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Optimization of Coordinated Flow Control and Skip-stopping Schemes for Urban Rail Stations Considering Platform Carrying Capacity

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This study proposes and solves the joint optimization problem of coordinated flow control and skip-stopping scheme considering platform carrying capacity. Platform demand constraints and platform stranded constraints are designed according to the maximum carrying capacity of the platform to control the number of allowable arrivals ensuring platform safety. A mixed integer programming model is established to minimize the number of passengers outside the station and stranded on the platform.

Background & Aim

- ❖ The platform carrying capacity of urban rail transit stations is limited and overcrowding of the platform will lead to serious safety risks for passengers and trains.
- ❖ Available joint optimization problem of coordinated flow control and skip-stopping scheme ignore platform carrying capacity.
- ❖ Available methods usually use the binary variable define arrival varible or depature varible.

The main aim of this study is:

- ❖ To develop coordinated flow control and skip-stopping schemes considering platform carrying capacity.
- ❖ To designe platform demand constraints and platform stranded constraints according to the maximum platform carrying capacity.

Proposed Mathematical Models

➢ Objective Function

❖ The optimisation objective is to jointly minimize the number of passengers outside the station and the number of passengers stranded on the platform.

$$\min Z = \sum_{j=1}^{N^j} \sum_{t=1}^{N^t} (W_j^{out}(t) + W_j^{in}(t))$$

➢ Constraints

❖ Passenger flow control constraints for each time period

$$\begin{cases} E_j(t) = D_j(t), & \forall j \in J, t = 1 \\ E_j(t) = D_j(t) + W_j^{out}(t-1), & \forall j \in J, t \in T/1 \end{cases}$$

$$W_j^{out}(t) = E_j(t) - \overline{E}_j(t), \forall j \in J, t \in T$$

$$E_j(t) \geq \overline{E}_j(t), \forall j \in J, t \in T$$

$$\begin{cases} B_j(t) = \overline{E}_j(t), & \forall j \in J, t = 1 \\ B_j(t) = W_j^{in}(t-1) + \overline{E}_j(t), & \forall j \in J, t \in T/1 \end{cases}$$

❖ Binary variables define train departure times and train parking index

$$t_{i,j}^d = \left[\sum_{t=1}^{N^t} t \cdot d_{i,j}(t)\right] \cdot t_{unit}, \forall i \in I, j \in J, \quad t \in T$$

$$Y_{i,j}(t) = d_{i,j}(t) \cdot a_{i,j}, \forall i \in I, j \in J, t \in T$$

❖ Station-train service capacity constraints for each time period

$$\begin{cases} \overline{B}_{i,j}(t) = Y_{i,j}(t) \cdot \min\{B_j(t), CAP \cdot \varphi\}, \forall i \in I, j = 1, t \in T \\ \overline{B}_{i,j}(t) = Y_{i,j}(t) \cdot \min\{B_j(t), CAP \cdot \varphi - R_{i,j-1} + A_{i,j}\}, \forall i \in I, \\ j \in J/1, t \in T \end{cases}$$

$$\overline{B}_{i,j} = \sum_{t=1}^{N^t} \overline{B}_{i,j}(t), \forall i \in I, j \in J, t \in T$$

$$A_{i,j}(t) = 0, \forall i \in I, j = 1, t \in T$$

$$\begin{cases} R_{i,j} = \overline{B}_{i,j}, & \forall i \in I, j = 1 \\ R_{i,j} = R_{i,j-1} + \overline{B}_{i,j} - A_{i,j}, & \forall i \in I, j \in J/1 \end{cases}$$

$$\overline{B}_j(t) = \sum_{i=1}^{N^i} \overline{B}_{i,j}(t), \forall i \in I, j \in J, t \in T$$

$$Y_j(t) = \sum_{i-1}^{N^i} Y_{i,j}(t), \forall i \in I, j \in J, t \in T$$

$$W_j^{in}(t) = B_j(t) - Y_j(t) \cdot \overline{B}_j(t), \forall i \in I, j \in J, t \in T$$

$$W_j^{out}(t) \geq 0, \forall j \in J, t \in T$$

$$0 \leq \overline{B}_{i,j} \leq CAP \cdot \varphi, \forall i \in I, j \in J$$

$$R_{i,j} \leq CAP \cdot \varphi, \forall i \in I, j \in J$$

❖ Platform capacity constraints

$$0 \leq B_j(t) \leq P_j, \forall i \in I, j \in J, t \in T$$

$$0 \leq W_j^{in}(t) \leq P_j, \forall i \in I, j \in J, t \in T$$

❖ Train operating plan constraints

$$a_{i,1} = a_{i,J} = 1, \forall i \in I, j \in J$$

$$a_{i,j} + a_{i,j-1} \geq 1, \forall i \in I, j \in J$$

$$a_{i,j} + a_{i-1,j} \geq 1, \forall i \in I, j \in J$$

$$\tau_{i,j} = a_{i,j} \cdot \tau, \forall i \in I, j \in J$$

$$t_{i,j}^d = t_{i,j}^a + \tau_{i,j}, \forall i \in I, j \in J$$

$$t_{i,j}^a = t_{i,j}^a + r_j, \forall i \in I, j \in J$$

$$h_{\min} \leq t_{i,j}^d - t_{i,j}^a \leq h_{\max}, \forall i \in I, j \in J$$

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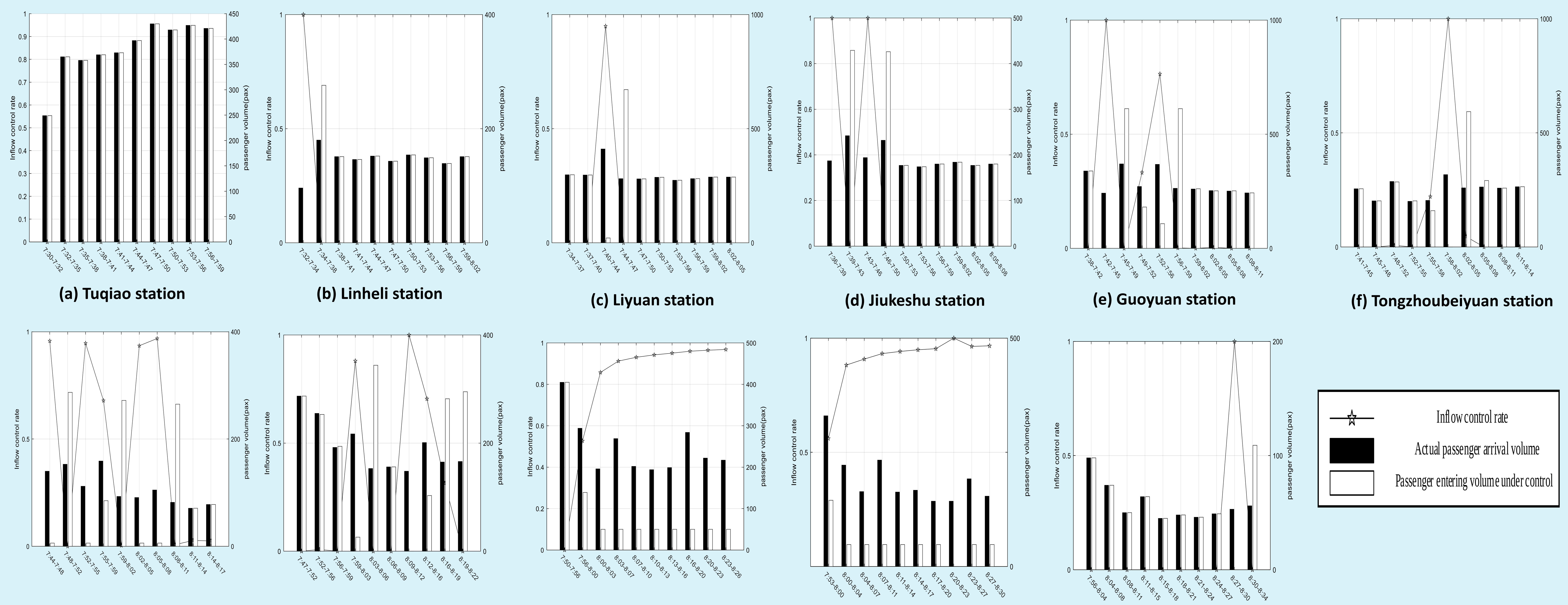
Results

The model is validated through a case study combining experiments simulation and the historical operation (AFC) data with the Beijing Batong line.

❖ The Results of Coordinated Flow Control Based On Stop-skipping Strategy

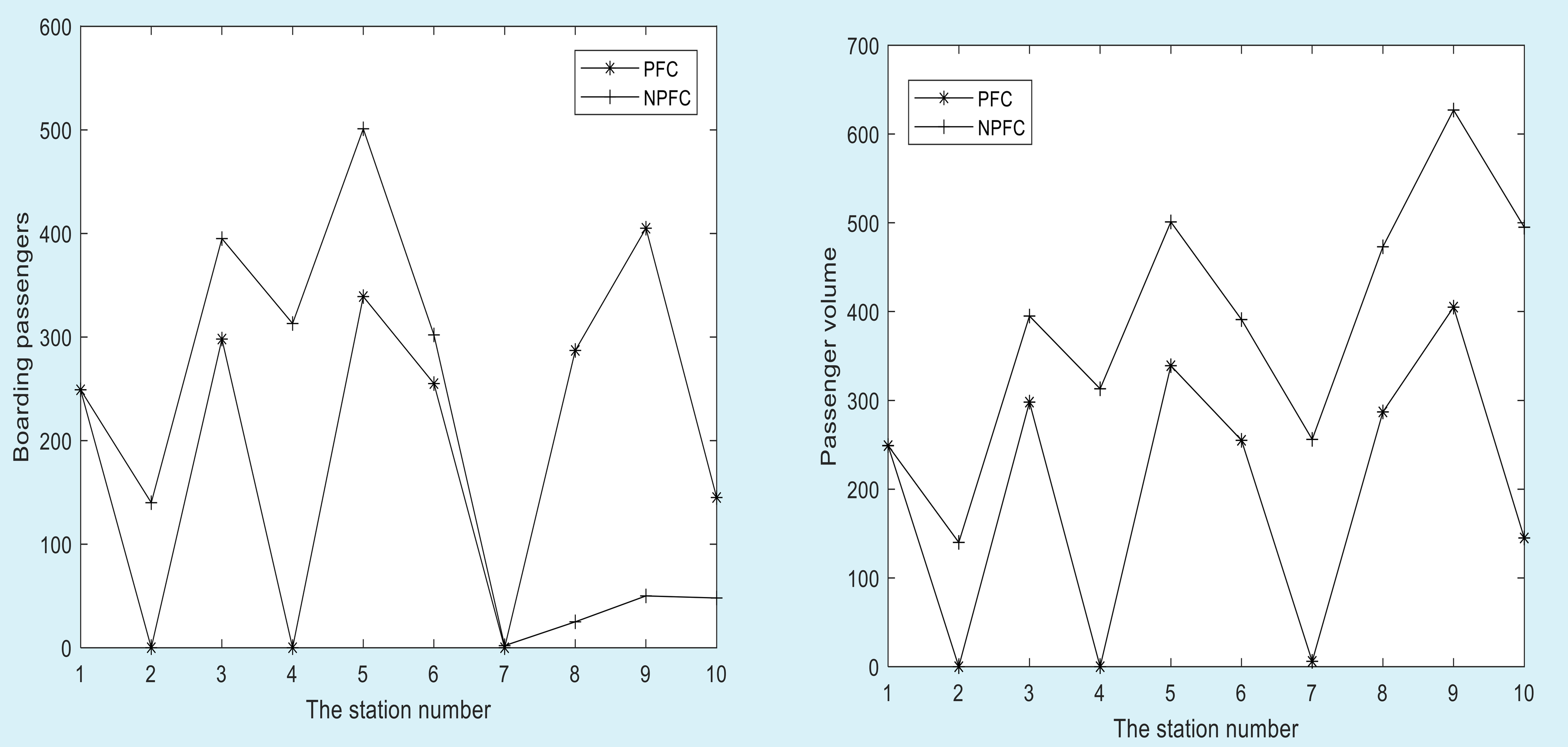


(a) Tuqiao station (b) Linheli station (c) Liyuan station (d) Jiukeshu station (e) Guoyuan station (f) Tongzhoubeiyuan station

(g) Baliqiao station (h) Guanzhuang station (i) Shuagnqiao station (j) Chuanmei Daxue station (k) Gaobeiqiao station Legend

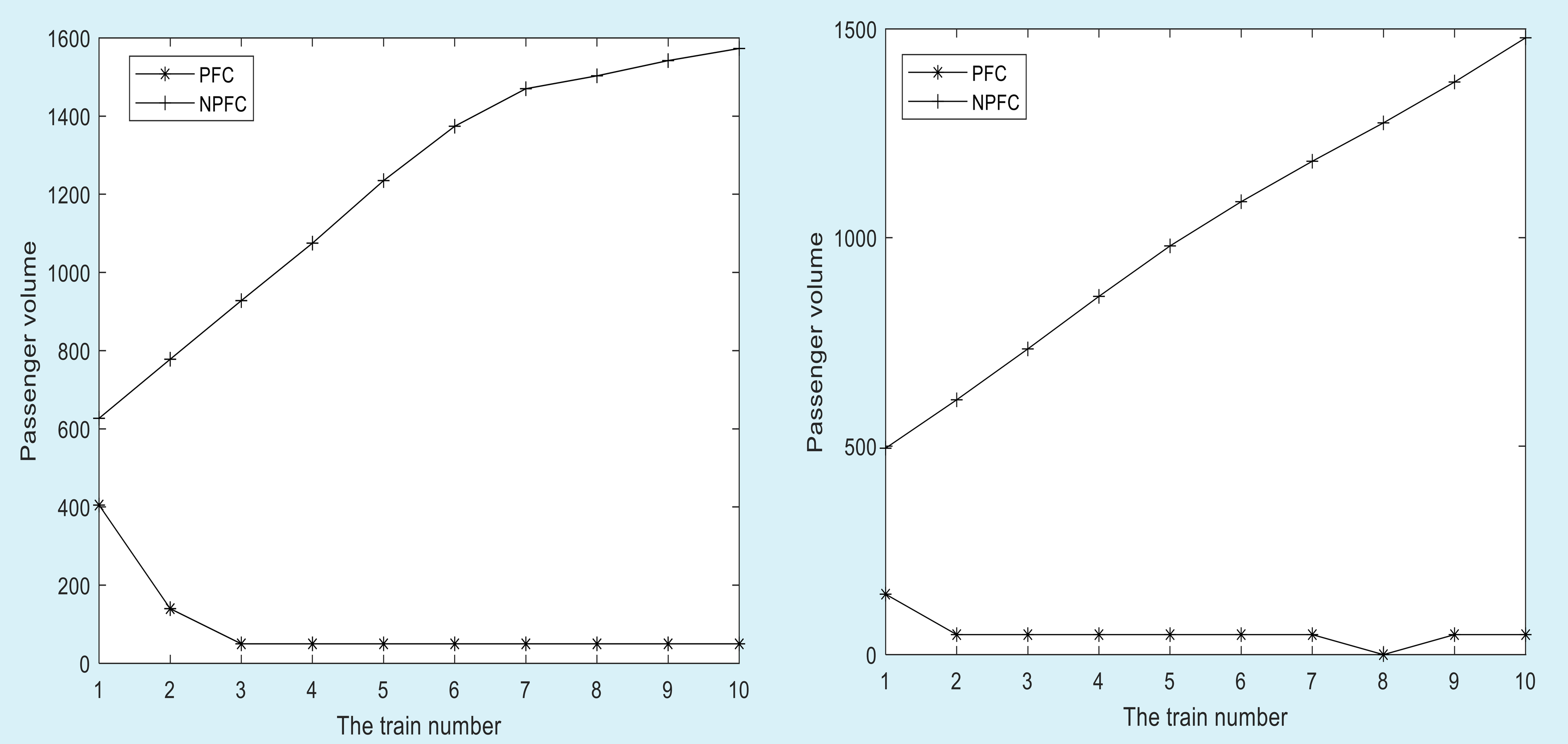
Figure 1.Coordinated passenger inflow control strategy of each station based on skip-stopping.

❖ Comparative Analysis



(a) Number of boarding passengers (b) Platform demand

Figure 2.Number of boarding and platform demand for Train 1 at each station before and after optimization.



(a) Shuangqiao station (b) Chuanmei Daxue Station

Figure 3.Comparison of the number of platform demands before and after the proposed optimization method

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