1 INTRODUCTION

- The Network Performance Model (NPM) provides performance monitoring and strategic decision support for urban railways.
- Learning passengers’ path choice behavior under station crowding (denied boarding) from automated fare collection (AFC) data is challenging.
- Current path choice studies are formulated based on AFC journey times, assuming no crowding and independence of individual journey times.
- The research addresses the path choice gaps by:
  - Proposing a simulation-based optimization (SBO) framework to estimate route choice using AFC data.
  - Comparing the performance of SBO optimizers.

2 METHODOLOGY

Framework

- **Input**
  - Timetable
  - OD Entry flow
  - Network
  - Capacity
  - Path choice
- **NPM Engine**
- **Performance Monitoring**
  - Station Crowding
  - Waiting Time
  - Train Load
  - Journey Time
  - OD Exit flow
- **SBO Engine**

**Problem formulation**

Minimize the difference (between estimated and observed) of OD exit flows and journey time distribution

\[
\beta \left( \sum_{i,j,k} q_{i,j,k} \right)^2 + \sum_{i,j,k} D_{KL}(p_{i,j,k}(x) \| p_{i,j,k}(s))
\]

Subject to:

- \(q_{i,j,k} = \text{NPM}(\beta, q_{i,j,k}, \theta)\) \(\forall i, j, k\),
- \(p_{i,j,k}(x) = \text{NPM}(\beta, q_{i,j,k}, \theta)\) \(\forall i, j, k \in \mathcal{S}\),
- \(L_\beta \leq \beta \leq U_\beta\),
- \(q^m_{i,j,k} = \text{Number of passengers entering station } i \text{ during time interval } m \text{ and exiting at station } j\),
- \(q^j_{i,j,k} = \text{Number of passengers exiting at station } i \text{ during time interval } n \text{ with origin } i\),
- \(p_{i,j,k}(x) = \text{Journey time distribution for passengers with origin } i, \text{ destination } j, \text{ and exit at time interval } n\),
- \(\beta\): Path choice parameters of a C-logit model
- \(L_\beta\): Lower bound of \(\beta\),
- \(U_\beta\): Upper bound of \(\beta\),
- \(\theta\): External inputs to the NPM model, including time table and transit network typology.

**Model assumption**

- The route choice fractions are estimated using a C-logit model. \(CF\) is the commonality factor.

\[
p_{i,j,k}^* = \frac{\exp(\beta_i \cdot X_{im} + \beta_j \cdot X_{jm} + \beta_k \cdot X_{km} + CF)}{\sum_{i,j,k} \exp(\beta_i \cdot X_{im} + \beta_j \cdot X_{jm} + \beta_k \cdot X_{km} + CF)}
\]

3 SIMULATION-BASED OPTIMIZATION ALGORITHMS

<table>
<thead>
<tr>
<th>Algorithms Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
</tr>
<tr>
<td>Direct search</td>
</tr>
<tr>
<td>Gradient-based</td>
</tr>
<tr>
<td>Response surface</td>
</tr>
</tbody>
</table>

4 RESULTS

**Case study**

- Synthetic data using Hong Kong MTR System
- Generate transaction tap-out times given a ‘true’ path choice model and tap-in times

**Model convergence and estimation results**

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>True Value</th>
<th>Estimated Parameter of C-logit Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMSA</td>
<td>-0.0653</td>
<td>-0.0663</td>
</tr>
<tr>
<td>MADS</td>
<td>-0.0542</td>
<td>-0.0803</td>
</tr>
<tr>
<td>SPSA</td>
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<td>-0.0623</td>
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<tr>
<td>BYO</td>
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<td>-0.0645</td>
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<tr>
<td>Number of transfers</td>
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<td>-0.4295</td>
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<tr>
<td>Transfer walking time</td>
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<td>-0.3100</td>
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<tr>
<td>Map distance</td>
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<td>-0.6132</td>
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<tr>
<td>Commonality factor</td>
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<td>-0.1940</td>
</tr>
<tr>
<td>Objective function</td>
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<td>-0.0908</td>
</tr>
</tbody>
</table>

5 CONCLUSION

- All algorithms converge to a small objective value with a limited number of function evaluations.
- The response surface methods (BYO and CORS) perform best in terms of the convergence speed, objective values and parameter estimates (compared to the ‘true’ choice model parameters).
- Despite a similar objective function value, algorithms may give different \(\beta\) estimates. For example, NMSA results in good value for the coefficients of in-vehicle time and number of transfers, but less accurate results for the commonality factors. SPSA shows similar properties.

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