UNIVERSITY OF TWENTE.

Public Transport in the era of MaaS

dr. Konstantinos Gkiotsalitis
Center for Transport Studies

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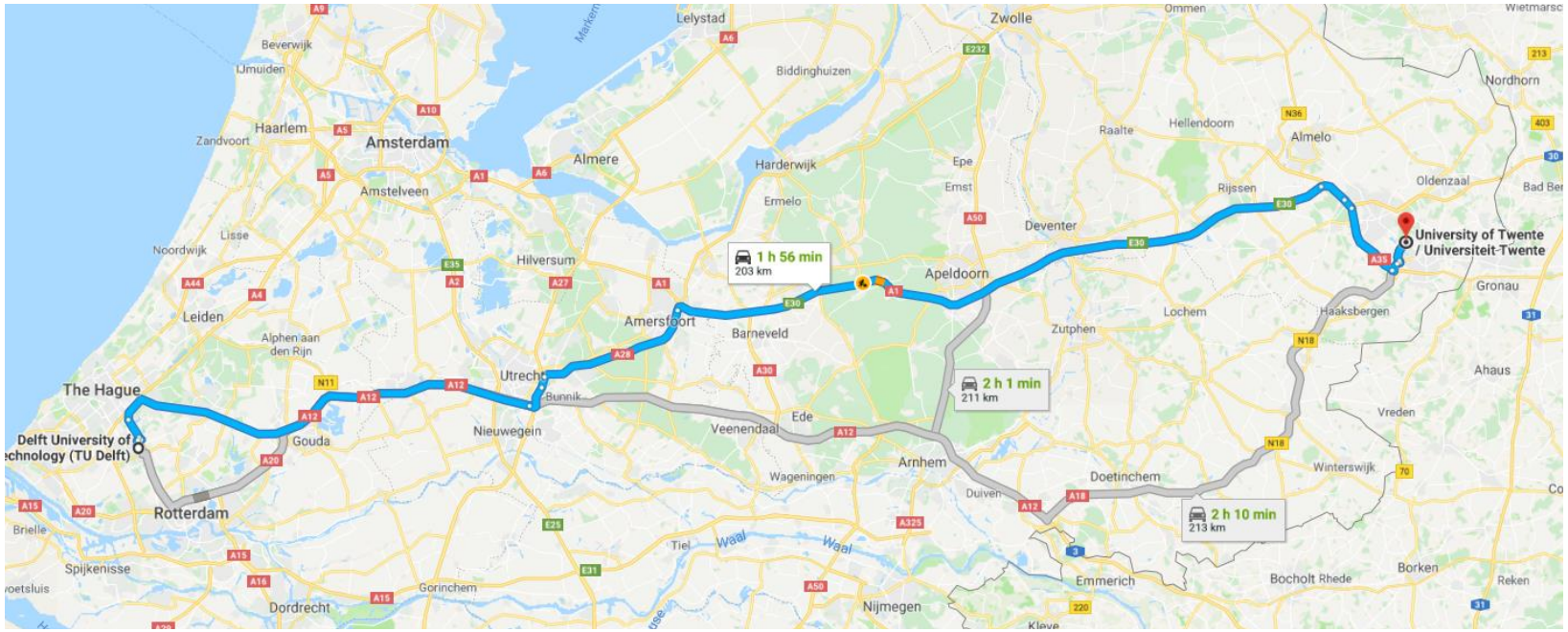
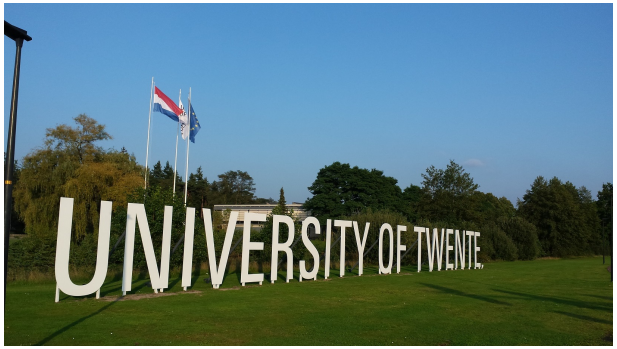
- Collaborates with **Delft University** of Technology, **Eindhoven University** of Technology and the **Wageningen University** and Research Centre under the umbrella of **4TU**.

Location


Lelystad
Zwolle
Beverwijk
IJmuiden
Haarlem
Zandvoort
Amsterdam
Amstelveen
Almere
Biddinghuizen
Harderwijk
Ermelo
Epe
Emst
Raalte
Hellendoorn
Almelo
Nordhorn
Oldenzaal
Rijssen
Deventer
Apeldoorn
Lisse
Noordwijk
Leiden
Alphen aan den Rijn
Hilversum
Amersfoort
Barneveld
Utrecht
Bunnik
Nieuwegein
Gouda
The Hague
Delft University of Technology (TU Delft)
Rotterdam
Brielle
Spijkenisse
Dordrecht
Gorinchem
Tiel
Waal
Wageningen
Ede
Veenendaal
Arnhem
Duiven
Nijmegen
Zutphen
Lochem
Haaksbergen
Gronau
Ahaus
Vreden
Winterswijk
Doetinchem
Emmerich
Bocholt Rhede
Borken
Reken
University of Twente / Universiteit Twente
1 h 56 min
203 km
2 h 1 min
211 km
2 h 10 min
213 km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UT Center for Transport Studies

PROFESSORS

prof.dr.ir. E.C. van Berkum (Eric)
Professor and Head of CTS

prof.dr.ing. K.T. Geurs (Karst)
Professor Transport Planning

prof.dr. M.H. Martens (Marieke)
Professor ITS & Human Factors

Structure

- Faculty of Engineering Technology
  - Department of Civil Engineering
    - **Center for Transport Studies**

My role at UT

Education

- **Public Transport Modelling** (course leader)
- **Traffic Operations** (course leader)
- Network Modelling (lecturer)
- Mathematical Optimization (lecturer)

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Research

- Public Transport Planning (tactical and operational level)
- Demand Prediction with new data forms (social media, cellular data)
- Traffic Operations (esp. connected vehicles)

Before that...

Research Associate - Research Scientist

PT Customers: Singapore, Tokyo, Hong Kong, India, Santiago

NEC

Laboratories Europe
Intelligent Transport Systems
Data Science Applications
2012-2018

11 FP7/H2020 Proposals

8 Filed Patents

3 Technology Transfers

TEAM Tomorrow's Elastic Adaptive Mobility

smartCEM

eCoMove Cooperative Mobility Systems and Services for Energy Efficiency

MOBINET Internet of mobility

COREALIS THE PORT OF THE FUTURE

Differences in New Life...

Business Forces

Area	Business Model	Impact
Singapore, London, Hong Kong	Almost every year another set of bus lines is open for bidding	Strong competition on improving operational KPIs and upgrading ICT
Twente (mostly in the Netherlands)	winner-takes-it-all contract for ∼10yrs	1. PTOs want to identify & terminate non-profitable lines 2. Market share is challenged from mobility start-ups

Biggest PTO problems

Make a guess...

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Biggest PTO problems

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- Bus drivers call in sick (rate way above the national average)
- Demand changes over the years and some lines are not profitable
- Passengers tap off some stops before arriving at their destination. Why?
- Fear or losing market share from mobility start-ups
- These are real problems. Well, if we ask UITP we will see adopting AI and other trends as No1 issue

Mid-term Research Area

Top-down Planning of MaaS / Seamless integration with PT

Now

- PTO terminates bus line services with low demand (mostly periurban) areas
- ”Old” buses are provided to volunteers who can facilitate those lines at will

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Future

- PTO uses more flexible schemes (interlining, short-turning) to reduce the number of terminated services
- unprofitable services are substituted from PTO-driven MaaS with a guaranteed regularity and fare price (i.e., KEO-bike)

Research Challenges

- Flexible Bus Planning
- Determination of (persistently) unprofitable lines
- Top-down MaaS modelling and service take-up (gamification, incentives, accessibility studies [H2020])

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Lines of Research

- Large-scale Optimization, Operational Research
- Demand Prediction
- Accessibility and Behavioral Analysis

H2020 Calls

- H2020 MG-4-5-2019: An inclusive digitally interconnected transport system meeting citizens' needs (1 stage, April 25th 2019)
- LC-MG-1-2-2018: Spatial planning implications of Regional multimodal Mobility Innovations in Europe
- Netherlands Organisation for Scientific Research (NWO)?

Selected Recent Research

Public Transport (2018)

- K.Gkiotsalitis, N.Maslekar (2018). Towards transfer synchronization of regularity-based bus operations with sequential hill-climbing, **Public Transport** 10(2), 335-361.
- K.Gkiotsalitis, O.Cats (2018). Reliable frequency determination: Incorporating information on service uncertainty when setting dispatching headways, **TR Part C: Emerging Technologies**, 88, 187-207.
- K.Gkiotsalitis, O.Cats (2018). A cost minimization model for bus fleet allocation incorporating the generation of short-turning and interlining options, **TR Part C: Emerging Technologies**, 2nd stage review.
- K.Gkiotsalitis, N.Maslekar (2018). Multiconstrained timetable optimization and performance evaluation in the presence of travel time noise, **ASCE Journal of Transp. Engineering Part A Systems**, 144(9), 04018058.

Demand Prediction

- K.Gkiotsalitis, A.Stathopoulos (2016). Joint leisure travel optimization with user-generated data via perceived utility maximization, **TR Part C: Emerging Technologies**, 68, 532-548.
- K.Gkiotsalitis, A.Stathopoulos (2015). A utility-maximization model for retrieving users' willingness to travel for participating in activities from big-data, **TR Part C: Emerging Technologies**, 58, 265-277.
- K.Gkiotsalitis, A.Stathopoulos (2016). Demand-responsive public transportation rescheduling for adjusting to the joint leisure activity demand, **International Journal of Transportation Science and Technology**, 5(2), 68-82.

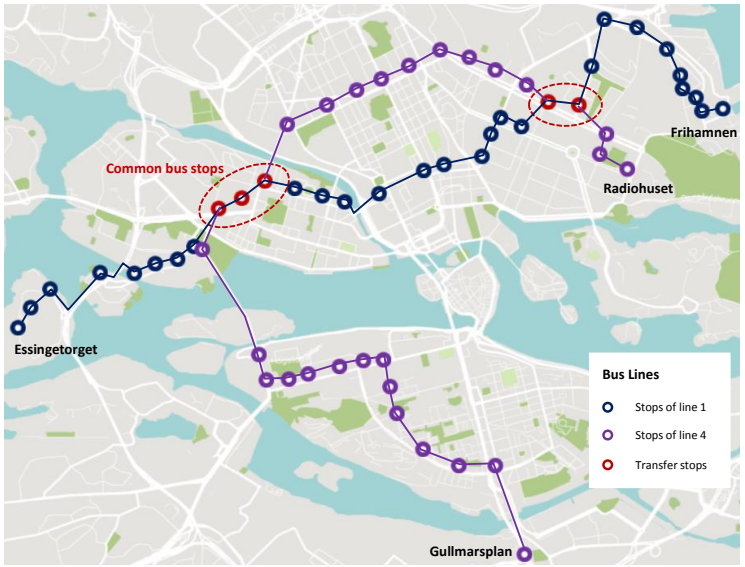
Traffic Theory

- AHF Chow, Y. Li, K.Gkiotsalitis (2015). Specifications of Fundamental Diagrams for dynamic traffic modeling, **ASCE Journal of Transportation Engineering**, 141(9), 04015015.

Ongoing Research

TECHNICAL TOPIC: Robust Network-wide synchronized scheduling of public transport services

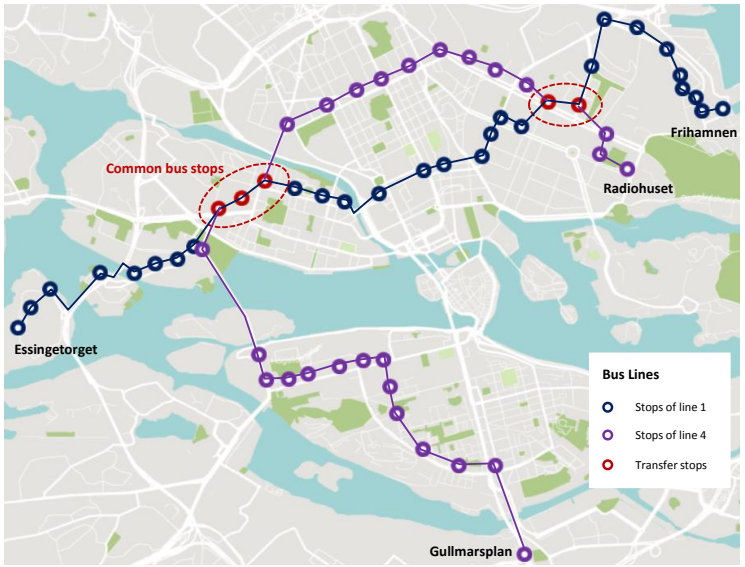
Objective of this work



*Bus lines **1** and **4** in Stockholm with **5** transfer stops*

Solving the **multi-line synchronization** problem of bus services at the **tactical planning** stage considering:

Objective of this work



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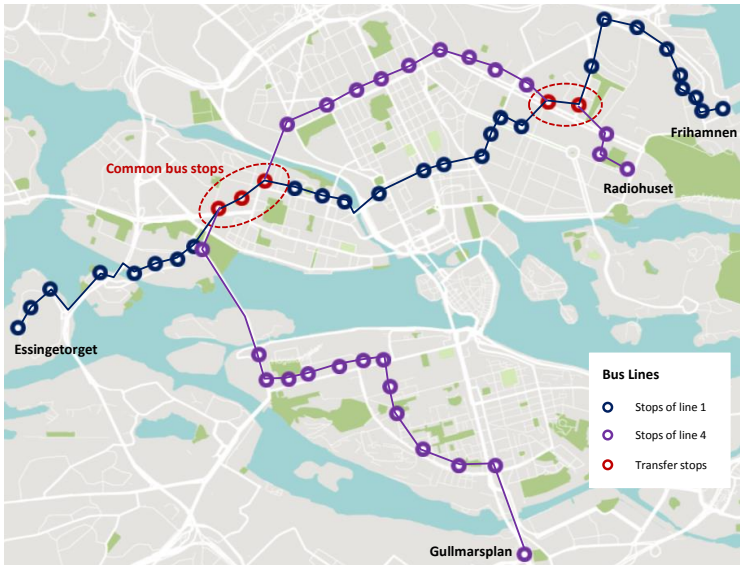

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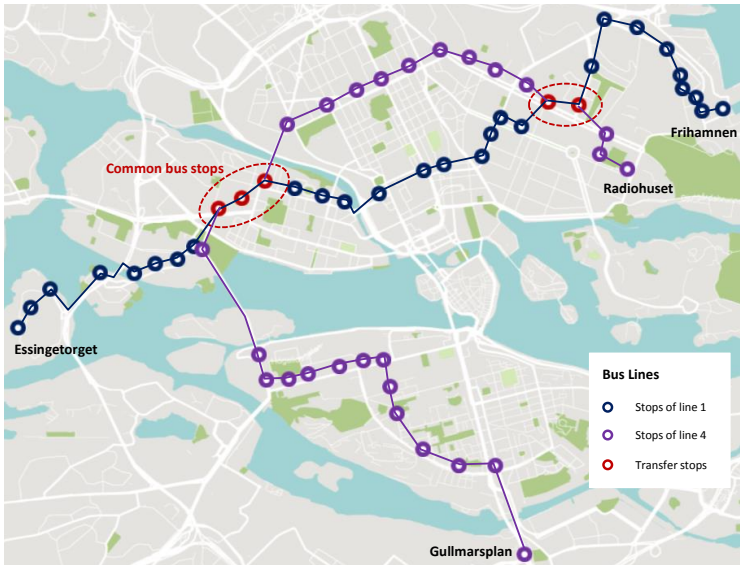

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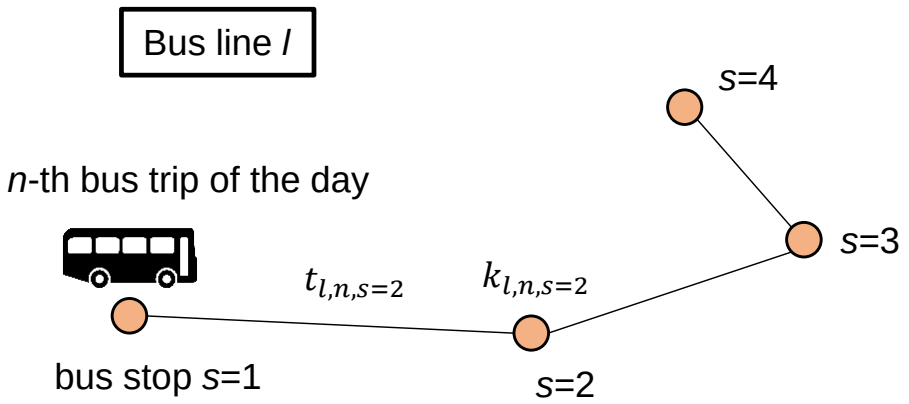
Solving the **multi-line synchronization** problem of bus services at the **tactical planning** stage considering:

- the **variability** of the travel and dwell times of bus trips;
- the **regularity** of individual bus lines;
- and the operational **regulatory constraints** related to the schedule sliding prevention; and the layover time limits.

Bus Movement in the presence of uncertainty



Which is the **arrival time** of bus trip n at stop s if it is dispatched at time $x_{l,n}$?

It is given by: $$a_{l,n,s} = x_{l,n} + \sum_{z=2}^{s} (t_{l,n,z} + \xi_{l,n,z}) + \sum_{z=1}^{s-1} (k_{l,n,z} + \zeta_{l,n,z}) \quad (1)$$

Mathematical Program of the Network-wide Synchronization

Objective: Improve Regularity of individual services (solution that performs best at its worst-case noise scenario)

Constraints: Transfer Synchronization; Avoid Schedule Sliding

Decision Variables: Dispatching times of all bus trips

$$(Q): \quad \min_{x} \max_{\xi,\zeta} \quad f(x,\xi,\zeta) \tag{2}$$

$$\text{s.t.:} \quad x \in \mathcal{F}(\xi,\zeta) = \left\{ \; x \;\middle|\; x \text{ satisfies the constraints} \; \right\} \tag{3}$$

$$x_{l,1} = \delta_l^{min} \;, \quad \forall l \in L \tag{4}$$

$$\xi_{l,s}^{min} \leq \xi_{l,n,s} \leq \xi_{l,s}^{max} \;, \quad \forall l \in L, \forall n \in N(l), \forall s \in S(l) \setminus \{1\} \tag{5}$$

$$\zeta_{l,s}^{min} \leq \zeta_{l,n,s} \leq \zeta_{l,s}^{max} \;, \quad \forall l \in L, \forall n \in N(l), \forall s \in S(l) \tag{6}$$

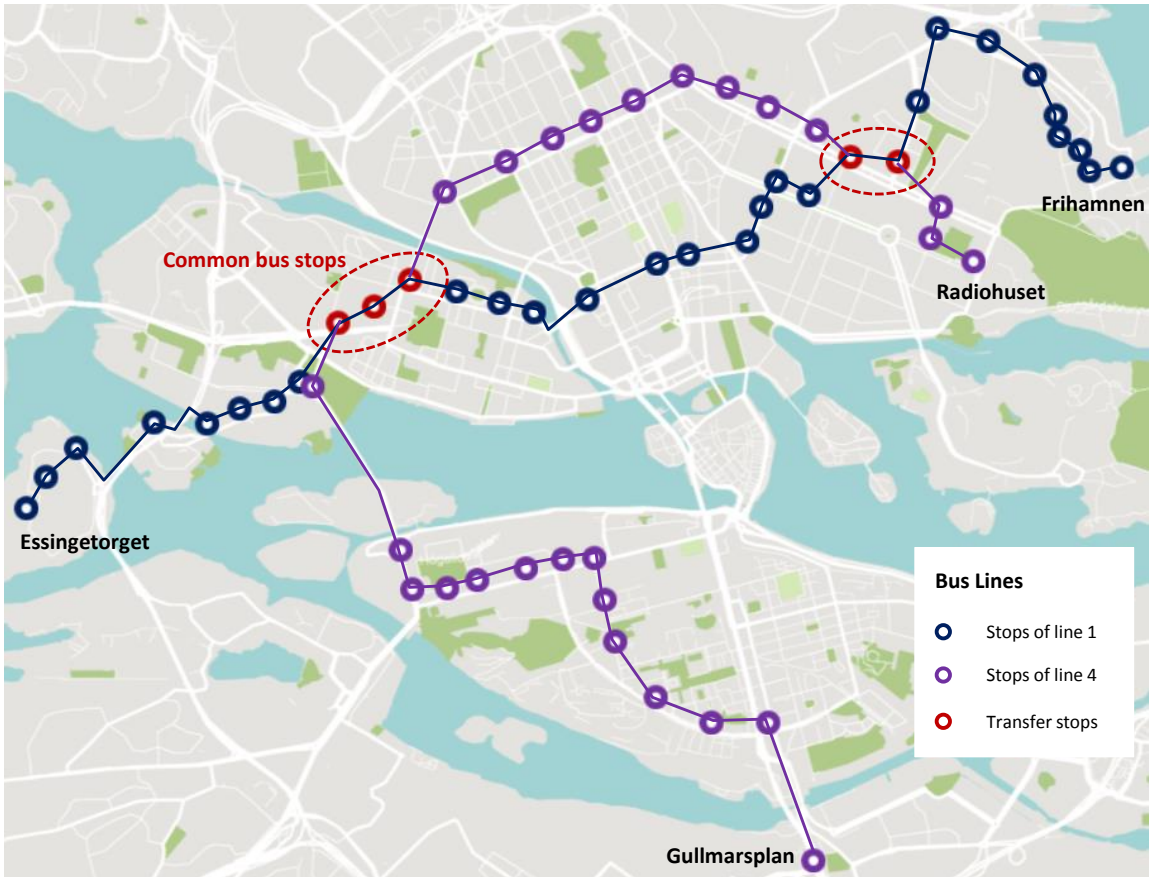
Infeasibility problem

If the travel and dwell times can take any value resulting to extreme-case scenarios there might be **no dispatching time solution** that:

- satisfies the schedule sliding constraints;
- ensures that all trips at transfer stops are synchronized.

We thus introduce a penalty function $\tilde{f}(x, \xi, \zeta)$ that penalizes the objective function $f(x, \xi, \zeta)$ if some constraints are not satisfied.

Case Study


Common bus stops
Frihamnen
Radiohuset
Essingetorget
Gullmarsplan
Bus Lines
Stops of line 1
Stops of line 4
Transfer stops

Indication of Search for a Robust Solution

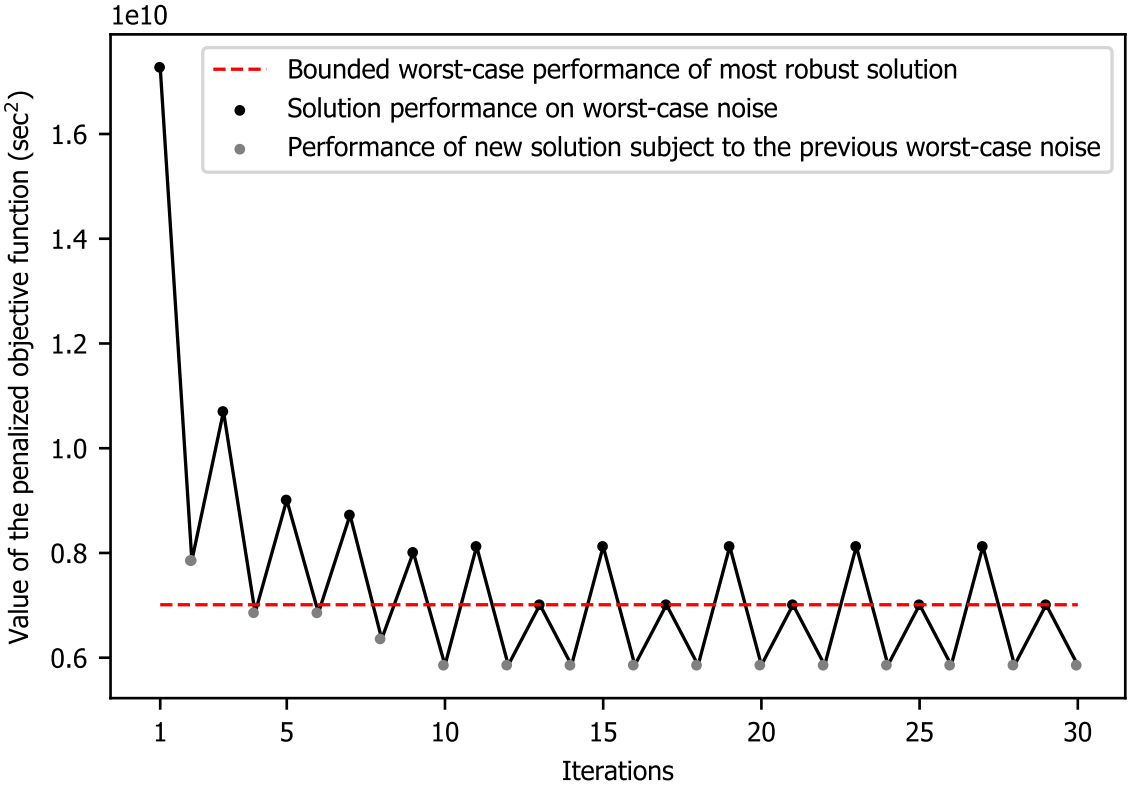


Figure: Convergence of the alternating optimization. The robust solution reduces the worst-case penalized objective function value in worst-case scenarios by ∼60% from $1.727E{+}10$ to $0.701E{+}10$

Main Dilemma

Case 1: Robust synchronization to common-case scenarios (travel time and dwell time deviations of up to 10%) might not be robust enough to extreme cases

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Main Dilemma

Case 1: Robust synchronization to common-case scenarios (travel time and dwell time deviations of up to 10%) might not be robust enough to extreme cases

Case 2: Robust synchronization to extreme scenarios (i.e., travel and dwell time deviations of up to 30% from their expected values) might perform badly during normal days

$\Rightarrow$ find the sweet spot of each case study

Observations using 30 days of data

Average Excessive Waiting Time per passenger (min)	min.	Q_1	median	Q_3	max.	median impr.	max. impr.
Originally Planned Schedule	1.443	1.583	1.626	1.673	1.810	N/A	N/A
Robust to 10% deviations	1.372	1.495	1.542	1.587	1.710	5.17%	5.52%
Robust to 30% deviations	1.442	1.622	1.654	1.661	1.681[1]	-1.72%	7.13%
Average Waiting Time for Transferring Passengers (min)	**min.**	**Q_1**	**median**	**Q_3**	**max.**	**median impr.**	**max. impr.**
Originally Planned Schedule	1.888	2.229	2.381	2.579	2.910	N/A	N/A
Robust to 10% deviations	1.511	1.692	1.710	1.984	2.811	28.18%[2]	3.40%
Robust to 30% deviations	1.819	2.231	2.403	2.468	2.581	-0.92%	11.31%[3]

[1] service regularity will remain very close to the median value in extreme cases when using an ”overprotective” timetable

[2] extremely strong improvement of the median of the waiting times of transferring passengers when planning for 10% deviations

[3] waiting times of transferring passengers will remain very close to the median value in extreme cases when using an ”overprotective” timetable (the same improvement was only 3.40% when planning for 10% deviations)

Ongoing Research

TECHNICAL TOPIC: Bus fleet allocation incorporating the generation of short-turning and interlining options

Low Bus Occupancy problem

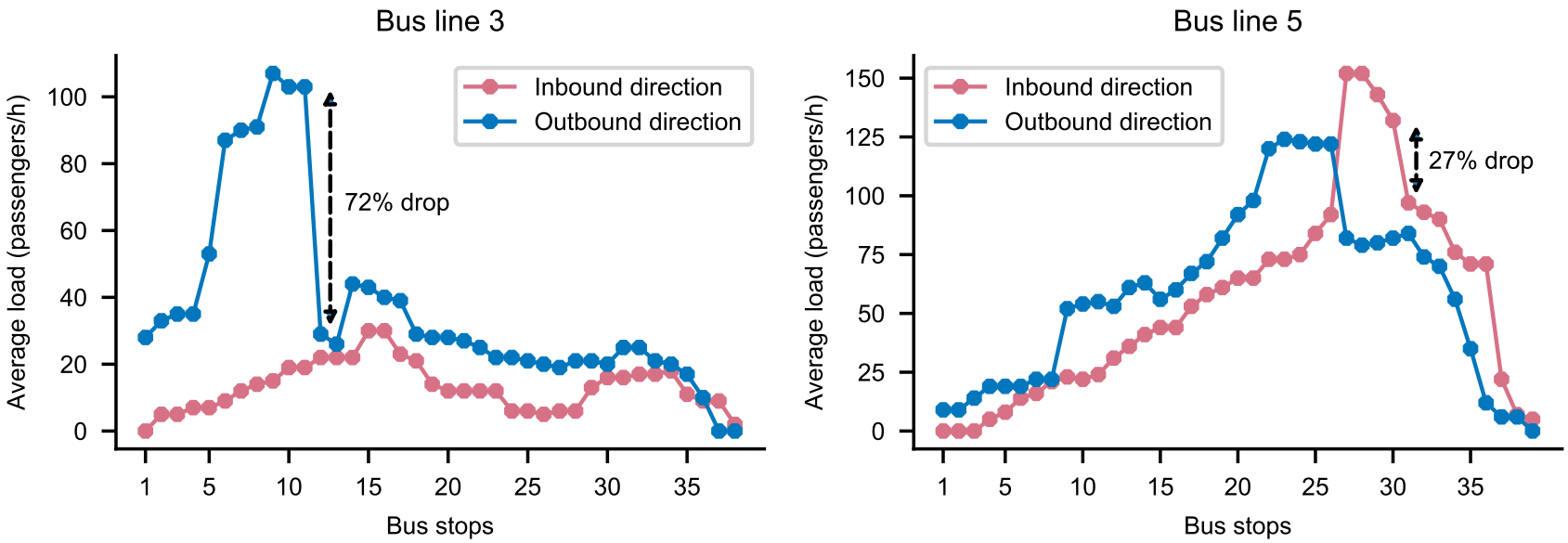


Figure: Average bus-load per bus stop for bus line 3 and bus line 5 in The Hague from 4 pm to 5 pm

Rule-based split of original lines

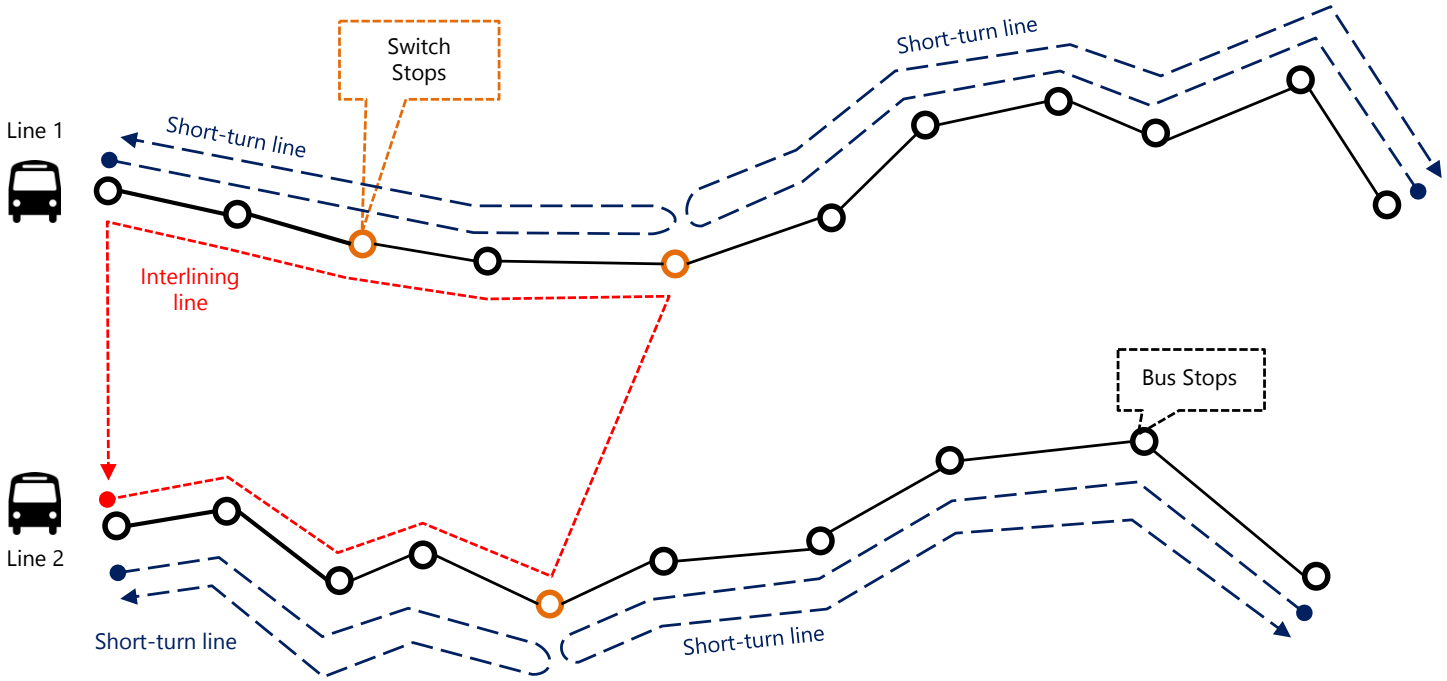
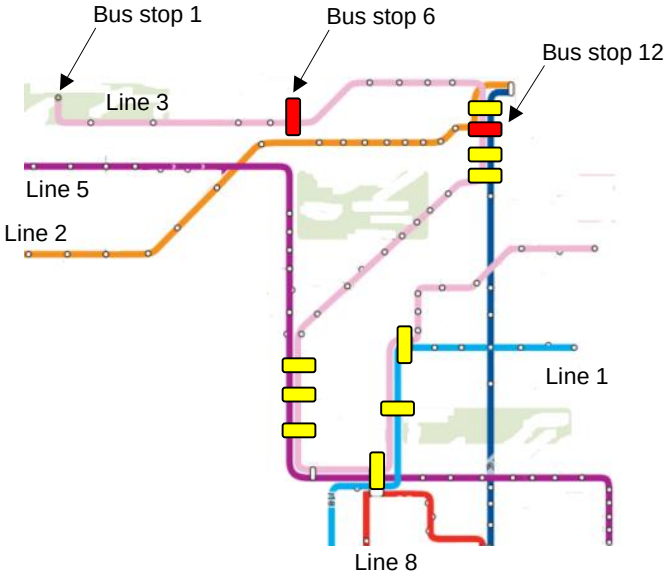


Figure: Potential generation of short-turning lines (blue dashed) or interlining lines (red) at specific switch stops (orange)

Rule-based split of original lines



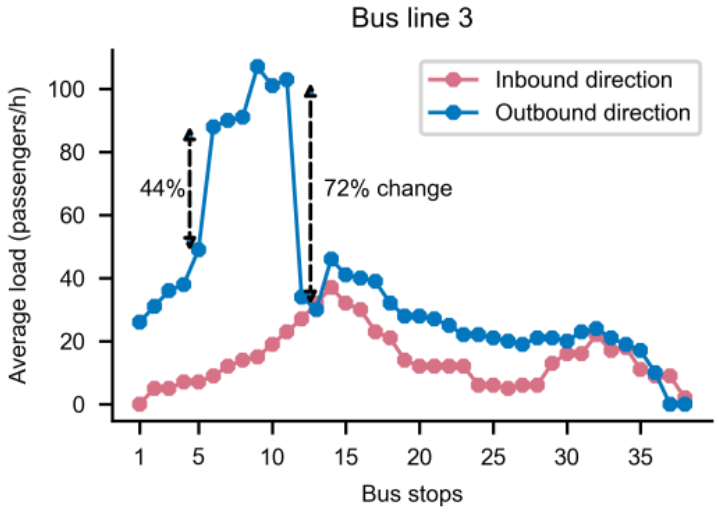


Figure: Example of rule-based generation of all possible switch stops for bus line 3 in Den Haag

Example of Implementation in Den Haag

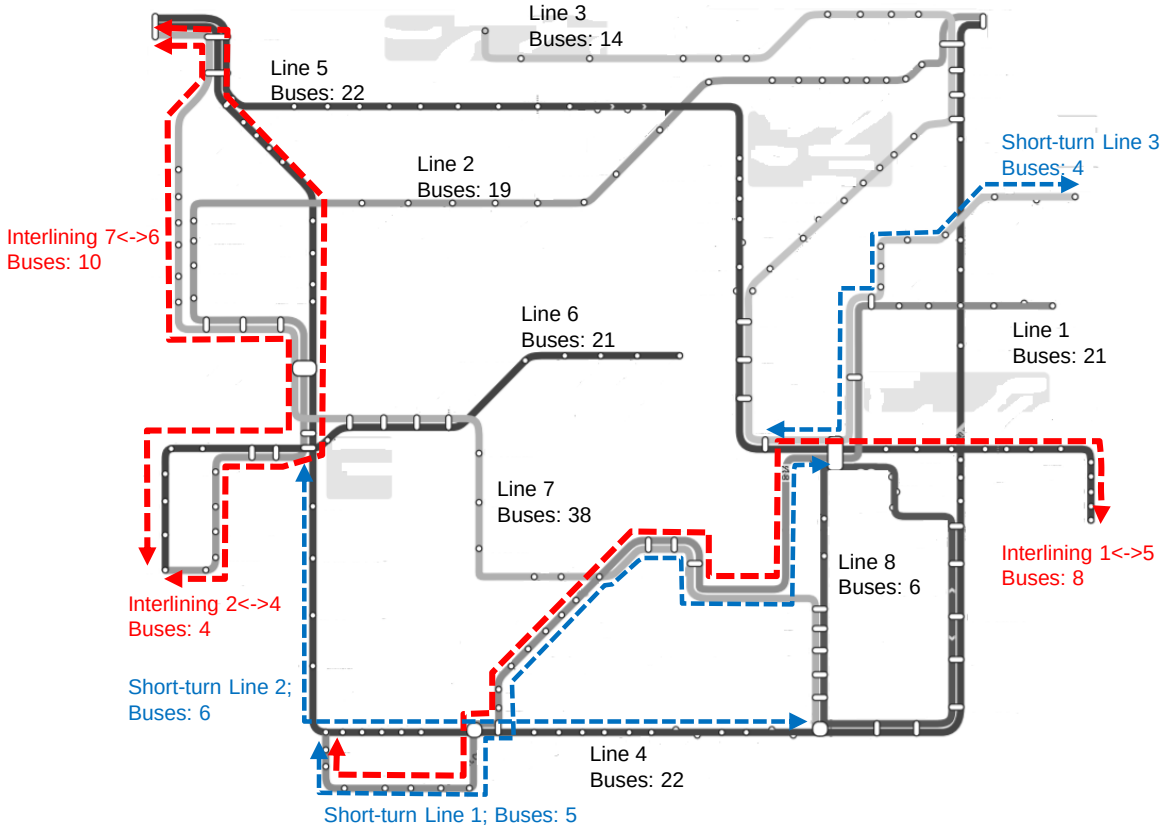


Figure: Original bus network in Den Haag and allocation to short-turning and interlining lines

Theoretical Gain

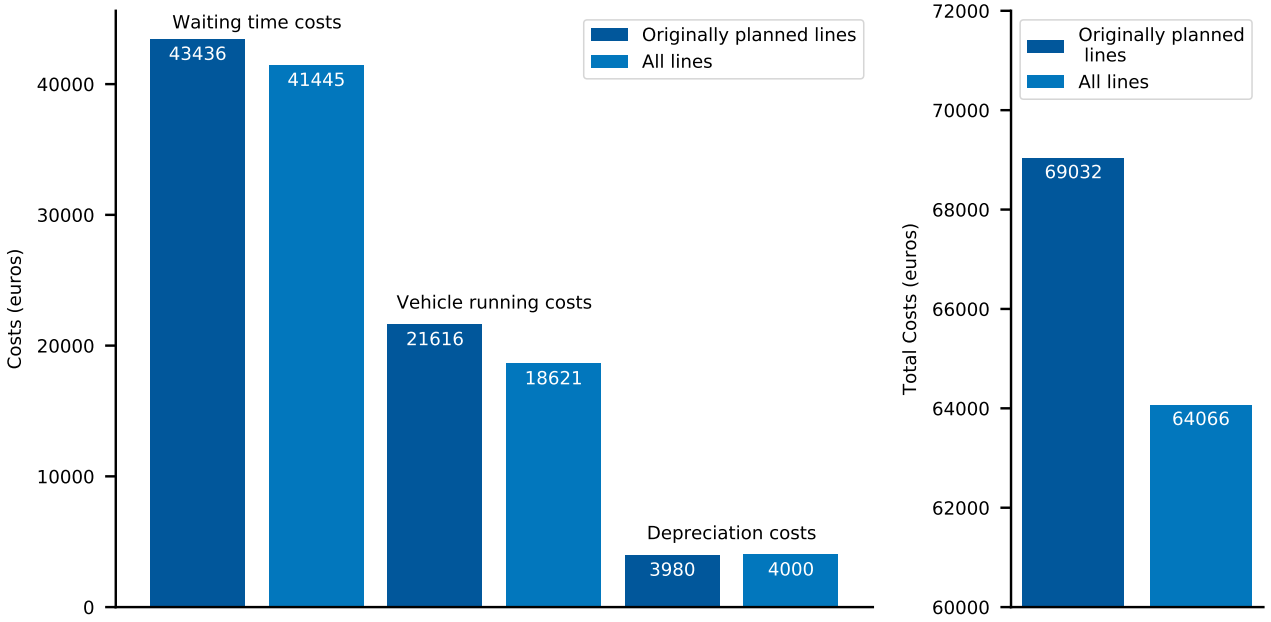


Figure: Costs when using (a) originally planned lines only and (b) originally planned lines along with interlining and short-turning lines

But what will happen if we need more practical schedules?

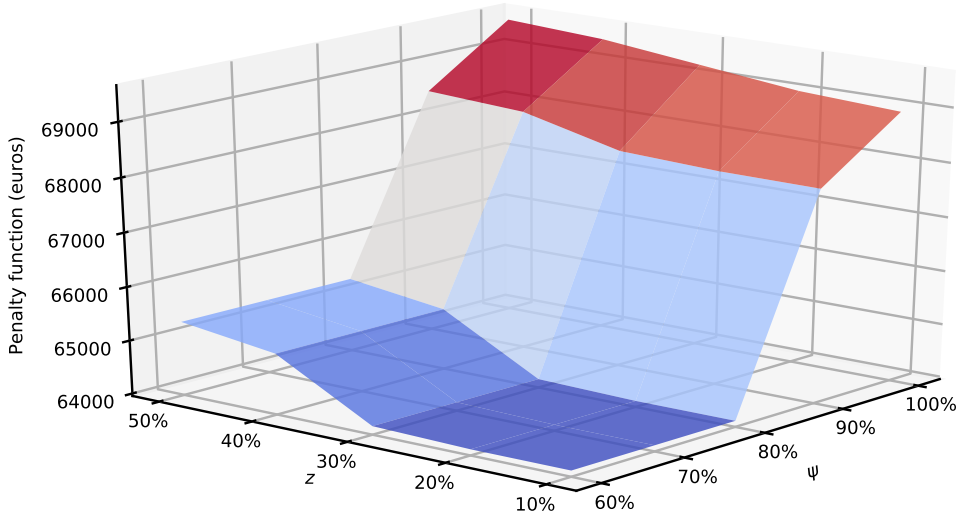


Figure: Total Cost changes: (i) ψ controls the minimum percentage of buses that should be allocated to originally planned lines; (ii) z controls the minimum ridership change from stop to stop that justifies the generation of a switch stop

New Research Items

- Correlation of Driver Behavior with Traffic Density (PhD Candidate Emiliano Heyns)
- Real-time Bus Holding with Reinforcement Learning (Dr Francesco Alesiani)
- Forecasting spatio-temporal variations in ODs of bike sharing systems (MSc Jan M. Engels - Yellowbike)
- Dynamic optimization of train allocation to a trainyard (MSc Bram Schasfoort - ARCADIS)
- Scheduling of Electric Buses (Dr Guelcin Emris)
- Increase MaaS inclusion by studying user-groups with the use of smartcard, cellular, smartphone App data and surveys (Prof Karst Geurs)

Thank-you

Thank-you for your time!

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