Real-time Short-turning in High Frequency Bus Services Based on Passenger Cost

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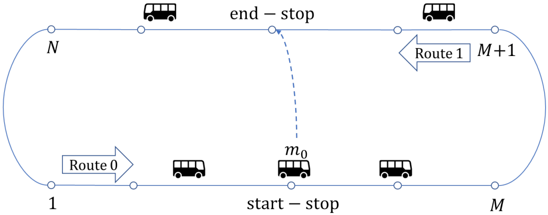
Stockholm, Sweden

Workshop on Advances in Public Transport Control and Operations
Conclusions and Lessons from ADAPT-IT

2017-06-16

Definition of short-turning



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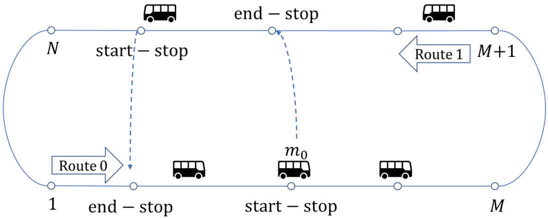
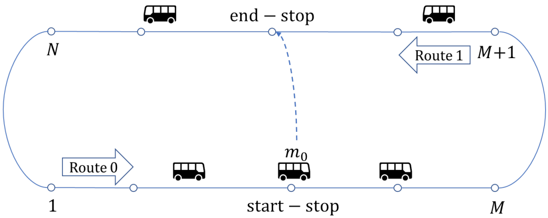


- Tactical planning strategy

Definition of short-turning



- Real-time control strategy

Why is short-turning used?

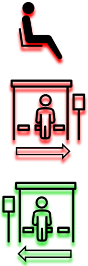
- Passenger perspective
  - waiting time
  - in-vehicle time
  - transfers
- Operator perspective
  - schedule adherence
  - headway regularity
  - disruption recovery

Research objectives

- Contribute to library of data-driven, real-time control tactics
- Extend methodology for short-turning to consider passenger costs
- Improve on tools used to evaluate short-turning as a real-time strategy

3 impacted passenger groups

- Passengers forced to alight
- Passengers waiting to board at, and downstream of start-stop
- Passengers waiting to board at, and downstream of end-stop



We want to balance the costs of these passenger groups!

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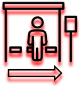

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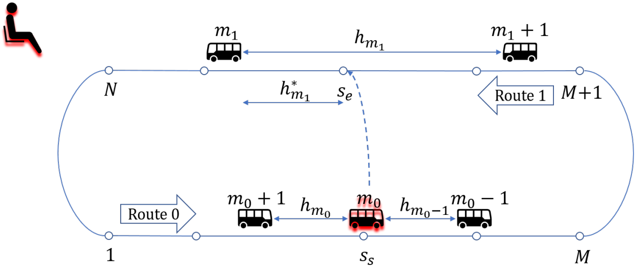
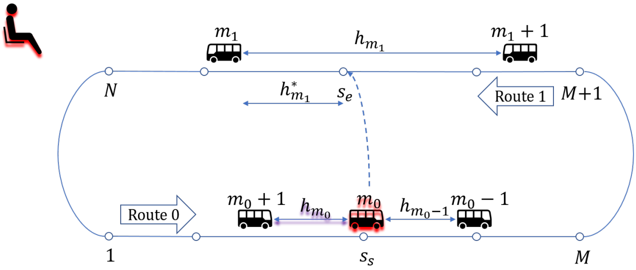
Forced alighters



$$\beta_F \cdot h_{m_0} \cdot (q_{m_0 s_s} - q^a_{m_0 s_s})$$

Forced alighters



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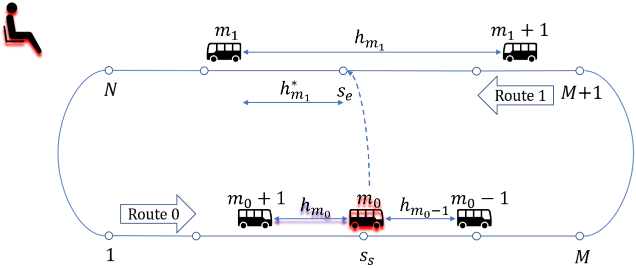

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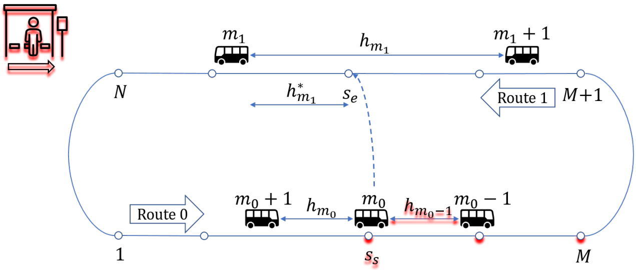
Downstream boarders



$$\beta_W \cdot h_{m_0} \cdot \sum_{i=s_s}^{M} \lambda_i \cdot h_{m_0-1}$$

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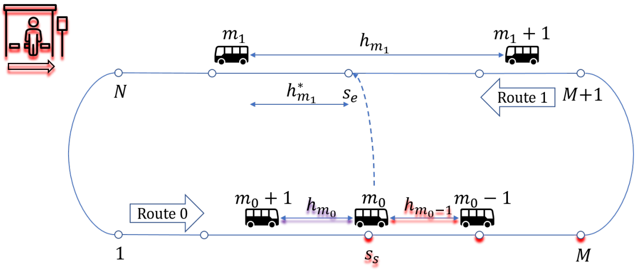

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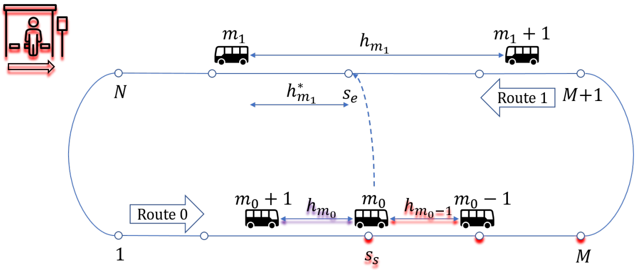

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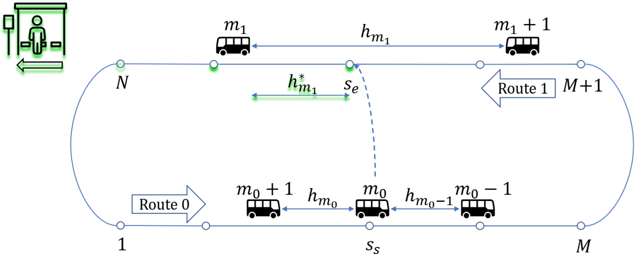

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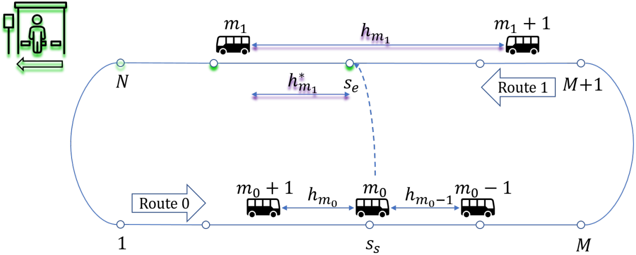

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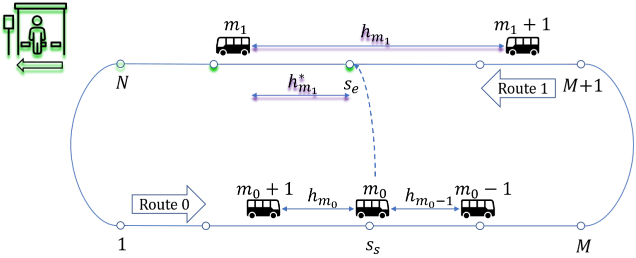

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Decision rule

$$z := \beta_W \cdot (h_{m_1} - h^*_{m_1}) \cdot \sum_{i=s_e}^{N} \lambda_i \cdot h^*_{m_1} \text{ reverse ds boarders}$$
$$- \beta_W \cdot h_{m_0} \cdot \sum_{i=s_s}^{M} \lambda_i \cdot h_{m_0-1} \text{ ds boarders}$$
$$- \beta_F \cdot h_{m_0} \cdot (q_{m_0 s_s} - q^a_{m_0 s_s}) \text{ forced alighters}$$

- If $z > 0$ short-turn, otherwise do nothing

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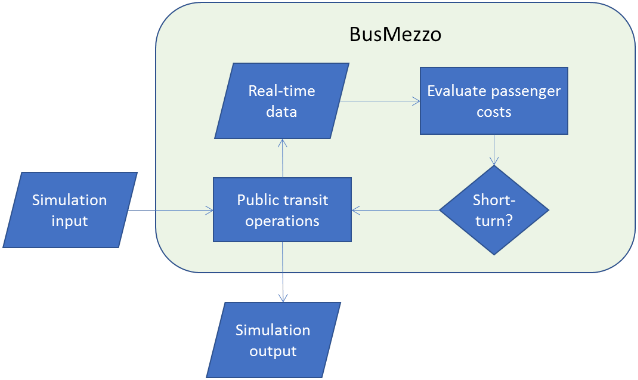
Experimental set-up

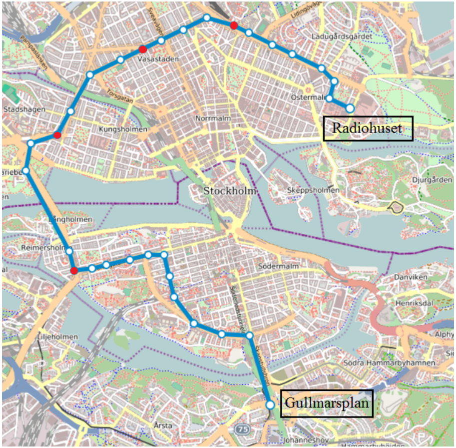


Line 4 Gullmarsplan ↔ Radiohuset

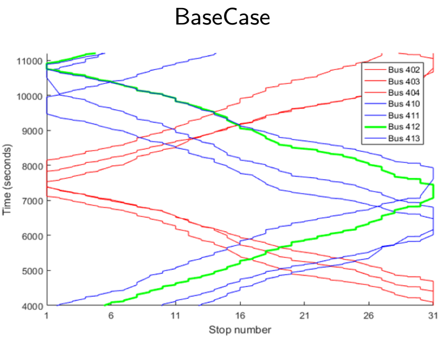
- Planned fleet size of 23 buses
- Scheduled headway of 5 minutes
- 4 candidate short-turning stops

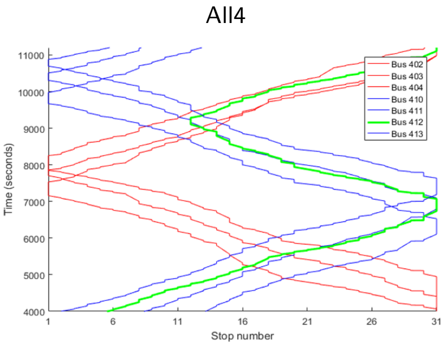
- Short-turn GR onto RG
- PM peak hour
- 3 different scenarios:

1. BaseCase
2. All4
3. Hornstull



Results


BaseCase
Time (seconds)
Stop number
Bus 402
Bus 403
Bus 404
Bus 410
Bus 411
Bus 412
Bus 413


All4
Time (seconds)
Stop number
Bus 402
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Bus 412
Bus 413

Arrival headways

Table 1: Measures of arrival headways in seconds

Scenarios	Average HW	Average HW (RG)	Average HW (GR)	Stdev HW	Stdev HW (RG)	Stdev HW (GR)	$\%ST_{Trips}$	$\%ST_{Calls}$
BaseCase	302	299	304	275	253	296	-	-
All4	302	283	325	257	223	290	26%	14%
Hornstull	301	298	304	259	235	282	4%	10%

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Table 2: Measures of passenger costs in seconds

Scenarios	Average Waiting Time	Average In-vehicle Time	Stdev Waiting Time	Stdev In-vehicle Time
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Conclusions and Future Work

Conclusions:

- Formulated a method that produces short-turns that qualitatively appear reasonable
- Aggressive use of this method can improve headway reliability at the expense of passenger waiting times
- Conservative use of this method has potential to benefit passengers while still improving headway regularity

Future work:

- Further balancing of costs in decision rule (e.g. discount distant passengers, consider load of neighboring bus)
- Simulate other scenarios (e.g. demand profile, other start/end-stop pairs...)
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The End

Thank you for listening!

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dleffler@kth.se

Notation and Decision rule

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$$- \beta_W \cdot h_{m_0} \cdot \sum_{i=s_s}^{M} \lambda_i \cdot h_{m_0-1}$$
$$- \beta_F \cdot h_{m_0} \cdot (q_{m_0 s_s} - q^a_{m_0 s_s})$$

Sets

$\mathcal{R}$	set of routes; $r \in \mathcal{R} := \{0, 1\}$
$\mathcal{S}$	set of all ordered stops; $s \in \mathcal{S} := \{1, \dots, M, M+1, \dots, N\}$
$\mathcal{S}_r$	set of stops on route r; $s \in \mathcal{S}_r := \begin{cases} \{1, \dots, M\}, & \text{if } r = 0 \\ \{M+1, \dots, N\}, & \text{if } r = 1 \end{cases}$
$\mathcal{T}^0$	set of candidate short-turns with start-stop s_s on route 0 to end-stop s_e on route 1; $(s_s, s_e) \in \mathcal{T}^0 \subseteq \mathcal{S}_0 \times \mathcal{S}_1$
$\mathcal{M}$	set of all buses; $m \in \mathcal{M} := \{1, \dots, K\}$
$\mathcal{M}_r$	set of buses currently running trips on route r; $m_r \in \mathcal{M}_r \subseteq \mathcal{M}$

Inputs

q_{ms}	number of passengers on-board bus m upon arrival to stop s
q^a_{ms}	number of passengers on-board bus m upon arrival to stop s that wish to alight at stop s
a_{ms}	arrival time of bus m to stop s
h_m	backwards headway of bus m (i.e., time distance between bus m and following bus $m+1$). For this study these are defined based on arrivals, i.e., $h_m = a_{m+1,s} - a_{ms}$, where s is the last stop visited by m and $a_{m+1,s}$ is the predicted arrival of $m+1$ to stop s based on scheduled travel times.
$\tau^{s_e}_{s_s}$	short-turn travel time from stop s_s to stop s_e
DT_{ms_s}	dwell time of bus m at stop s_s
$STT_{s_1 s_2}$	scheduled travel time between stop s_1 and stop s_2 on the same route, i.e., $s_1, s_2 \in \mathcal{S}_r$ for $r \in \mathcal{R}$

Parameters

λ_s	passenger arrival rate at stop s
β_W	unit cost of waiting time relative to in-vehicle time
β_F	unit cost of waiting time for forced alighters relative to in-vehicle time

Arrival headways

Measures of arrival headways in seconds

Scenarios	$\bar{x}$	$\bar{x}_{RG}$	$\bar{x}_{GR}$	σ_x	σ_{RG}	σ_{GR}	$\%ST_{Trips}$	$\%ST_{Calls}$
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$\%ST_{trips}$ are out of 120 trips (12 for peak hour over 10 replications)
$\%ST_{Calls}$ are out of a total of 218 for All4 and 48 for Hornstull

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Measures of passenger costs in seconds.

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