Data-Driven Network Performance Model (NPM) for Urban Rail Systems

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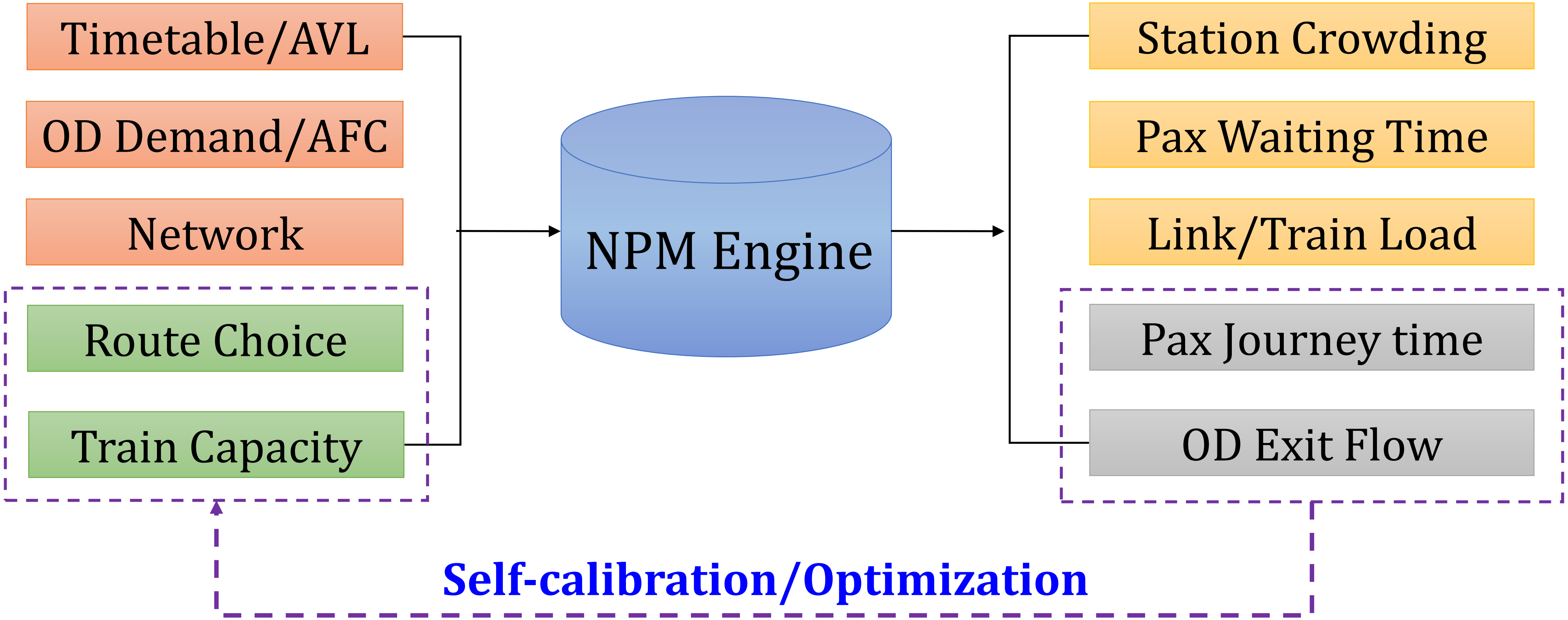
Motivation

- Monitoring network performance (online/offline) is crucial
  - Understand system
  - Improve service attractiveness
  - Assist planning and operations

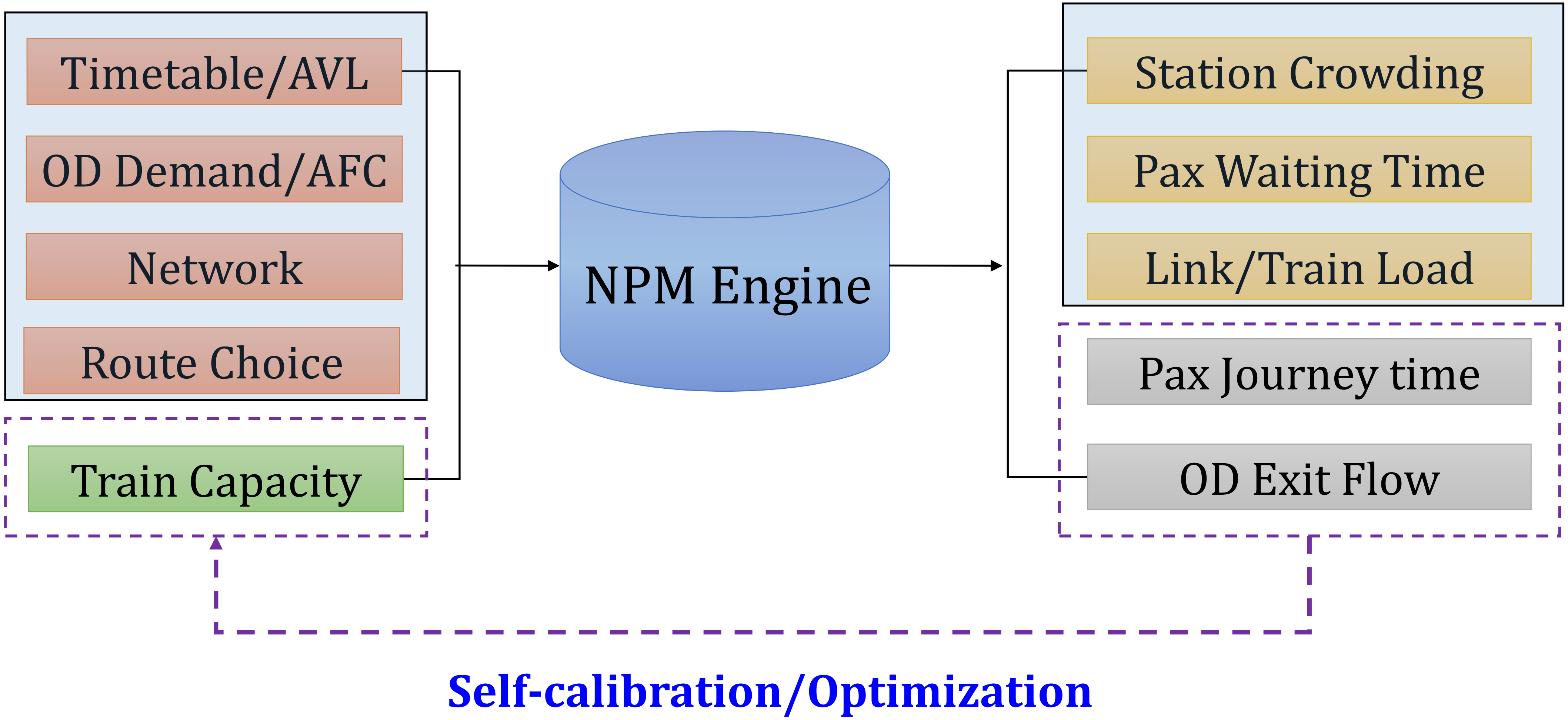
- Objective
  - Develop a self-calibrated data-driven monitoring & decision support platform
    - Performance monitoring
    - Operations planning

Network Performance Model (NPM)



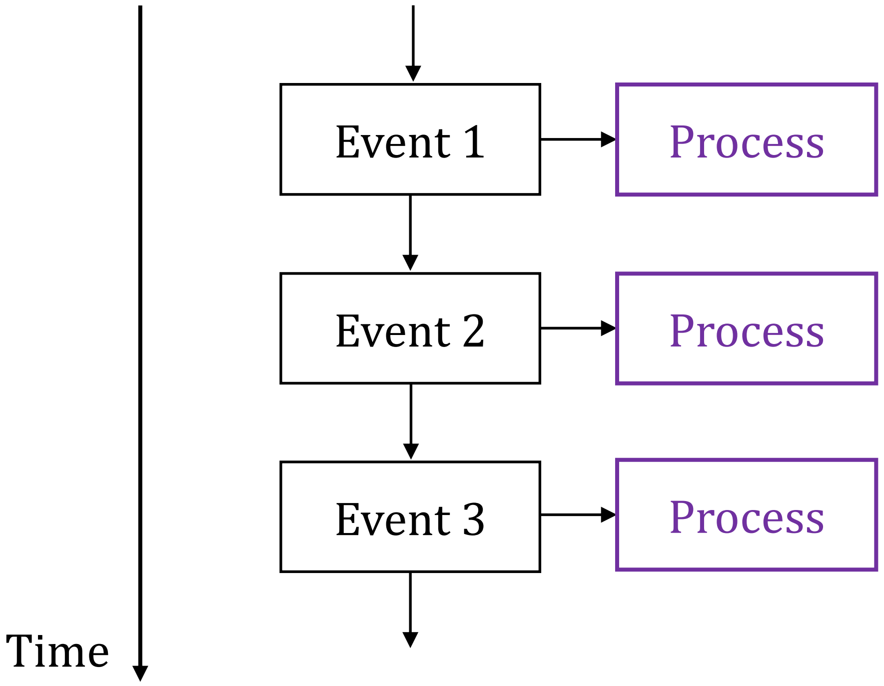
AFC: Automated Fare Collection
AVL: Automated vehicle location

Network Performance Model (NPM)



NPM Engine

- Event-based simulation:
  - First-come-first-serve
  - Strick capacity constraints



- Train arrival:
  - Offload passengers
- Train departure:
  - Load passengers
  - Update states of train and platform

Train Capacity

- **Effective train capacity**:
  - Number of passengers in the train when it departures while there are left-behind passengers on the platform.
- Train capacity may vary by station and crowding levels
  - Platform geometry and access impact passenger distribution along the platform, and hence, load distribution on trains.
  - Different crowding levels affect passenger willingness to board
- Expectation:
  - High train load → high effective capacity [Liu et al. 2018]
  - High crowding on the platform → high effective capacity

Effective Capacity Model

- Effective capacity of a train at platform i (EC_i) is:

$$EC_i = \begin{cases} C + \beta_1 L_i + \beta_2 Q_i & \text{if platform } i \text{ is in the list of congested stations} \\ C & \text{otherwise} \end{cases}$$

where C_i: base capacity

L_i: train load and

Q_i: number of passengers waiting at platform

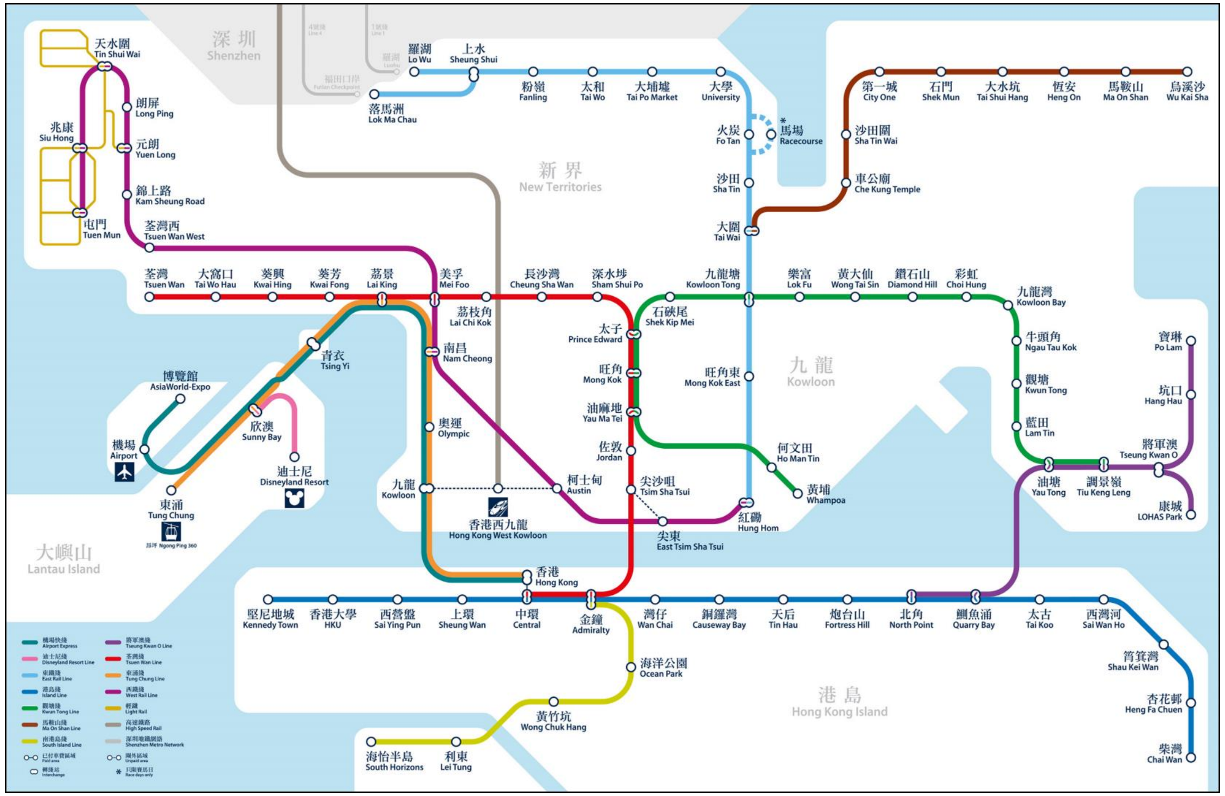
Estimation of Capacity Model Parameters

- Simulation-Based Optimization
- Minimize the error between
  - observed OD exit flow and model-derived OD exit flow
  - observed journey time distribution (JTD) and model-derived JTD

$$
\begin{aligned}
\min_{\beta_1, \beta_2} \quad & w_1 \boxed{\sum_{i,j,t} (q^{i,j_t} - \tilde{q}^{i,j_t})^2} + w_2 \boxed{\sum_{i,j,t} D_{\mathrm{KL}}(p_{i,j_t}(x) \| \tilde{p}_{i,j_t}(x))} \\
\text{s.t.} \quad & q^{i,j_t}, p_{i,j_t}(x) = \mathrm{NPM}(\beta_1, \beta_2) \qquad \forall i, j, t \\
& D_{\mathrm{KL}}(p_{i,j_t}(x) \| \tilde{p}_{i,j_t}(x)) = \int_x p_{i,j_t}(x) \cdot \log \frac{p_{i,j_t}(x)}{\tilde{p}_{i,j_t}(x)} \mathrm{d}x.
\end{aligned}
$$

Applications

- Hong Kong MTR network
- Demand on March 16th, 2017. Evening Peak
- Path choice from survey
- Validation
  - OD exit flow by time
  - Left behind survey at key stations



Path Choice

- Path choices are modeled using a C-logit model from survey data

$$p_r^{i_m,j} = \frac{\exp\left(\beta_X \cdot X_{r,m} + \beta_{CF} \cdot CF_r\right)}{\sum_{r' \in \mathscr{R}(i,j)} \exp\left(\beta_X \cdot X_{r',m} + +\beta_{CF} \cdot CF_{r'}\right)}$$

TABLE 3: Route Choice Model Estimation Results

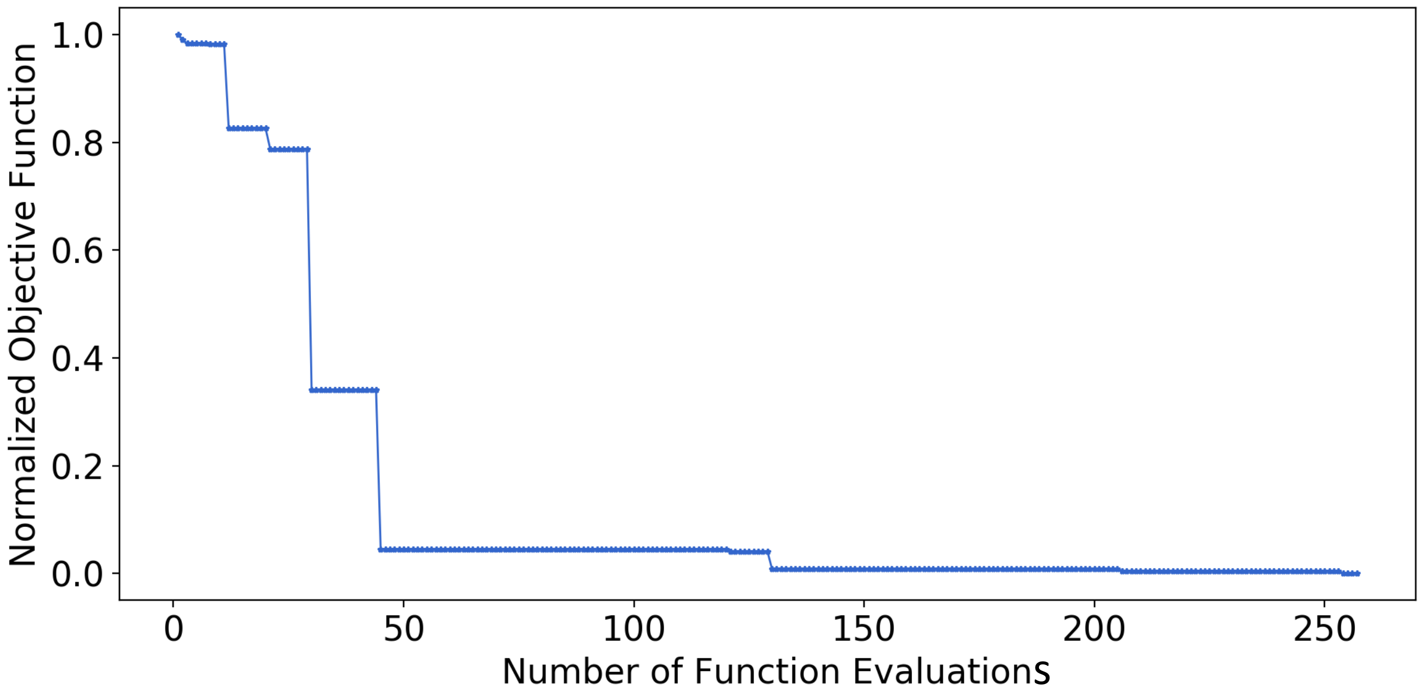
	Estimate	Std. Error	t-value	
In-vehicle time	-0.147	0.011	-13.64	***
Relative walking time	-1.271	0.278	-4.56	***
Number of transfers	-0.573	0.084	-6.18	***
CF	-3.679	1.273	-2.89	**
$\rho^2 = 0.54$				

***: p<0.01; **:p<0.05.

- AFC-data based path choice estimation [Poster session A139]

Results: Effective Capacity

- Parameter estimation (Bayesian Optimization Algorithm)



$$EC_i = \begin{cases} C + \beta_1 L_i + \beta_2 Q_i \\ C \end{cases}$$

C = 230 pax/car × Num of cars in a train (fixed)

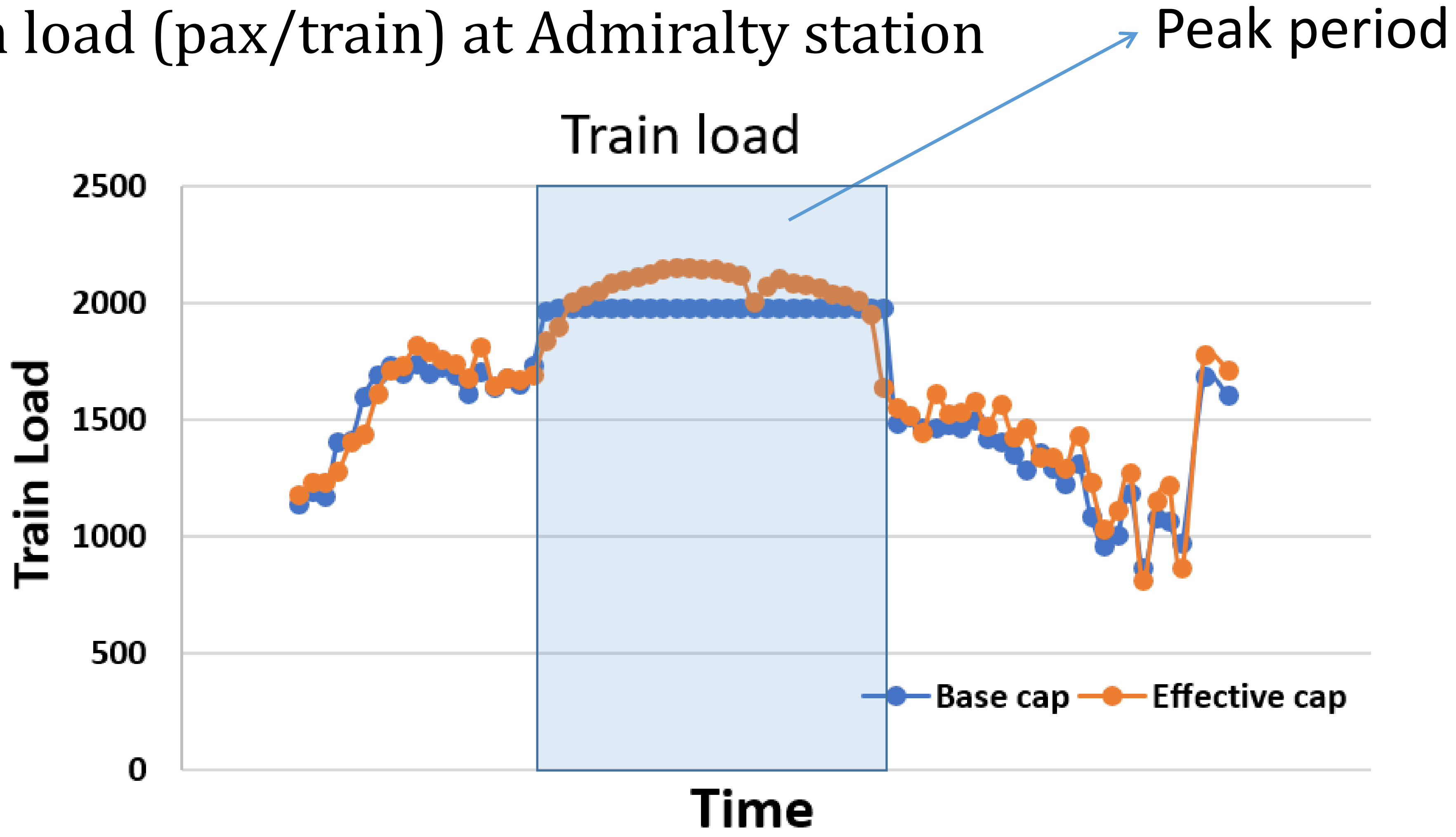
Optimal Solution:

β_1= 0.0904

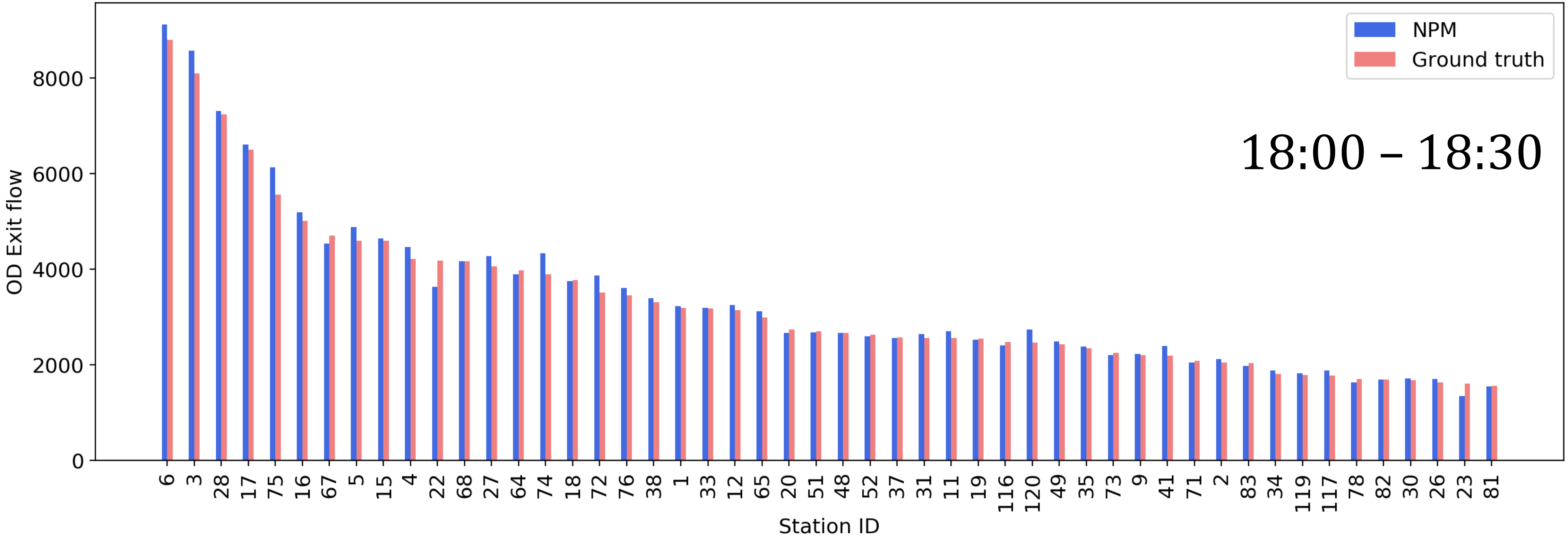
β_2= 0.0718

Results: Effective Capacity

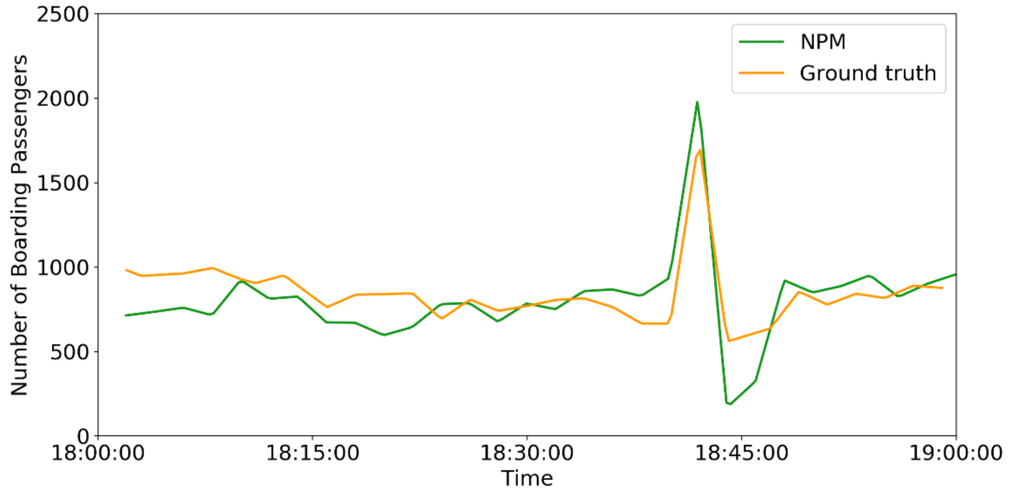
- Train load (pax/train) at Admiralty station



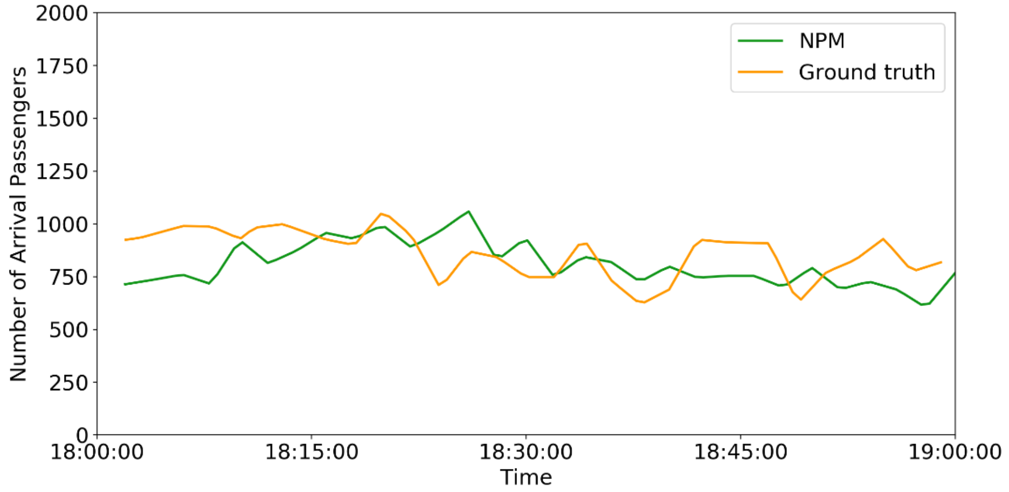
Validation: OD Exit Flow Estimates



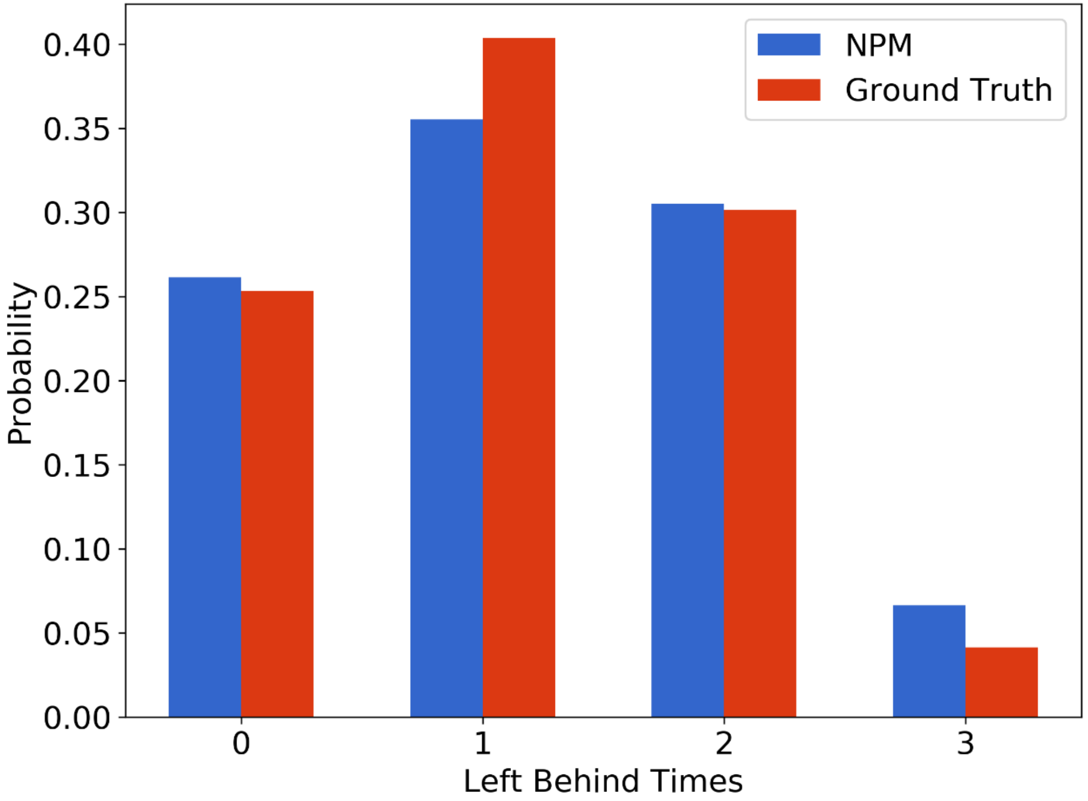
Validation: Left Behind Estimates



Num of boarding pax



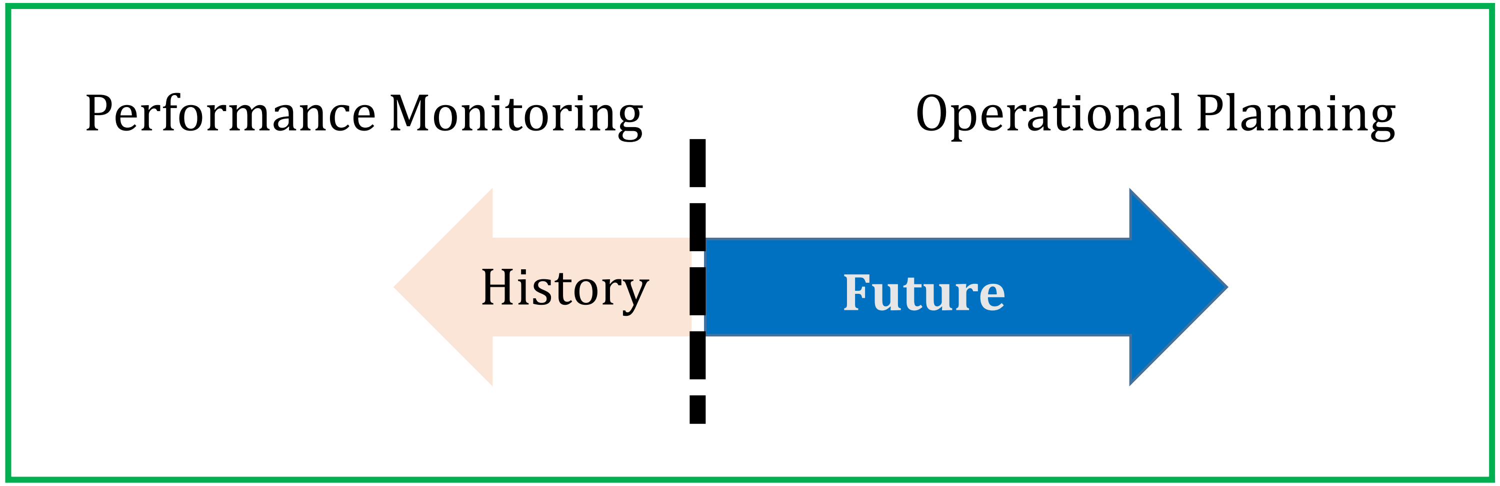
Num of arrival pax



Left behind

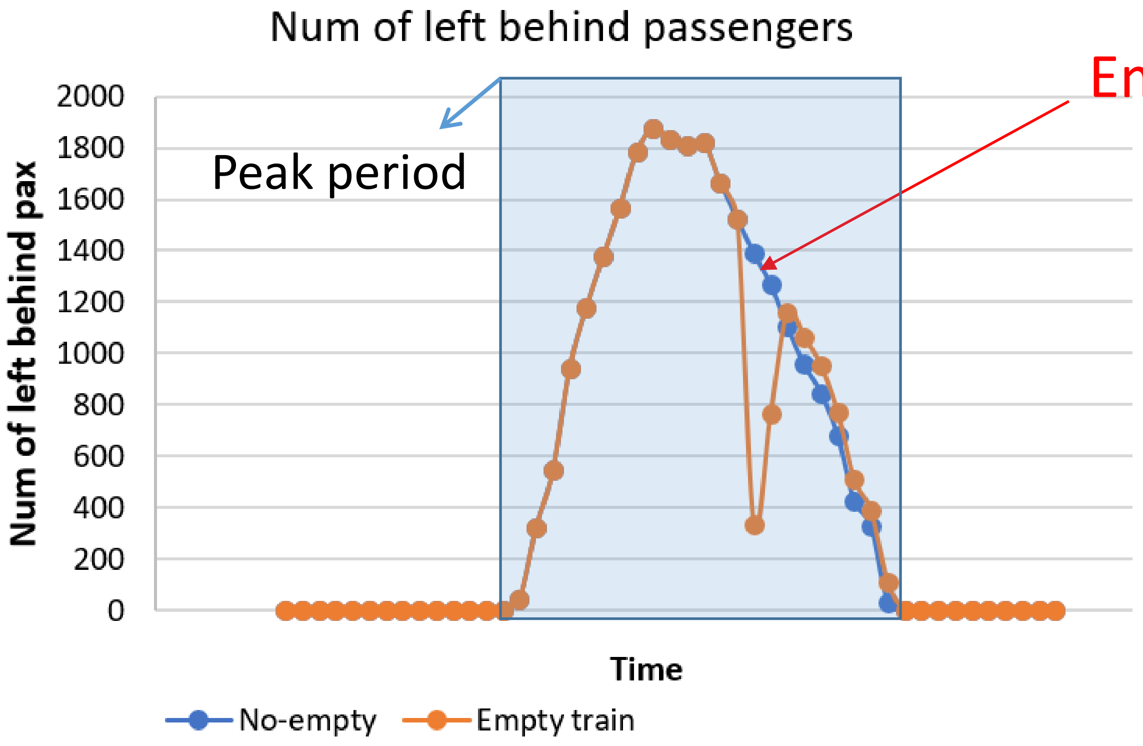
Applications

- [History] **Monitor crowding patterns**: train load, left behind, waiting time, …
- [History] **Diagnose crowding sources**: where does the congestion come from?
- [History] **Evaluate network resilience**: how does system change if link disruption happens?
- [Future] **Operations planning**: time table evaluation, dispatching strategies, …



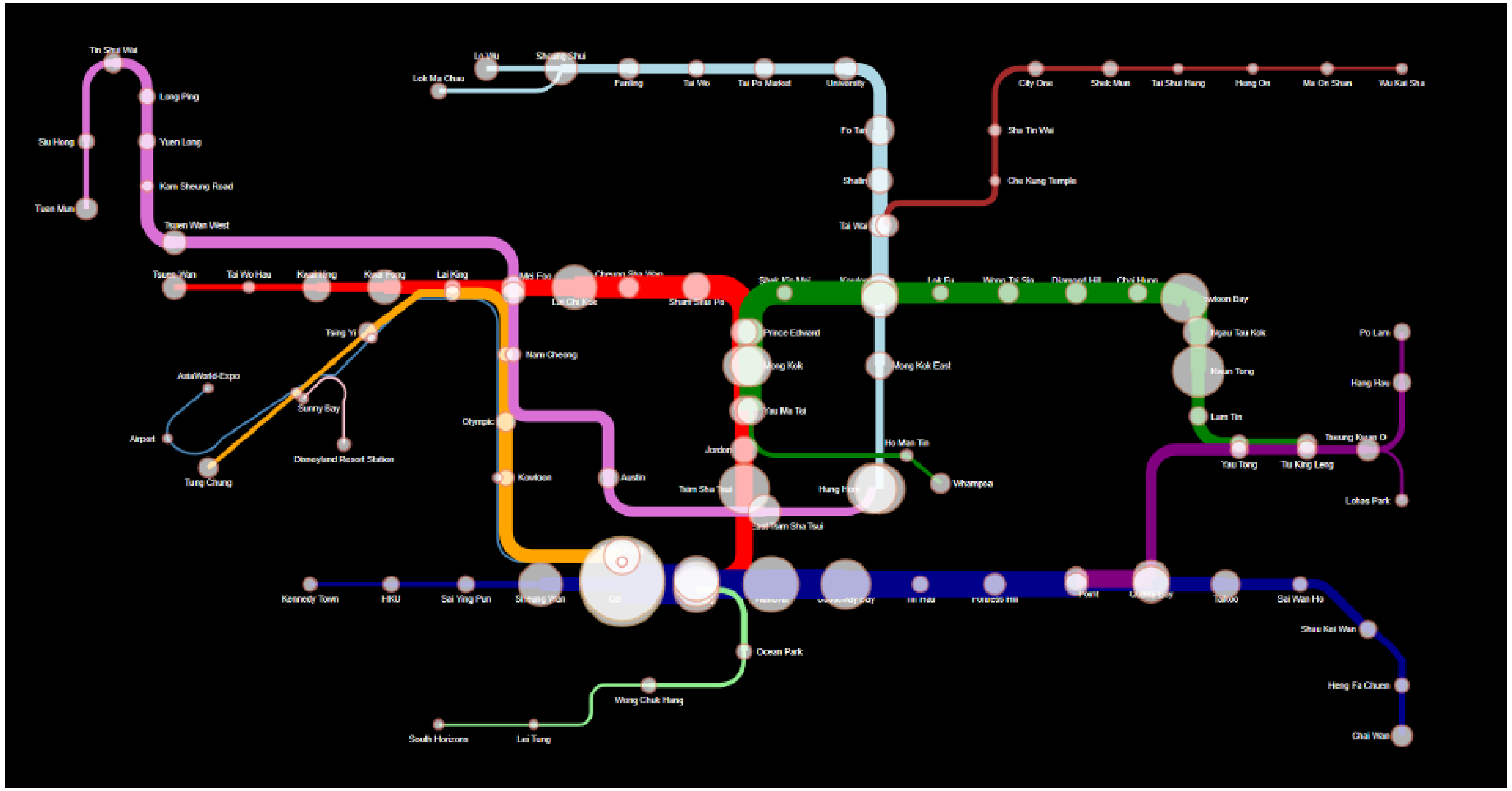
Dispatching strategies evaluation

- Impact of dispatching an empty train from upstream to relieve the crowding in the platform at Admiralty station



Empty train from Station 1 to Station 2

Interactive Visualization



- What is happening?
- What is the problem?
- Why it happens?
- What will happen
  - *if nothing change?*
  - *if things change?*
  - *if actions taken?*

Conclusion

- Data-driven NPM platform:
  - Performance monitoring (what was/is…)
  - Operations control and strategic planning (what if…)
- Effective train capacity formulation
- Effective train calibration using AFC data
- Future work
  - Simultaneous calibration of route choice and train capacity

Thanks

Q&A