Public Transport in the era of MaaS

dr. Konstantinos Gkiotsalitis
Center for Transport Studies
University of Twente — Quick Facts

- Is highly specialized in engineering.
University of Twente — Quick Facts

- Is highly specialized in engineering.
- >10,000 students & 1,000 successful ventures to date.
University of Twente — Quick Facts

► Is highly specialized in engineering.
► >10,000 students & 1,000 successful ventures to date.
► Collaborates with Delft University of Technology, Eindhoven University of Technology and the Wageningen University and Research Centre under the umbrella of 4TU.
Location
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. Mortens (Marick)
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)
My role at UT

Education

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

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
## Differences in New Life...

### Business Forces

<table>
<thead>
<tr>
<th>Area</th>
<th>Business Model</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singapore, London, Hong Kong</td>
<td>Almost every year another set of bus lines is open for bidding</td>
<td>Strong competition on improving operational KPIs and upgrading ICT</td>
</tr>
<tr>
<td>Twente (mostly in the Netherlands)</td>
<td>winner-takes-it-all contract for ~10yrs</td>
<td>1. PTOs want to identify &amp; terminate non-profitable lines</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Market share is challenged from mobility start-ups</td>
</tr>
</tbody>
</table>
Biggest PTO problems

Make a guess...

- 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
Biggest PTO problems

Make a guess...

- Bus drivers call in sick (rate way above the national average)
Biggest PTO problems

Make a guess...

- Bus drivers call in sick (rate way above the national average)
- Demand changes over the years and some lines are not profitable
Biggest PTO problems

Make a guess...

- 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?
Biggest PTO problems

Make a guess...

- 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
Biggest PTO problems

Make a guess...

- 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
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

**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])
Research Challenges

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

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)


Demand Prediction


Traffic Theory

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

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;
Objective of this work

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;
Objective of this work

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:

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

(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

\[
(Q) : \min_x \max_{\xi,\zeta} \ f(x, \xi, \zeta) \tag{2}
\]

s.t.: 
\[
x \in \mathcal{F}(\xi, \zeta) = \{ \ x \mid x \text{ satisfies the constraints} \} \tag{3}
\]
\[
x_{l,1} = \delta_{l}^{\min}, \ \forall l \in L \tag{4}
\]
\[
\xi_{l,s}^{\min} \leq \xi_{l,n,s} \leq \xi_{l,s}^{\max}, \ \forall l \in L, \forall n \in N(l), \forall s \in S(l) \setminus \{1\} \tag{5}
\]
\[
\zeta_{l,s}^{\min} \leq \zeta_{l,n,s} \leq \zeta_{l,s}^{\max}, \ \forall l \in L, \forall n \in N(l), \forall s \in S(l) \tag{6}
\]
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

Stops of line 1

Stops of line 4

Bus Lines

Transfer stops

Essingetorget

Frihamnen

Gullmarsplan

Radiohuset

Public Transport in the era of MaaS
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 $\sim 60\%$ 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
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
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.

⇒ find the sweet spot of each case study
### Observations using 30 days of data

<table>
<thead>
<tr>
<th></th>
<th>min.</th>
<th>$Q_1$</th>
<th>median</th>
<th>$Q_3$</th>
<th>max.</th>
<th>median impr.</th>
<th>max. impr.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Excessive Waiting Time per passenger (min)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Originally Planned Schedule</td>
<td>1.443</td>
<td>1.583</td>
<td>1.626</td>
<td>1.673</td>
<td>1.810</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Robust to 10% deviations</td>
<td>1.372</td>
<td>1.495</td>
<td>1.542</td>
<td>1.587</td>
<td>1.710</td>
<td>5.17%</td>
<td>5.52%</td>
</tr>
<tr>
<td>Robust to 30% deviations</td>
<td>1.442</td>
<td>1.622</td>
<td>1.654</td>
<td>1.661</td>
<td>1.681</td>
<td></td>
<td>-1.72%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>min.</th>
<th>$Q_1$</th>
<th>median</th>
<th>$Q_3$</th>
<th>max.</th>
<th>median impr.</th>
<th>max. impr.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Waiting Time for Transferring Passengers (min)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Originally Planned Schedule</td>
<td>1.888</td>
<td>2.229</td>
<td>2.381</td>
<td>2.579</td>
<td>2.910</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Robust to 10% deviations</td>
<td>1.511</td>
<td>1.692</td>
<td>1.710</td>
<td>1.984</td>
<td>2.811</td>
<td>28.18%</td>
<td>3.40%</td>
</tr>
<tr>
<td>Robust to 30% deviations</td>
<td>1.819</td>
<td>2.231</td>
<td>2.403</td>
<td>2.468</td>
<td>2.581</td>
<td>-0.92%</td>
<td>11.31%</td>
</tr>
</tbody>
</table>

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
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) $\psi$ 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!

E: k.gkiotsalitis@utwente.nl
T: +31534891870
W: https://people.utwente.nl/k.gkiotsalitis?tab=about-me