Robust Control for Regulating Frequent Bus Services:
Supporting the Implementation of Headway-based Holding Strategies

Ellen van der Werff, MSc.
Dr. ir. Niels van Oort
Dr. Oded Cats
Prof. dr. ir. Serge Hoogendoorn

Smart Public Transport Lab
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Introduction

- Vehicle bunching
- Unregularity affects passenger travel time and crowding level
Preventing bunching

- Vehicle holding might be a solution
- Trade off in-vehicle time vs. waiting time
<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Strategy*</th>
<th>Solution method (Control objective)</th>
<th>Evaluation</th>
<th>Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abkowitz &amp; Lepošsky (1990)</td>
<td>HC (forward hw)</td>
<td>Rule-based (Regularity)</td>
<td>Passenger and operator</td>
<td>Single line</td>
</tr>
<tr>
<td>Chandrasekar (2002)</td>
<td>SA (forward hw) + TSP</td>
<td>Rule-based (Regularity)</td>
<td>Passenger and operator</td>
<td>Single line</td>
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<tr>
<td>Furth &amp; Muller (2007)</td>
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<td></td>
<td>Passenger and operator</td>
<td>Single line</td>
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<tr>
<td>Daganzo &amp; Plachowski (2009)</td>
<td>HC (even hw) + SA + SS</td>
<td>Rule-based (Regularity)</td>
<td>Passenger and operator</td>
<td>Single line</td>
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<tr>
<td>Plachowski (2009)</td>
<td>SA (even hw)</td>
<td>Rule-based (Regularity)</td>
<td>Passenger and operator</td>
<td>Single line</td>
</tr>
<tr>
<td>Xuan, Argote &amp; Daganzo (2011)</td>
<td>HC (forward hw with virtual schedule)</td>
<td>Rule-based (Regularity + Punctuality)</td>
<td>Passenger and operator</td>
<td>Single line</td>
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<tr>
<td>Ma, Xie &amp; Han (2012)</td>
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<td></td>
<td>Passenger and operator</td>
<td>Single line</td>
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<tr>
<td>van Oort, Boterman &amp; van Nes (2012)</td>
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<td></td>
<td>Passenger and operator</td>
<td>Single line</td>
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<tr>
<td>Ampountolas &amp; Kring (2015)</td>
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<td>Passenger and operator</td>
<td>Single line</td>
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<tr>
<td>Argote-Carbanero, et al. (2015)</td>
<td></td>
<td></td>
<td>Passenger, operator and driver</td>
<td>Two lines</td>
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<tr>
<td>Teng &amp; Jin (2015)</td>
<td></td>
<td></td>
<td>Passenger and operator</td>
<td>Single line</td>
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<tr>
<td>Liu &amp; Gao (2016)</td>
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<td>Passenger and operator</td>
<td>Two lines</td>
</tr>
<tr>
<td>Sanchez-Martinez et al. (2016)</td>
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<td></td>
<td>Passenger and operator</td>
<td>Single line</td>
</tr>
<tr>
<td>Present study</td>
<td></td>
<td></td>
<td>Passenger, operator and driver</td>
<td>Two lines</td>
</tr>
</tbody>
</table>

* Note:
- HC = Holding control
- SA = Speed adjustment
- TSP = Transit Signal Priority
- SS = Stop-skipping
- BL = Boarding limit

Challenge the future
Implementation of a holding regime

- Stakeholders

- Headway-based vs. schedule based

- Punctuality in concession requirements

- Holding control:
  - What are the effects?
  - How, when, where?
  - Regular vs disturbed operations
  - Implementation issues with regard to communication and crew
Main research questions

- How could holding control strategies be assessed and implemented?
- What is the effect of different holding control strategies, with respect to the operator, passengers and the transport authority?
- Two perspectives
  - Regular operations
  - Disturbances
Framework

KPIs:
- Operator
- Passenger
- Authority

Model input

Model output, Per trip

Performance assessment

Expert judgement

Generation of strategies

Generation of scenarios
BusMezzo

- Dynamic Agent-based Transit Operations & Assignment Simulation Model
- Developed by Oded Cats, Smart PT Lab, TU Delft
- Open-source, <1 min for full-size network assignment

- Traffic dynamics
- Transit operations
- En-route passenger decisions
- Disruptions
- Day to day learning

More info at: www.OdedCats.weblog.TUDelft.nl or
Case BRT line

- Leiden- Zoetermeer
- Both ~130,000 inhabitants
- 14 km; 11 stops
- 10-12 buses/hour/direction
- ~ 28 min trip time
- Current operations: Smartcard and AVL data
Results – Regular operations
Headway-based vs schedule-based

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Holding condition</th>
<th>Control points</th>
<th>Holding time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Schedule-3-no max</td>
<td>Schedule-based</td>
<td>3</td>
<td>No max</td>
</tr>
<tr>
<td>2 Schedule-9-no max</td>
<td>Schedule-based</td>
<td>9</td>
<td>No max</td>
</tr>
<tr>
<td>3 Hw-3-no max</td>
<td>Headway-based</td>
<td>3</td>
<td>No max</td>
</tr>
<tr>
<td>4 Hw-3-300</td>
<td>Headway-based</td>
<td>3</td>
<td>Max 300 sec</td>
</tr>
<tr>
<td>5 Hw-3-60</td>
<td>Headway-based</td>
<td>3</td>
<td>Max 60 sec</td>
</tr>
<tr>
<td>6 Hw-9-no max</td>
<td>Headway-based</td>
<td>9</td>
<td>No max</td>
</tr>
<tr>
<td>7 Hw-9-300</td>
<td>Headway-based</td>
<td>9</td>
<td>Max 300 sec</td>
</tr>
<tr>
<td>8 Hw-9-120</td>
<td>Headway-based</td>
<td>9</td>
<td>Max 120 sec</td>
</tr>
<tr>
<td>9 Hw-9-60</td>
<td>Headway-based</td>
<td>9</td>
<td>Max 60 sec</td>
</tr>
</tbody>
</table>

Savings in passenger travel times are minimal: ±1% (20s)
Disrupted situations
Bridge

Schedule-based control - Direction 1

Headway-based control - Direction 1

Time [sec]

1. Leiden
2. Breestraat
3. Korevaarstraat
4. Station Lammenschans
5. A4 P+R
6. Dorp
7. Stompwijk
8. Meerpolder
9. Binnenpark
10. Woonh. West
11. Centrum West

Stop
Results – Disturbed operations

- Best strategy:
  Headway based

- Passengers
  - Savings in travel times: ± 5-20%
  - Less crowded vehicles

- Longer cycle times (+5%)
- Variation in cycle times decreased
What holding strategy?

- Early arrivals
  - Yes
    - Many disruptions
      - Yes: Headway-based control
      - No: Schedule-based control
    - No: Enough turnaround time
      - Yes
        - High demand at terminal
          - Yes: Schedule-based control
          - No: Headway-based control
      - No: Headway-based control
- Requirements:
  - Providing regular service
Conclusions / Recommendations

- Framework assessing potential of scheduled- and headway based holding for multiple stakeholders
- Case study in Leiden: most benefits of headway-based holding if operations are disturbed
- Insights into factors affecting holding type choice

Next steps

- Scientific
  - Network-related assessment
  - Regularity in concession requirements

- Practical
  - Pilot study
  - Implementation
Questions / contact

Ellen van der Werff, MSc.
EvdWerff@Goudappel.nl

dr. ir. Niels van Oort
N.vanOort@TUDelft.nl

Dr. Oded Cats
O.Cats@TUDelft.nl

http://smartptlab.tudelft.nl/
https://nielsvanoort.weblog.tudelft.nl/

Amsterdam May 2019

http://ppts-course.org/