REAL-TIME CONTROL FOR TRANSIT SYSTEMS WITH TRANSFERS

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OUTLINE

- Introduction
- Model description
- Case study
- Conclusions & future work

BACKGROUND

- Real-time operations control
  - Improve service quality and passengers delay
  - Increase reliability and regularity
  - Respond to deviations from plan
  - Enabled by advances in IT
    - Automatic vehicle location (AVL)
    - Automatic passenger counters (APC)
- Commonly single line
  - schedule or headway control
  - Using holding and speed change

CONTROL OF MULTIPLE LINES

- Integrated public transportation systems
- Conflicting goals for passengers
  - At stops
    - Even headways
  - On board
    - Avoid holding
  - Transferring
    - Coordination
  - Unable to board
    - Short following headway

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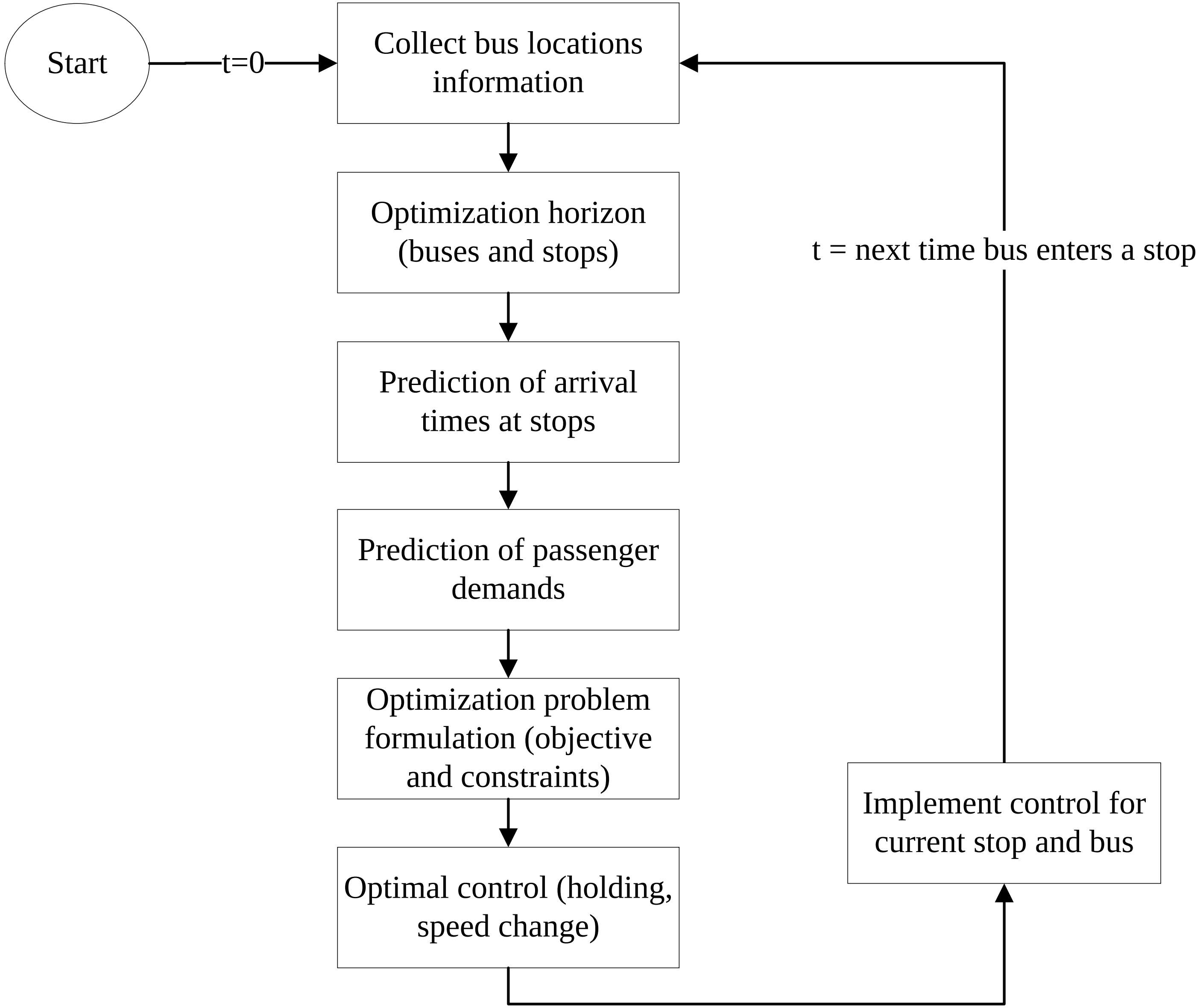
CONTROL OF MULTIPLE LINES (2)

- Mostly optimization-based
  - Dessouky et al. (1999, 2003); Khoat et al. (2007); Hadas and Ceder (2008, 2010); Yu et al. (2012); Ceder et al. (2013), Nesheli et al (2015) , Ibarra and Munoz (2016)
  - Minimize passenger delay
  - Maximize encounters
- Holding at single point transfer stops
- In some cases change speed, stop-skipping and short turning

THIS RESEARCH

- Prediction-based operations control
- Multiple lines with transfers jointly
- Optimization formulation
  - Minimize passengers' time
  - Bus capacity constraints
- Use holding, change speed

OVERALL FRAMEWORK



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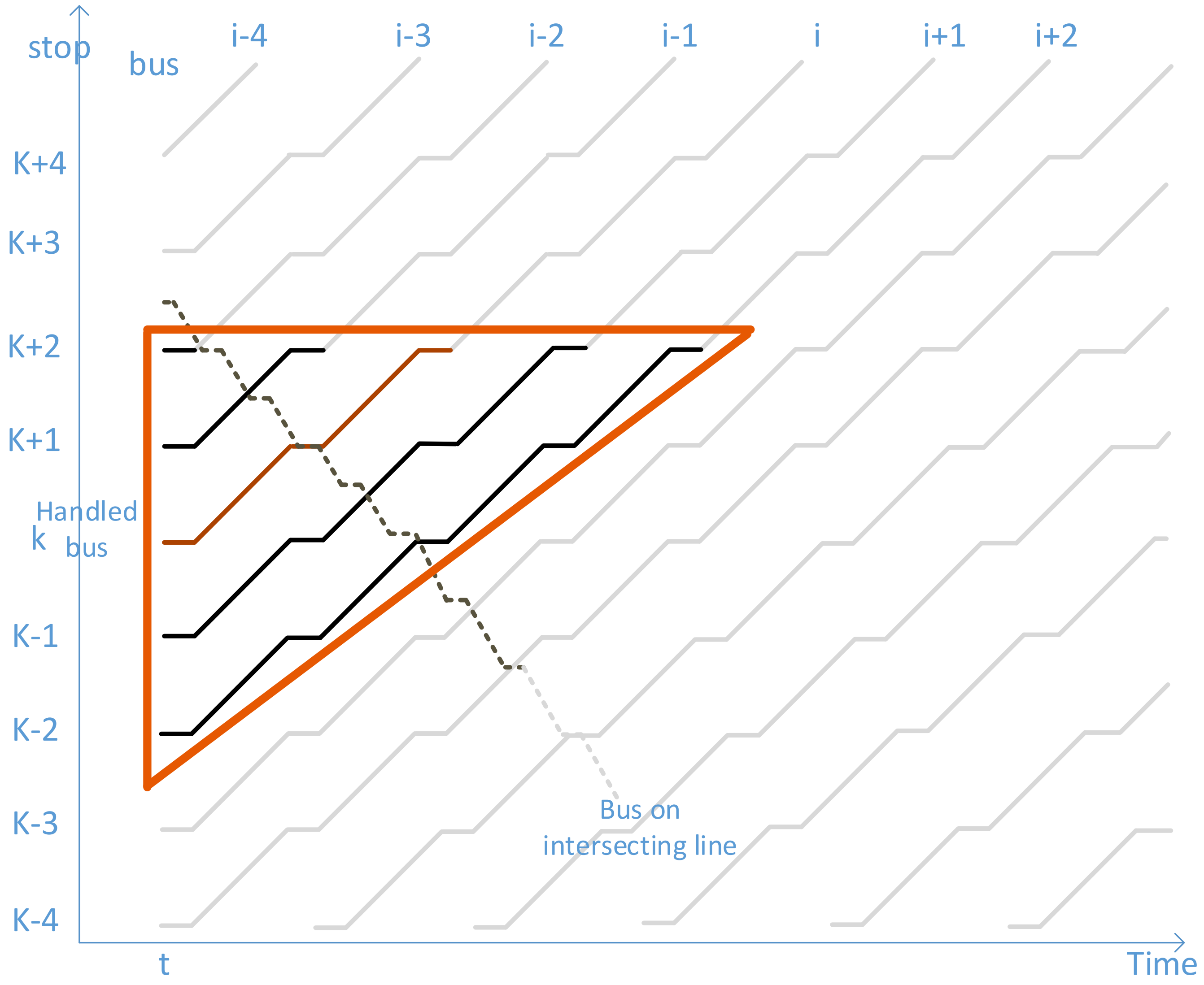
ROLLING HORIZON IMPLEMENTATION



OPTIMIZATION PROBLEM

- Total passengers time in the system
  - Dwell, in-vehicle, wait, transfer, skipped
  - Speed and holding time constraints

$$Z = \min_{H,TT} \sum_{s=1}^{M} \sum_{l=1}^{N} \sum_{k=i}^{i+j} \theta_1 \cdot DT_k^{s,l} + \theta_2 \cdot IVT_k^{s,l} + \theta_3 \cdot WT_k^{s,l} + \theta_4 \cdot TWT_k^{s,l} + \theta_5 \cdot DBT_k^{s,l}$$

s.t.

$$TT_{k,min}^{s,l} \leq TT_k^{s,l} \leq TT_{k,max}^{s,l}$$

$$0 \leq H_k^{(s,l)} \leq \beta \cdot headway^{s,l}$$

k - stop, *l* - bus, *s* - line

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PASSENGER TIME COMPONENTS

- Dwell $$DT_k^{s,l} = \left(np_k^{s,l} - \left(na_k^{s,l} + ntd_k^{s,l} + nta_k^{s,l}\right)\right)\left(st_k^{s,l} + H_k^{s,l}\right)$$
- In-vehicle $$IVT_k^{s,l} = np_{k+1}^{s,l} TT_k^{s,l}$$
- Wait $$WT_k^{s,l} = (nb_k^{s,l} + nto_k^{s,l}) \cdot \left(\frac{dt_k^{s,l} - dt_k^{s,l-1}}{2}\right)$$
- Transfer $$TWT_k^{s,l} = ntb_k^{s,l}\left(dt_k^{s,l} - at_k^{m,n}\right)$$
- Skipped $$ST_k^{s,l} = ndb_k^{s,l-1}(dt_k^{s,l} - dt_k^{s,l-1})$$

at – arrival time, *dt* – departure time, *st* - service time *nb* - boarding, *na* - alighting, *np* - on the bus,

nto – boarding at origin, *ntb* – boarding at transfer *ntd* – alighting at destination, *nta* – alighting at transfer,

ndb – unable to board

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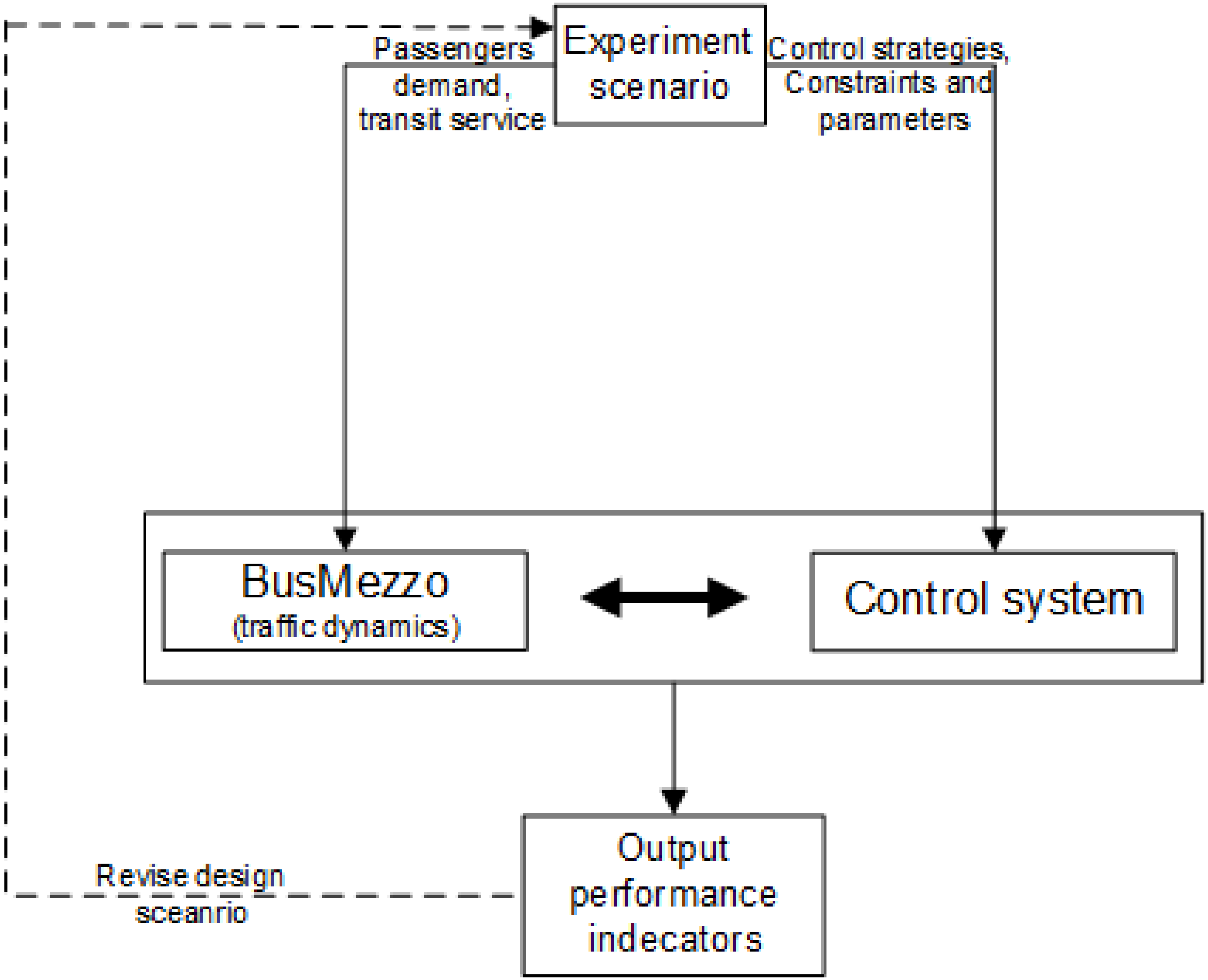
EVALUATION FRAMEWORK



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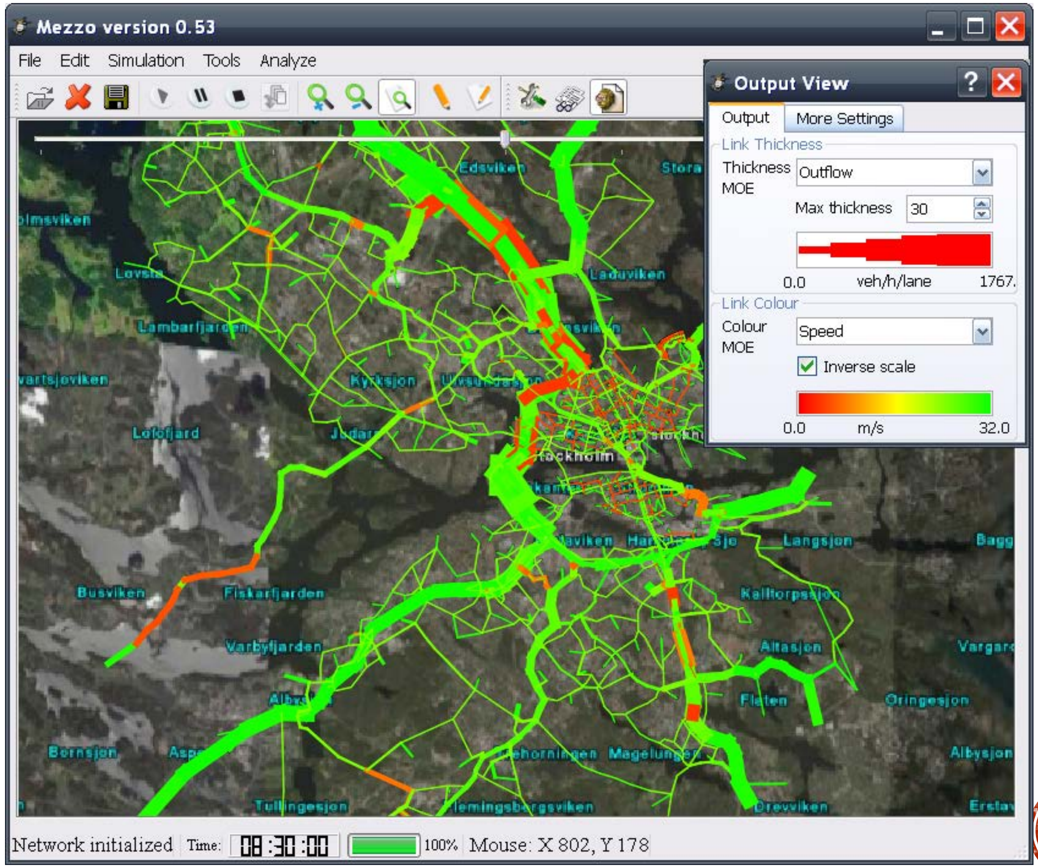
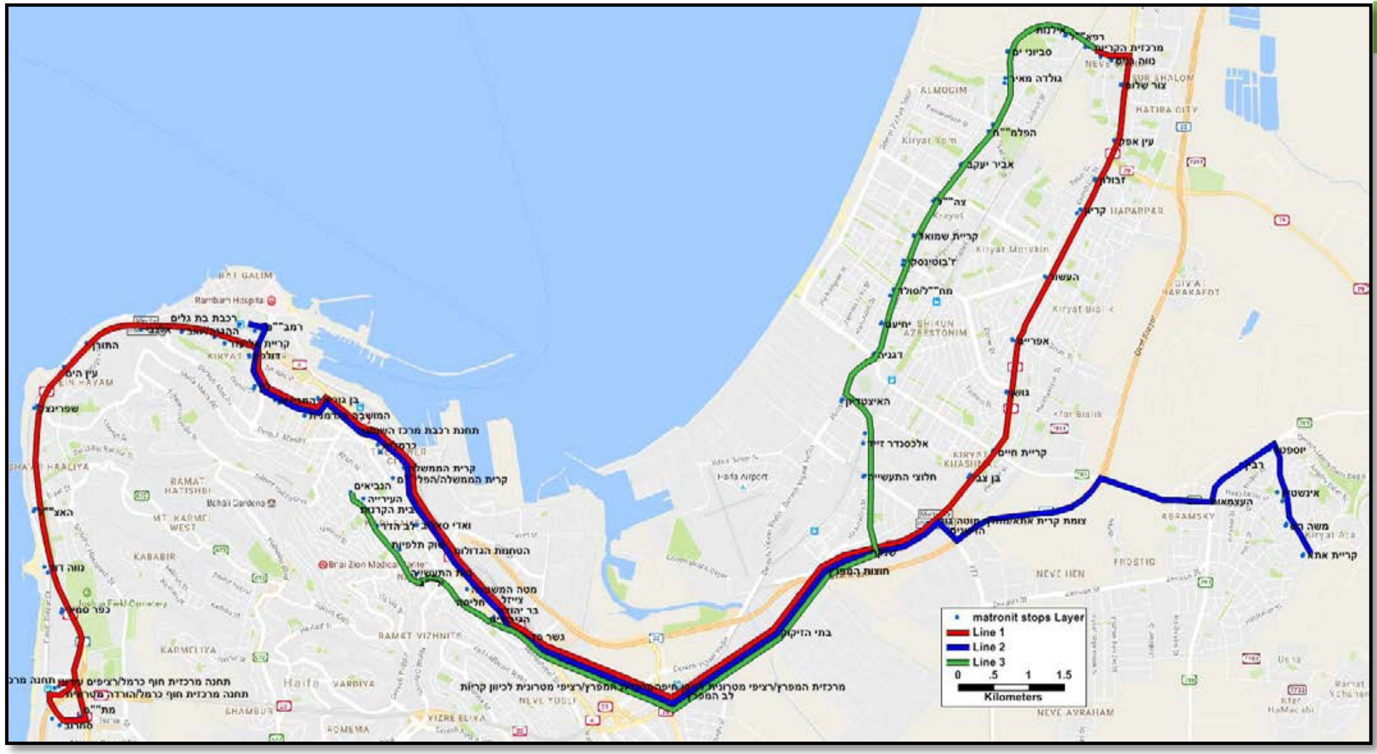
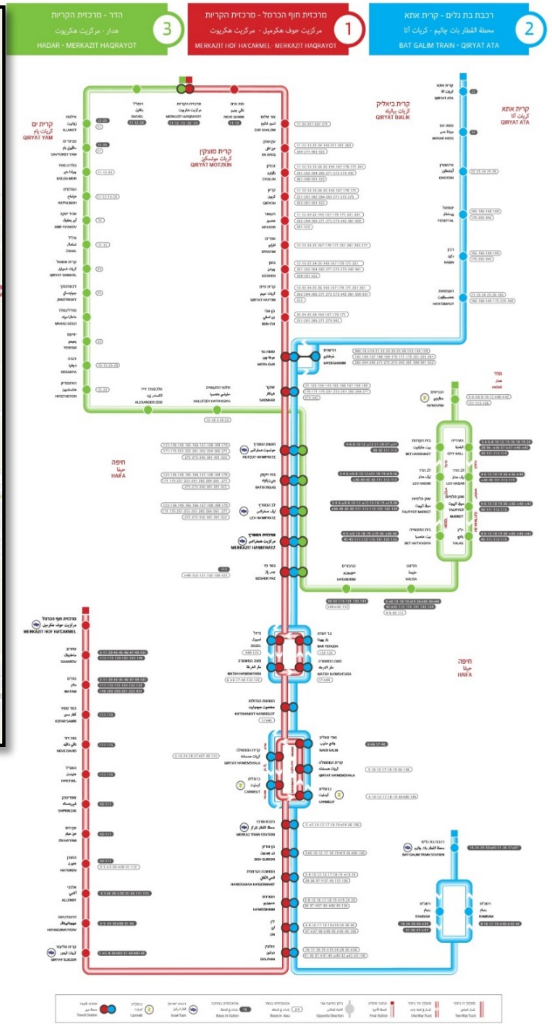
SIMULATION-BASED TESTING FRAMEWORK

- BusMezzo (Toledo et al. 2007, Cats 2011)
- Mescoscopic traffic simulation
- Used as “real world”



CASE STUDY- METRONIT

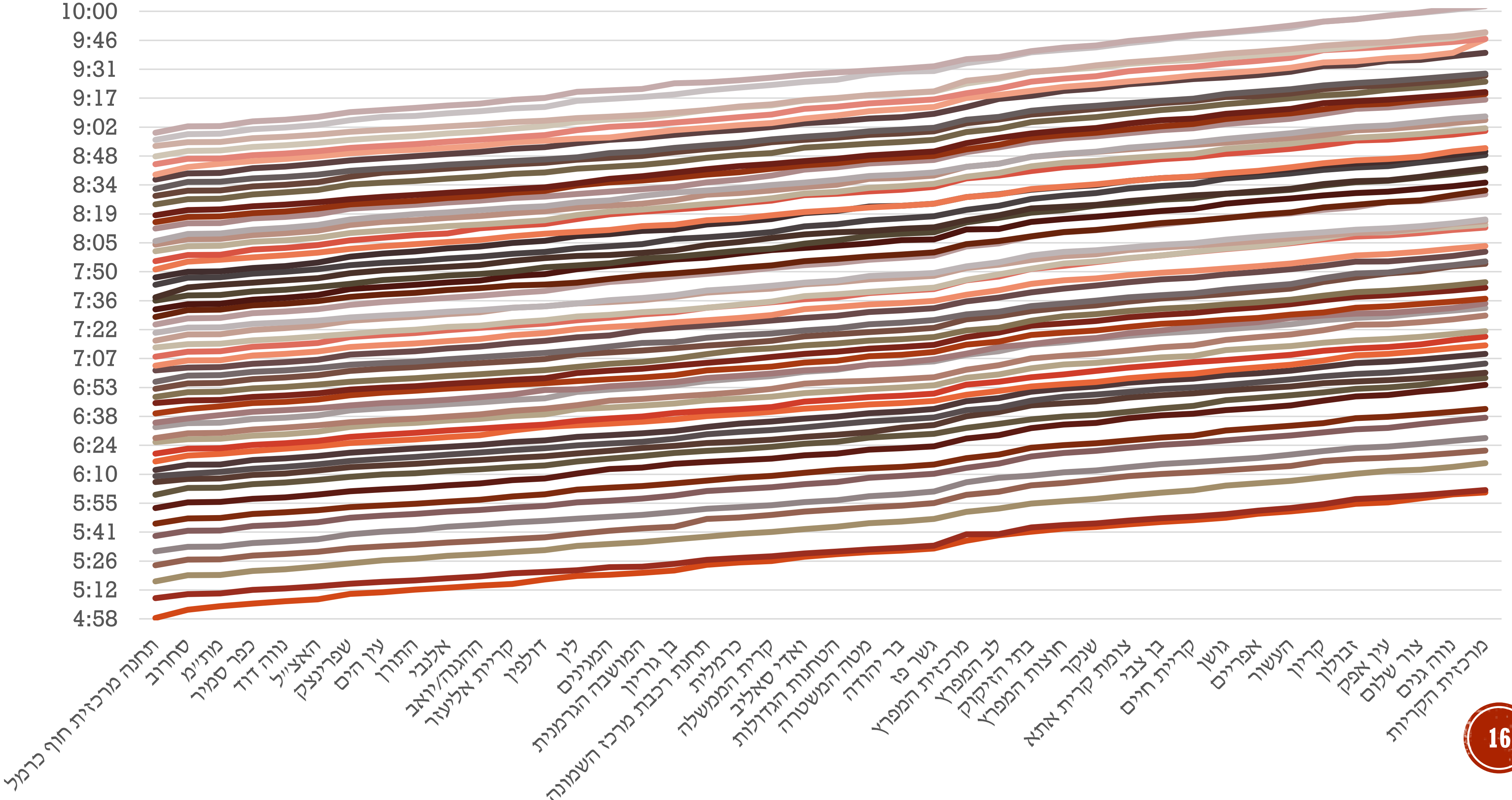




- First BRT system in Israel
- 60 km Long, 40 km dedicated lanes
- 3 lines
- 192 stops and 19 shared stops.
- Daily ridership: 92,000 (May 2015)

METRONIT SYSTEM

- Experiences bunching



CALIBRATION

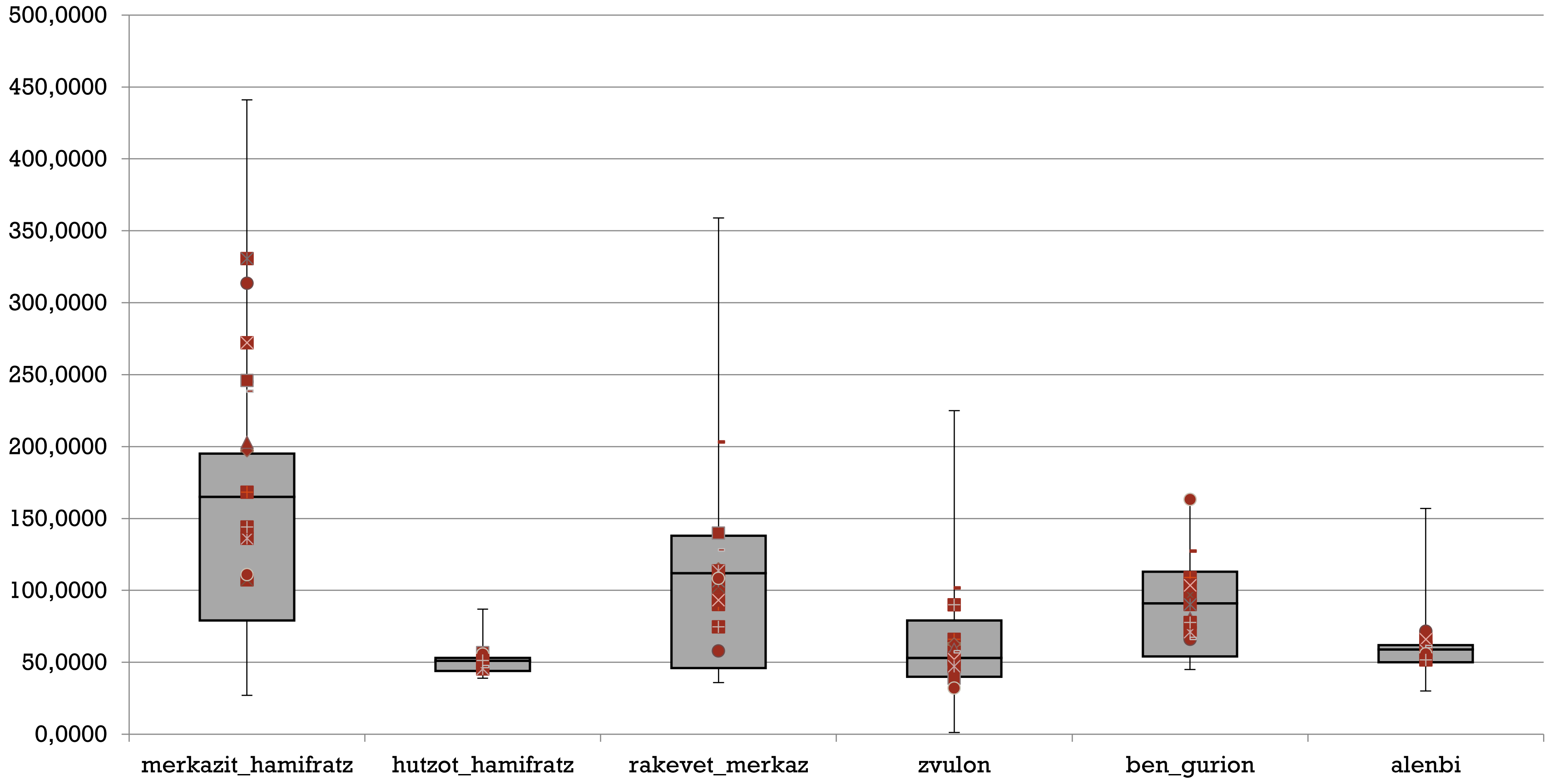
- Origin Destination Demand
  - Including transfers
- Data from AVL and APC
- Dwell time (Weidmann (1994))

$$PST_{s,l}^{k,f} = \beta_0 + [\beta_a^f \cdot A_{s,l}^k + \beta_b^f \cdot B_{s,l}^k] \cdot \left[1 + \frac{3}{4} \left(\max \left\{ \frac{L_{s,l}^k - seats^f}{cap^f - seats^f} \right\} \right) \right]$$

$$\beta_0 = 9.4, \quad \beta_b^f = 0.65, \quad \beta_a^f = 0.57$$

- Travel time distributions

TRAVEL TIME DISTRIBUTION



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BASE SCENARIO

- Base Scenario:
  - ~43,420 passengers in 4 hours
  - 12% of passengers make transfer

Stop Average headway	290.7 sec
Stop sd headway	156.2 sec
Stop Average dwell time	17 sec
Stop sd dwell time	7.7 sec

EXPERIMENTAL DESIGN

- Demand level
  - Base and increased
  - Transfer rates
- Disruptions
  - Bunching
  - Incidents
- Control parameters
  - Horizons
  - Prediction errors
  - Source of information
- Compared to no and independent controls

PRELIMINARY RESULTS

- Predictions:
  - GPS and historical data regarding demand , dwell time and travel time
- Horizon: 3 stops, 3 buses
- Weights: waiting and holding times double of riding time

Component	No control (hrs)	With control (hrs)	% Reduction
Total passengers riding time	11,075	10,616	-4%
Total passengers dwell time	2,275	2,322	2%
Total passengers waiting time	1,839	1,713	-7%
Total passenger holding time	-	116	
Total objective function	17,028	16,480	-3%

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SUMMARY

- Develop system for real time control
  - Prediction based
  - Account for transfers and vehicle capacities
  - Use holding and speed change
- Ongoing evaluation
  - Against no and independent controls
- Next steps
  - Predictions
  - Robustness