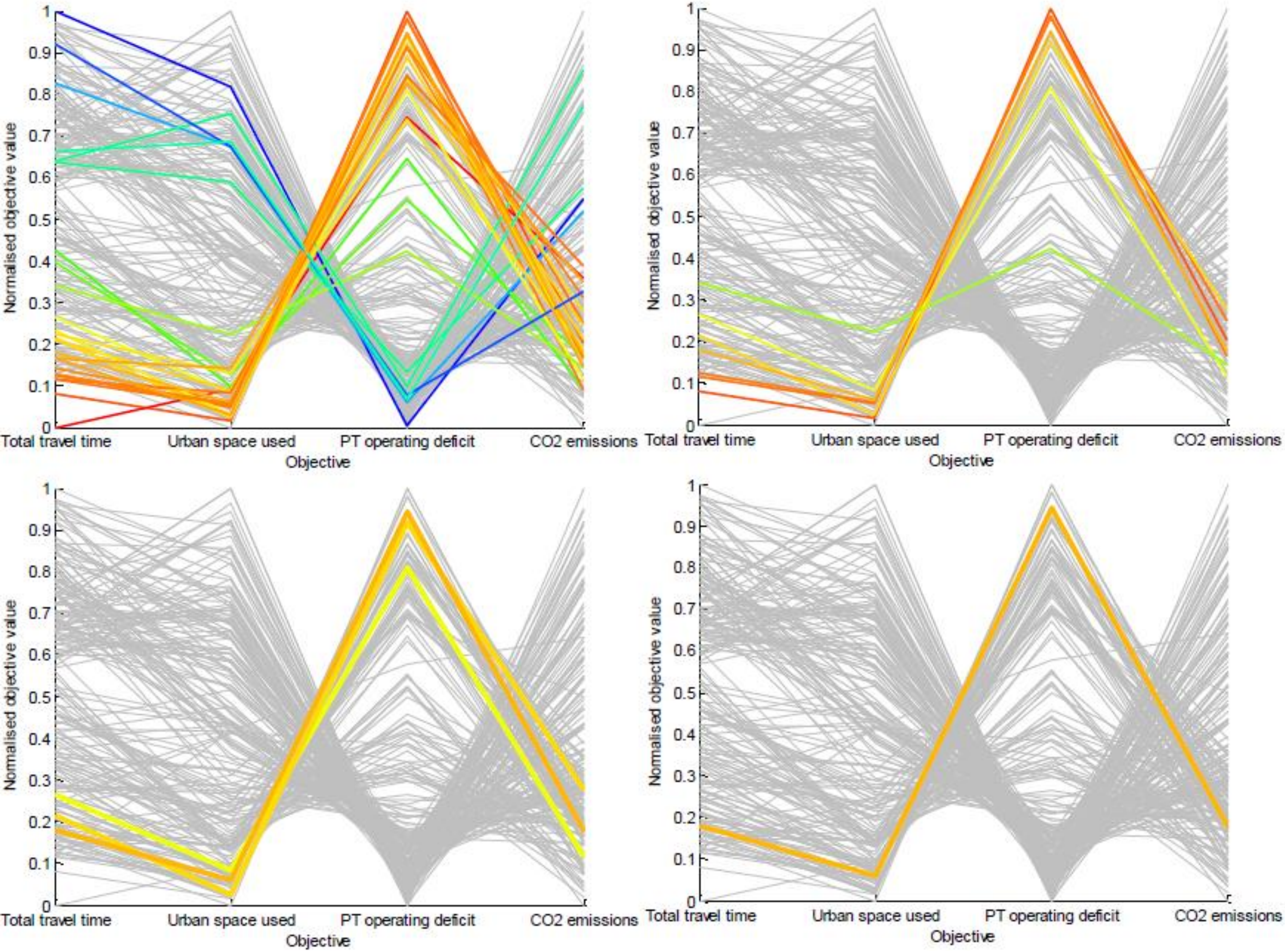
Percentage of active decision variables in Pareto set



Step-by-step pruning

- A post-optimisation method to reduce the number of solutions in the Pareto set step-by-step to come to a final solution for implementation
- Method is based on interviews with policy officers in The Netherlands
- Putting additional constraints to objective values
- Fixing certain decision variables, i.e. choosing a certain measure
  - Often political desires exist that are not included in the objective values


Normalised objective value
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Total travel time
Urban space used
PT operating deficit
CO2 emissions
Objective


Normalised objective value
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Total travel time
Urban space used
PT operating deficit
CO2 emissions
Objective

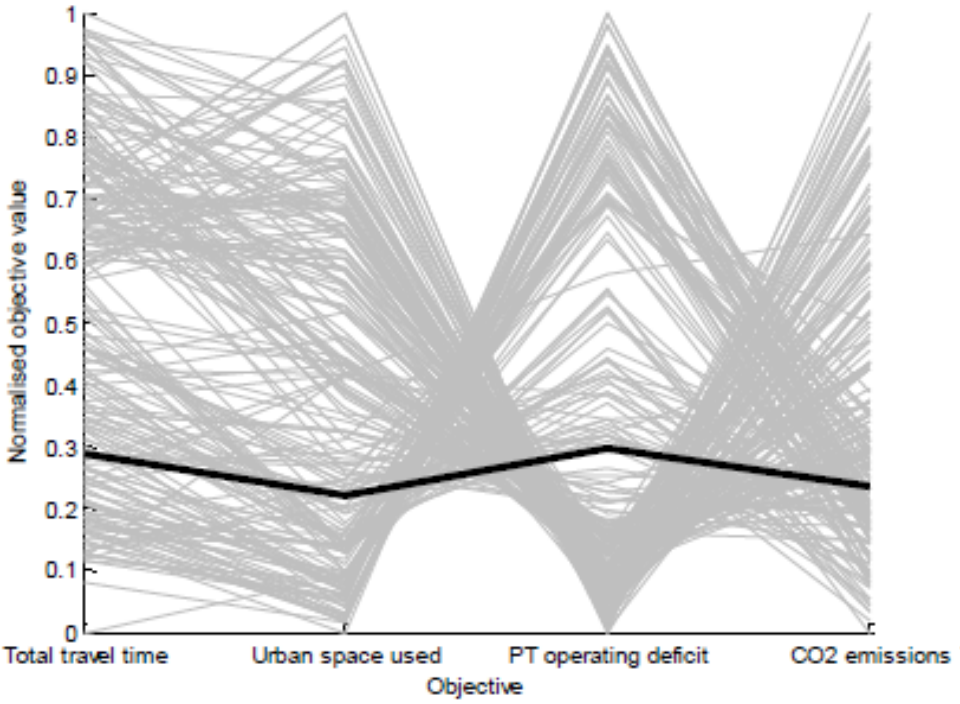
Choosing one solution as a compromise

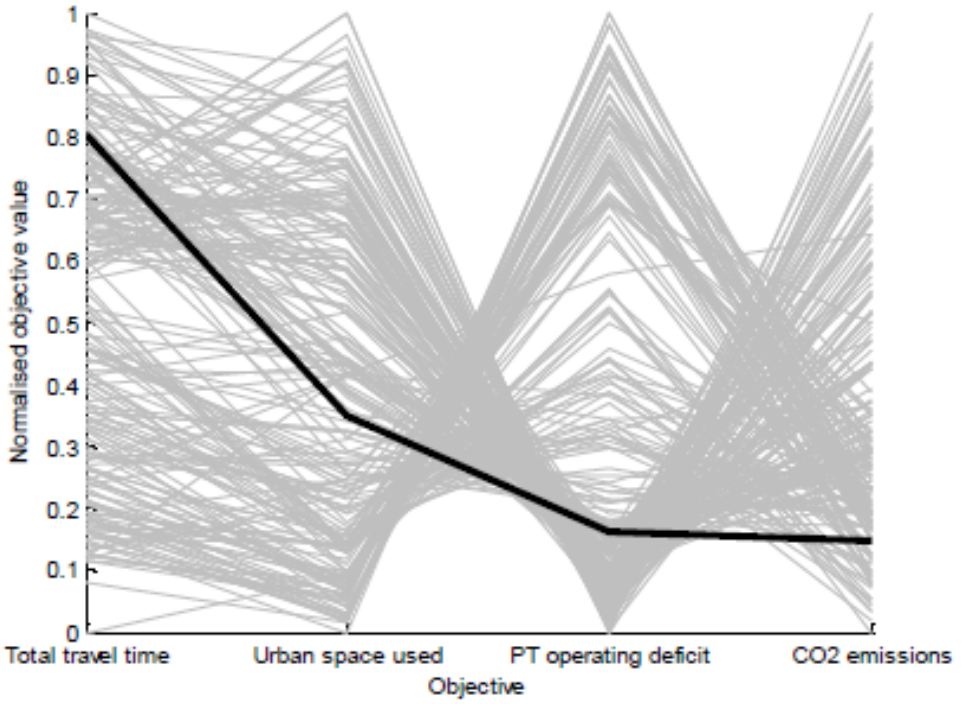
- A post-optimisation method to reduce the number of solutions in the Pareto set step-by-step to come to a final solution for implementation
- Assume each objective represents one political party
- In negotiation, no party will accept a solution with a very bad score
- → the least scoring objective is leading when choosing a compromise solution
- The min-max solution:

$$BCS_{W_C}(P) = \underset{\underline{y} \in P}{\operatorname{argmin}} \left(\max_{w \in W_C} \overline{Z}_w(\underline{y}) \right)$$

- Objective set W_C may contain all objectives, or a subset of objectives

Best compromise solution: min-max solution





Conclusions

- Methodology development
  - The Pareto set enables an interactive process to demonstrate consequences of certain choices directly
  - Trade-offs between objectives are seen as marginal costs, to judge whether additional investments are worthwhile
    - Visualise in scatterplot
  - Step-by-step pruning to come to a final decision
    - Visualise in parallel coordinate plot
  - Min-max solution as best compromise solution
    - Visualise in parallel coordinate plot

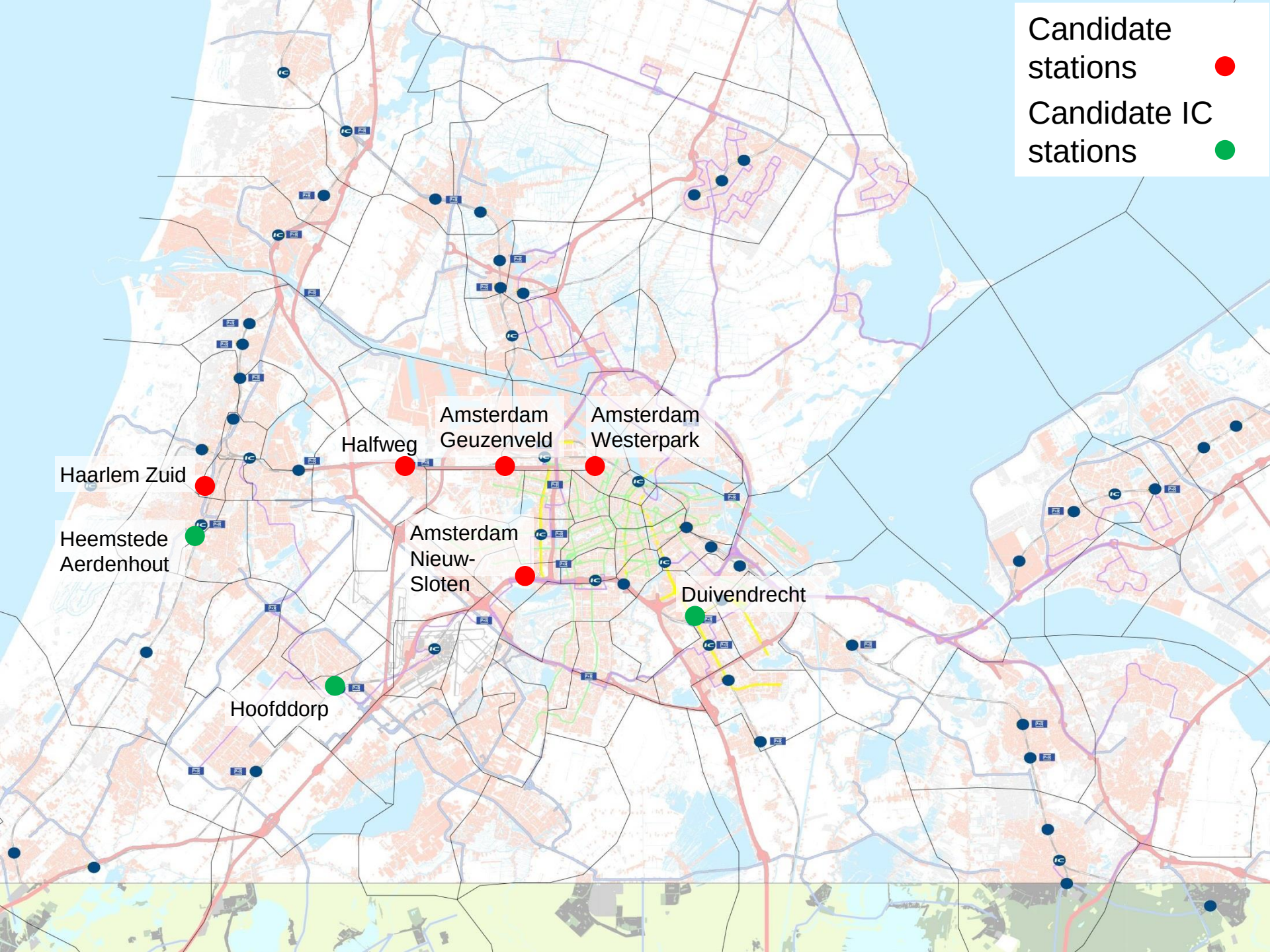
Conclusions

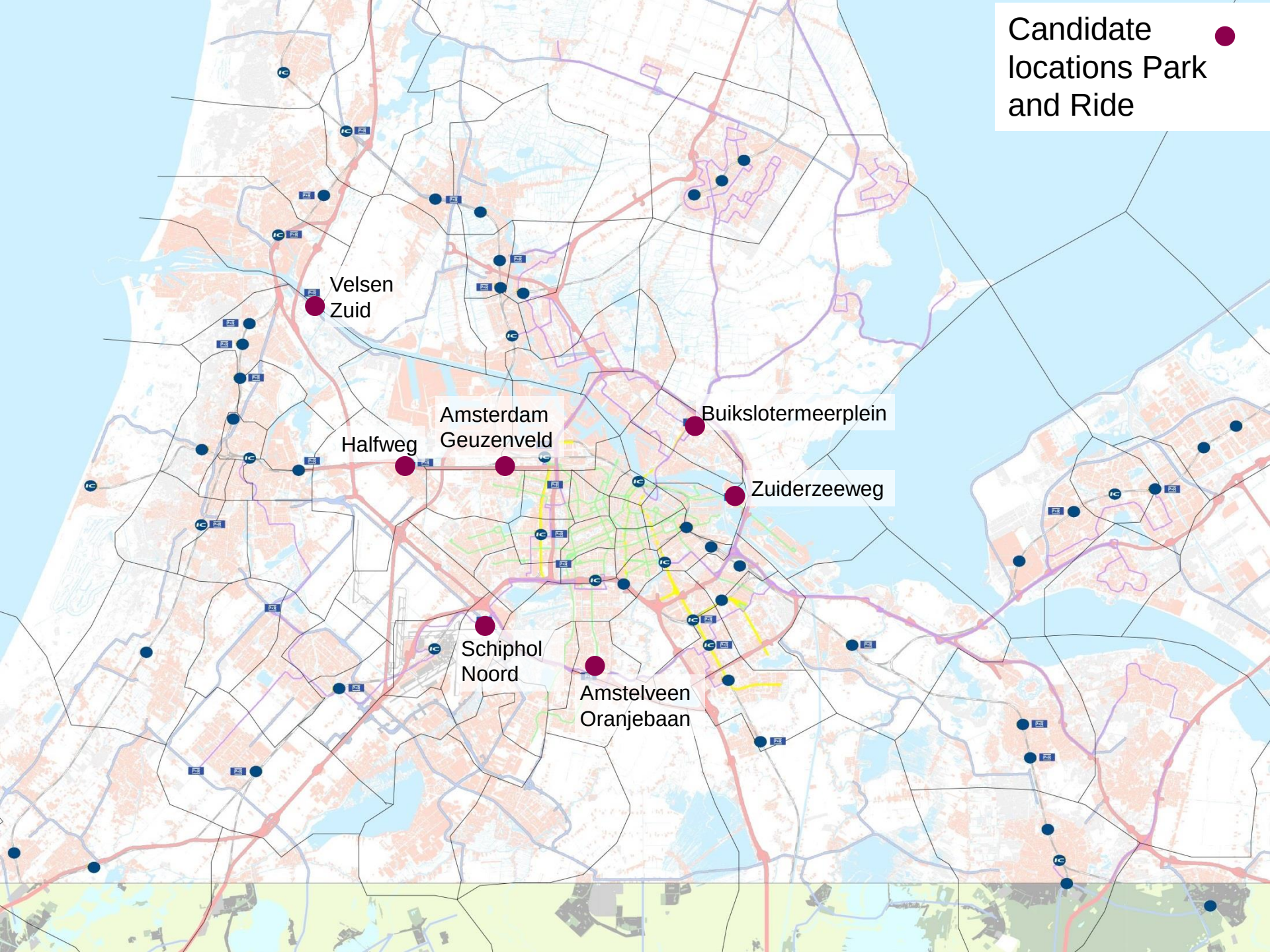
- Multimodal passenger NDP: case study in the Randstad
  - Small relative improvements, but considerable absolute improvements
  - A reduction of 0.4% is possible for all four objectives simultaniously
  - It is possible to satisfy all four objectives simultaneously to a large extent
  - Increasing frequencies in general is more effective than opening new train stations and park-and-ride facilities
  - In the case bus routes are in general complementary to train routes rather than competitive

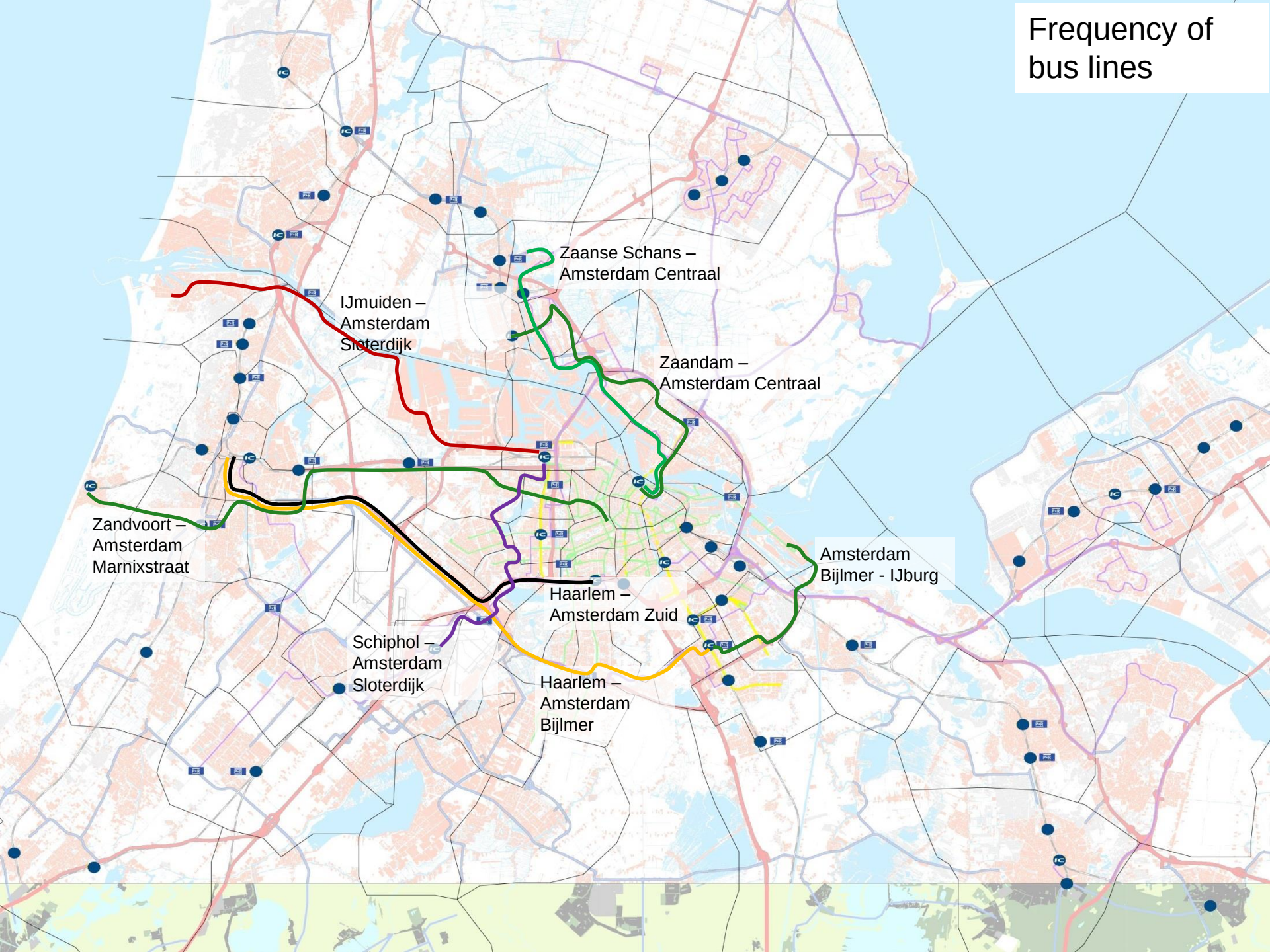
Further information

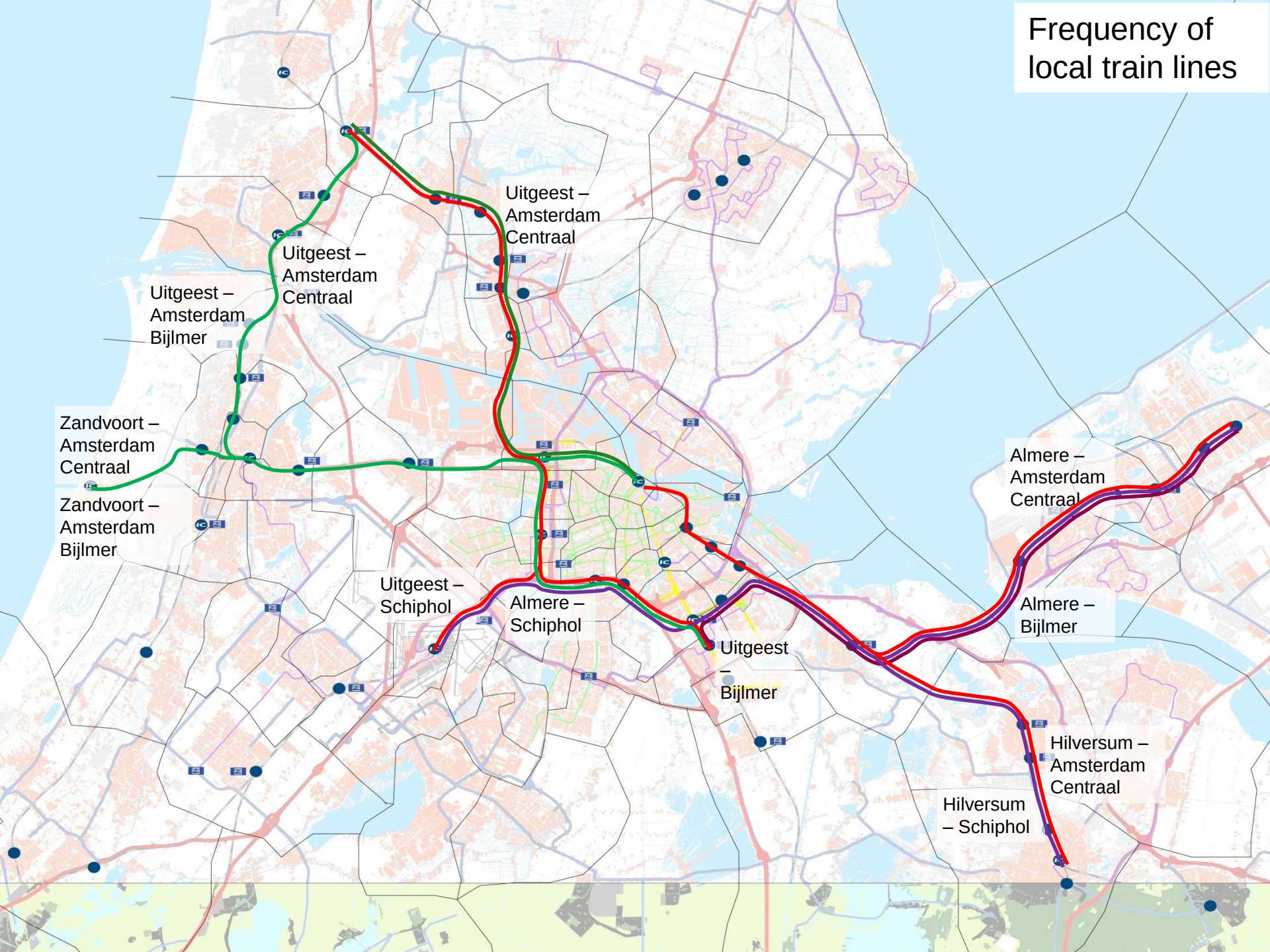
- Full paper included in conference proceedings
- Public defense at University of Twente: 15th of October, 14:45 PM
- Contact information tbrands@goudappel.nl

- Funding:
  - NWO (The Netherlands Organisation for Scientific Research)
  - program Sustainable Accessibility of the Randstad (SAR / DBR)
  - project Sustainable and Reliable Multimodal Transportation networks (SRMT)
  - See http://dbr.verdus.nl/pagina.asp?id=717


Candidate stations
Candidate IC stations
Amsterdam Geuzenveld
Amsterdam Westerpark
Halfweg
Haarlem Zuid
Heemstede Aerdenhout
Amsterdam Nieuw-Sloten
Duivendrecht
Hoofddorp


Candidate locations Park and Ride
Velsen Zuid
Amsterdam Geuzenveld
Halfweg
Buikslotermeerplein
Zuiderzeeweg
Schiphol Noord
Amstelveen Oranjebaan


Frequency of bus lines
Zaanse Schans – Amsterdam Centraal
IJmuiden – Amsterdam Sloterdijk
Zaandam – Amsterdam Centraal
Zandvoort – Amsterdam Marnixstraat
Amsterdam Bijlmer - IJburg
Haarlem – Amsterdam Zuid
Schiphol – Amsterdam Sloterdijk
Haarlem – Amsterdam Bijlmer


Frequency of local train lines
Uitgeest – Amsterdam Centraal
Uitgeest – Amsterdam Centraal
Uitgeest – Amsterdam Bijlmer
Zandvoort – Amsterdam Centraal
Zandvoort – Amsterdam Bijlmer
Uitgeest – Schiphol
Almere – Schiphol
Uitgeest – Bijlmer
Almere – Amsterdam Centraal
Almere – Bijlmer
Hilversum – Amsterdam Centraal
Hilversum – Schiphol

Decision variable type	*Decision variable*	*Decision variable name*	*Real value in base solution*
Opening / closure of train station	y_1	Halfweg-Zwanenburg	1
	y_2	Haarlem Zuid	0
	y_3	Amsterdam Geuzenveld	0
	y_4	Amsterdam Nieuw Sloten direction East	0
	y_5	Amsterdam Nieuw Sloten direction North	0
	y_6	Amsterdam Westerpark	0
Express train status of train station	y_7	Hoofddorp	0
	y_8	Duivendrecht	1
	y_9	Heemstede-Aardenhout	1
Opening / closure of P&R facility	y_{10}	Train station Halfweg-Zwanenburg	0
	y_{11}	Velsen South	0
	y_{12}	Amsterdam, Zuiderzeeweg	0
	y_{13}	Train station Geuzenveld	0
	y_{14}	Amsterdam, Buiksloternneerplein	0
	y_{15}	Amstelveen, Oranjebaan	0
	y_{16}	Schiphol North	0
Frequency of bus line	y_{17}	Haarlem - Amsterdam South	8
	y_{18}	Haarlem - Amsterdam Bijlmer	4
	y_{19}	IJmuiden - Amsterdam Sloterdijk	2
	y_{20}	Zandvoort - Amsterdam Marnixstraat	2
	y_{21}	Zaanse Schans - Amsterdam Centraal	8
	y_{22}	Zaandam - Amsterdam Centraal	8
	y_{23}	Schiphol - Amsterdam Sloterdijk	0
	y_{24}	Amsterdam Bijlmer – Ijburg	8
Frequency of local train line	y_{25}	Uitgeest - Amsterdam Centraal	2
	y_{26}	Uitgeest - Schiphol - Hoofddorp	0
	y_{27}	Uitgeest - Zaandam - Zuid - Bijlmer	0
	y_{28}	Zandvoort - Haarlem - Zuid - Bijlmer	0
	y_{29}	Uitgeest - Haarlem - Zuid - Bijlmer	0
	y_{30}	Zandvoort - Haarlem - Centraal	2
	y_{31}	Uitgeest - Haarlem – Centraal	2
	y_{32}	Amsterdam Centraal - Almere Oostvaarders	2
	y_{33}	Hoofddorp - Almere Oostvaarders	4
	y_{34}	Bijlmer - Almere Oostvaarders	0
	y_{35}	Utrecht - Hilversum - Amsterdam Centraal	4
	y_{36}	Utrecht - Hilversum - Hoofddorp	2
Extension of a tram line	y_{37}	Amsterdam Geuzenveld	0