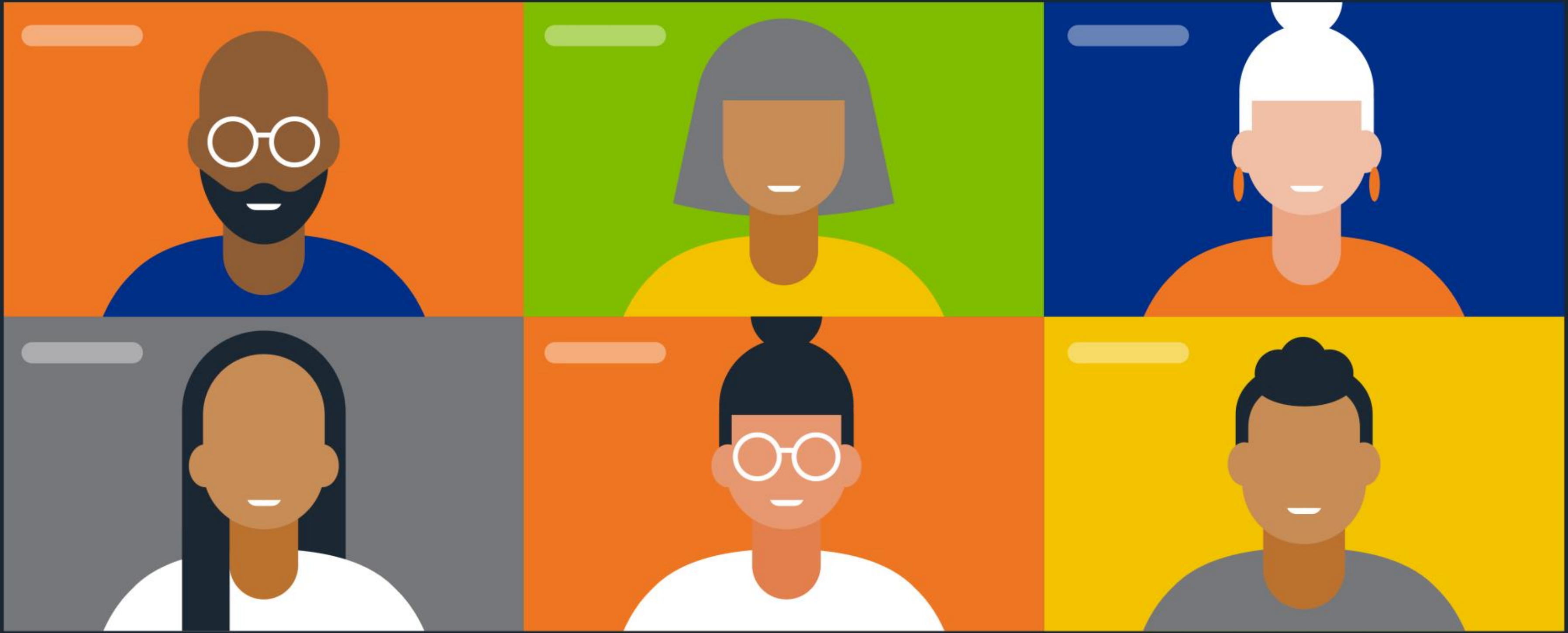

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Integration of the Train and Rolling Stock Rescheduling For Metro System

Presenters: Shuai Su, Boyi Su

OUTLINE

Introduction

Urban Metro

- **One of the most important means of transportation in China.**

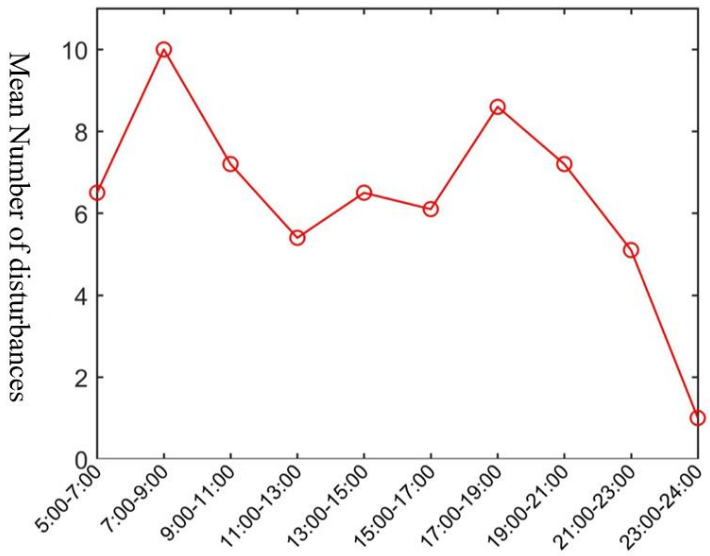
- **By the end of 2019**

40 Cities   6,730 kilometers

Introduction

Disturbances

- **Infrastructure failures**
- **Equipment faults**
- **Staff misoperation**



Introduction

The current way that metro system handles disturbances

Rescheduling	Ordering	Recording
Rescheduling timetable manually	Calling the drivers and notifying the staff in the station	Recording the operation process

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Introduction

Present status of research

Urban metro train timetable rescheduling have attracted extensive attention due to

- short headway time
- uncertain passenger flow
- vulnerability to disturbances

Innovations of this research

Taking practical rescheduling means into account

- train operation strategy during the troubleshooting phase
- integration of train and rolling stock rescheduling

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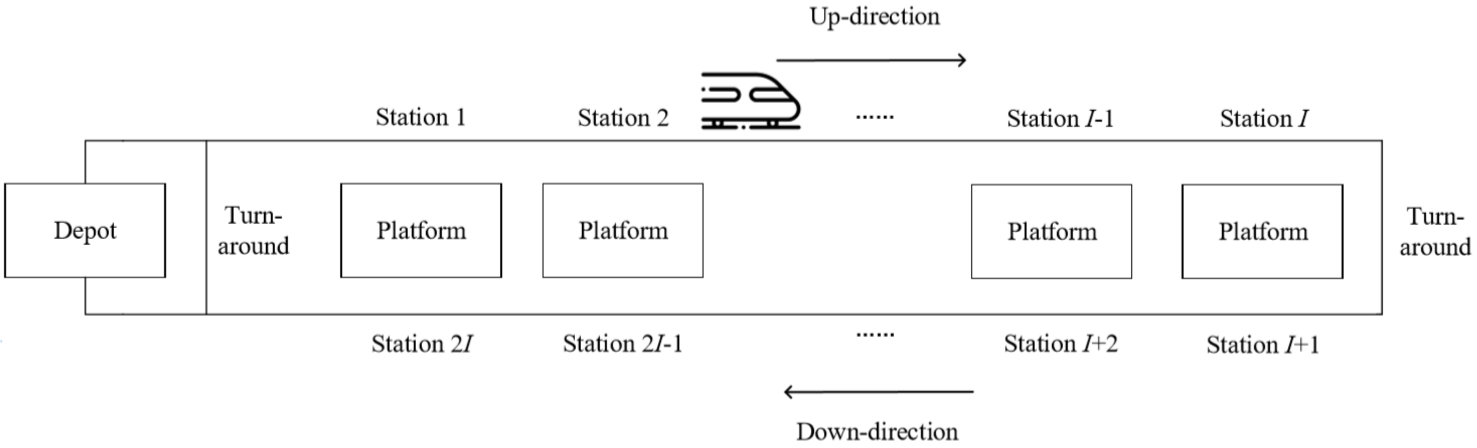
Problem Statement

The considered structure of metro line

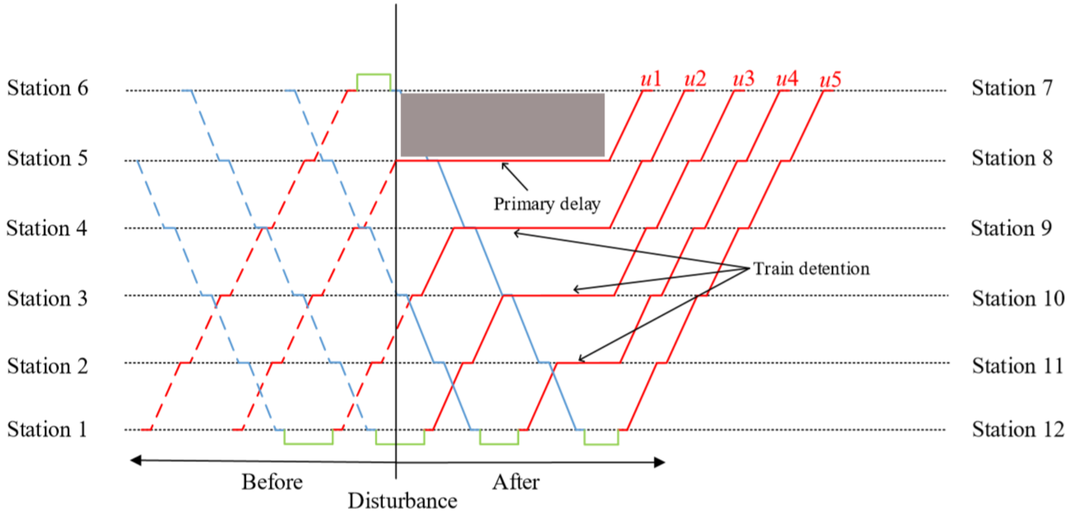
- Two running directions
- One depot
- 2*I* stations
- Some storage lines



Problem Statement

During the troubleshooting phase ▶

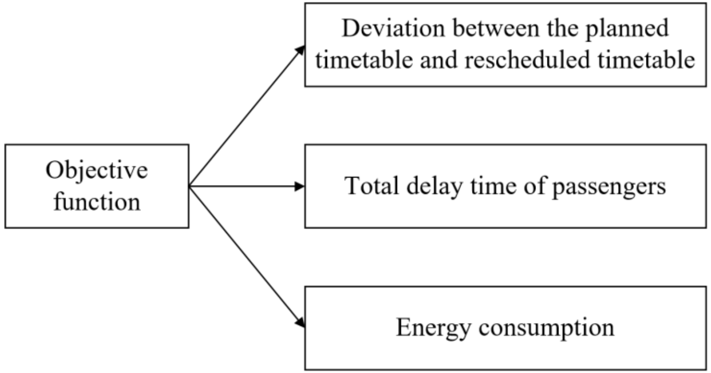
The dispatcher prefers to arrange trains to stop at stations during disturbances, which is defined as train detention.



Problem Statement

Objective Function ▶

$$\min Z = \omega_d T_{deviation} + \omega_t T_{delay} + \omega_e E_{consume}$$



$$T_{deviation} = \sum_{k \in \mathbb{K}} \sum_{i \in \mathbb{I}} \left(\left| T_{k,i}^{arrive} - \tilde{T}_{k,i}^{arrive} \right| + \left| T_{k,i}^{depart} - \tilde{T}_{k,i}^{depart} \right| \right)$$

$$T_{delay} = \sum_{k \in \mathbb{K}, i \in \mathbb{I}} \left[N_{k,i}^{alight} \left(\tilde{T}_{k,i}^{arrive} - T_{k,i}^{arrive} \right) \right]$$

$$E_{consume} = \sum_{k \in \mathbb{K}} \sum_{i \in \mathbb{I}} E_{k,i}$$

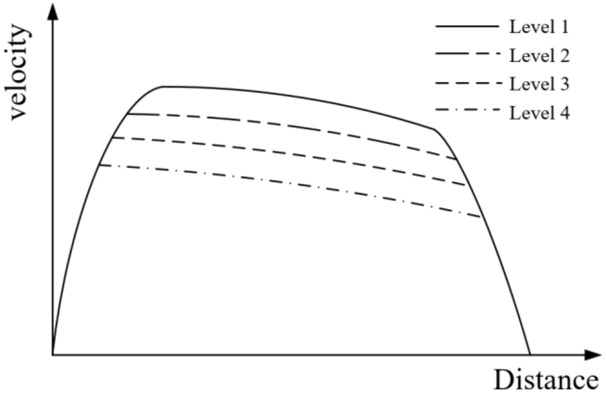
Problem Statement

Constraints ▶

a) Running time constraints

$$\tilde{T}^{\text{arrive}}_{k,i+1} - \tilde{T}^{\text{depart}}_{k,i} = \sum_{l \in \mathbb{L}} \delta^l_{k,i} R^l_{k,i}$$

$$\sum_{l \in \mathbb{L}} \delta^l_{k,i} = 1$$



The running time between two consecutive stations is determined by preprogrammed speed profiles uniquely.

Problem Statement

b) Dwelling time constraints

$$\tilde{T}_{k,i}^{\text{depart}} - \tilde{T}_{k,i}^{\text{arrive}} = \frac{N_{k,i}^{\text{board}} + N_{k,i}^{\text{alight}}}{\lambda}$$

λ is the boarding/alighting speed of passengers.

c) Headway constraints

$$\left(\tilde{T}_{l,i}^{\text{arrive}} - \tilde{T}_{k,i}^{\text{depart}}\right) y_{k,l} \geq h_{\text{min}}$$

$y_{k,l}$ is the sequence indicator, =1 if train service l follows k.

Problem Statement

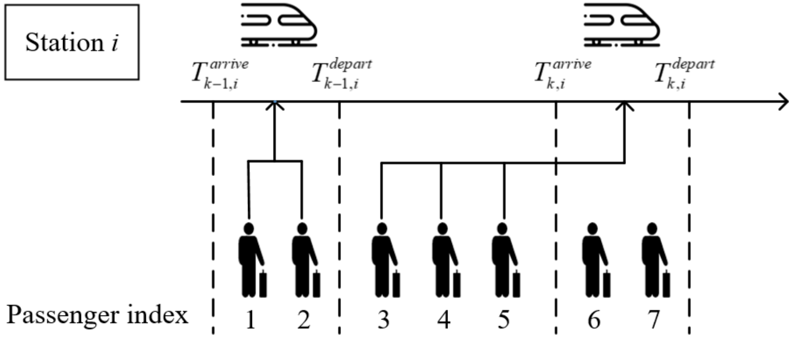
d) Train capacity constraints

$$N_{k,i} = N_{k,i-1} - N_{k,i-1}^{\text{arrive}} + N_{k,i-1}^{\text{board}} \le C$$

- Passenger OD matrix

$$P_{OD}(t) = \begin{pmatrix} p_{1,1}(t) & \cdots & p_{1,2I}(t) \\ \vdots & \ddots & \vdots \\ p_{2I,1}(t) & \cdots & p_{2I,2I}(t) \end{pmatrix}$$

- Passenger boarding and alighting process



$$T_{k,i}^{w} = \min\left\{T_{k,i}^{depart}, \max\left\{t \,\middle|\, C \ge N_{k,i-1} - N_{k,i}^{arrive} + \sum_{j=1}^{i-1}\int_{T_{k-1,j}^{w}}^{t} p_{j,i}(t)dt\right\}\right\}$$

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Problem Statement

e) Rolling stock circulation constraints

The train service *k* can be undertaken by two methods

- turning around of online rolling stock

$$\left(T_{k,i}^{\text{arrive}} - T_{l,i}^{\text{depart}}\right) u_{k,l,i} \geq t_{turn}$$

$u_{k,l,i}$ is the rolling stock succession indicator, =1 if train service k is executed after l by the same rolling stock

Problem Statement

e) Rolling stock circulation constraints

- coming out from the depot by backup rolling stock

$$\left(T_{k,i}^{\text{arrive}} - T_{m}^{\text{depart}}\right) z_{k,m,i} \geq t_{\text{online}}$$

$z_{k,m,i}$ is the rolling stock usage indicator, =1 if train service k is executed by backup rolling stock

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Problem Statement

f) Kinetic constraints

- Basic resistance $R_0 + R_1 \cdot v_{k,i}^l(t) + R_2 \cdot v_{k,i}^l(t)^2$

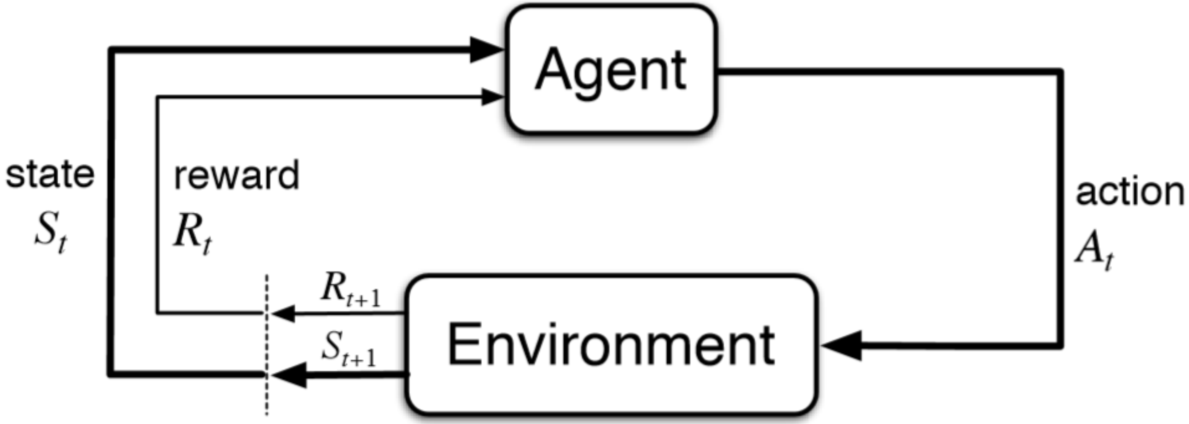
- Slope resistance $M_{k,i} g \cdot \tan\theta_{k,i}(t)$

- Traction $F_{k,i}^l(t) = M_{k,i}\left(a_{k,i}^l(t) + g \cdot \sin\theta_{k,i}(t)\right) + R_0 + R_1 v_{k,i}^l(t) + R_2 v_{k,i}^l(t)^2$

- Energy consumption $E_{k,i} = \delta_{k,i}^l \int_0^{t_{k,i}^{l,a}+t_{k,i}^{l,c}} F_{k,i}^l(t) v_{k,i}^l(t) dt, \forall 1 \leq k \leq K, 1 \leq i \leq 2I$

Solution Methodology

Markov decision process ▶

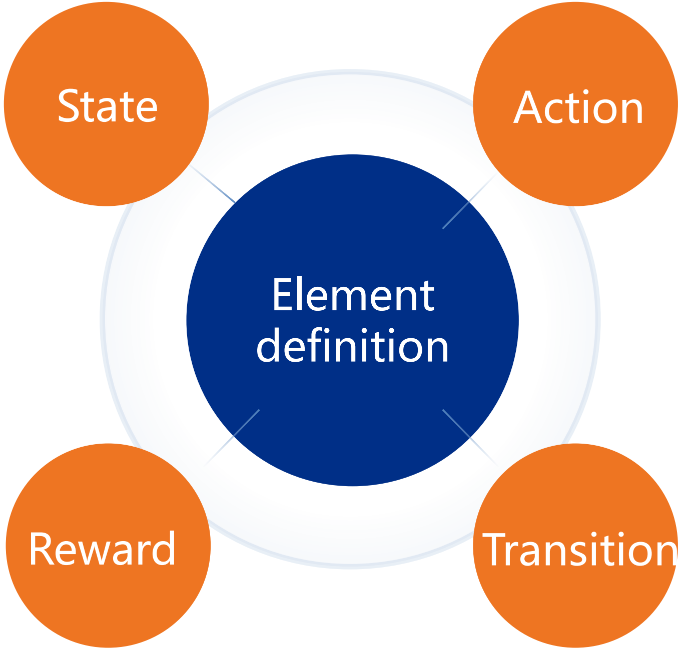


Solution Methodology

Markov decision process ▶

The state variables

for train at stations



The decision for

train at stations

The reward in each

stage determined by

the objective function.

The change of

state variables.

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Solution Methodology

Algorithm ▶

➢ Action selection

ε-greedy policy: With the probability ε, choose the action from the set of feasible actions randomly. With the probability $1-\varepsilon$, choose action by

$$a_i^n(k) = \arg\max_{a \in \mathbb{A}} Q\left(S_i^n(k), a_i^n(k)\right).$$

Solution Methodology

Algorithm ▶

➢ Value function update

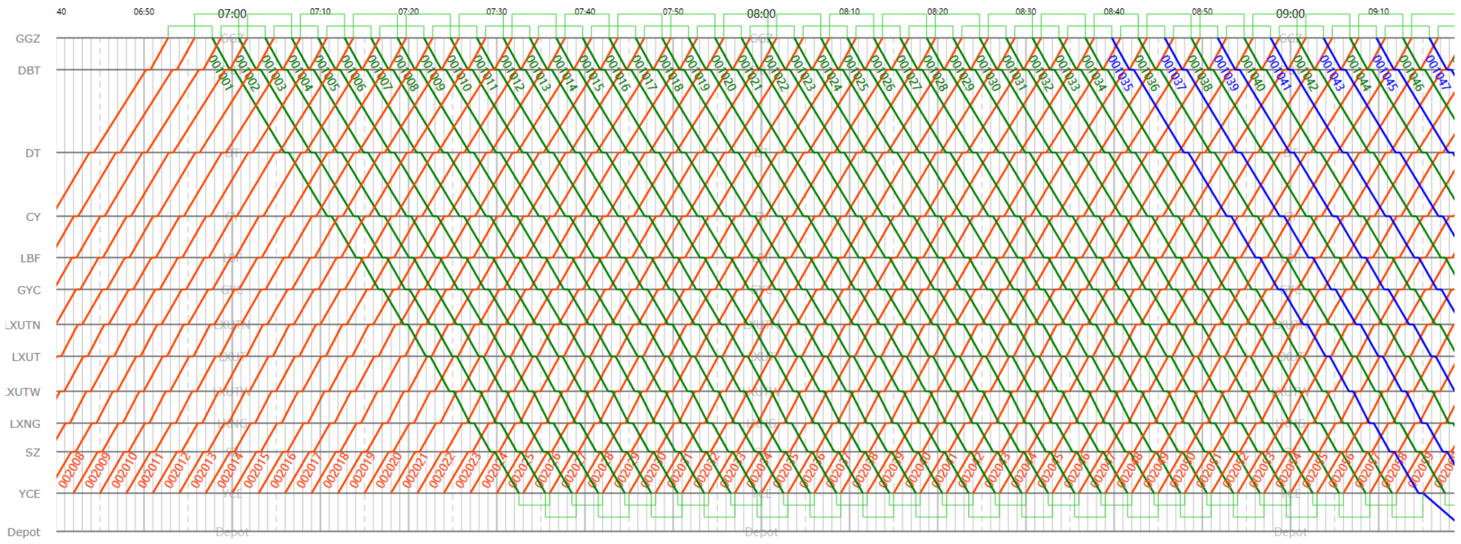
Q-learning:

$$Q(S_t, A_t) \leftarrow Q(S_t, A_t) + \alpha\left[R_{t+1} + \gamma \max_a Q(S_{t+1}, a) - Q(S_t, A_t)\right]$$

α is the learning rate γ is the discount factor

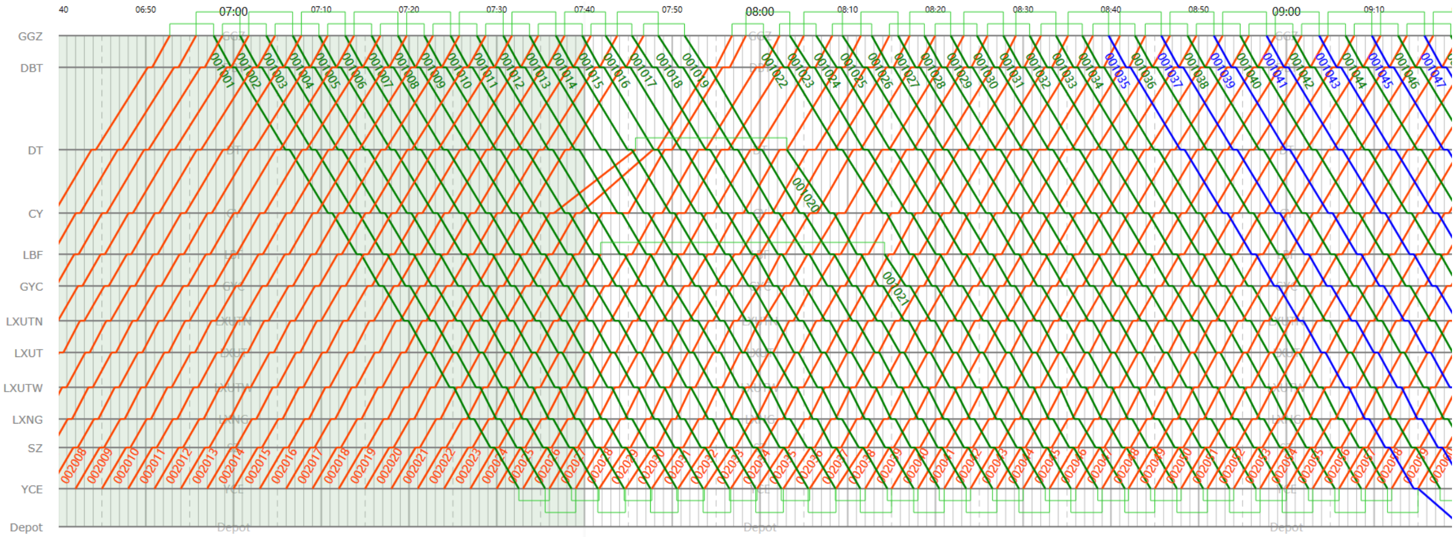
Case Study

Beijing Fangshan Metro Line



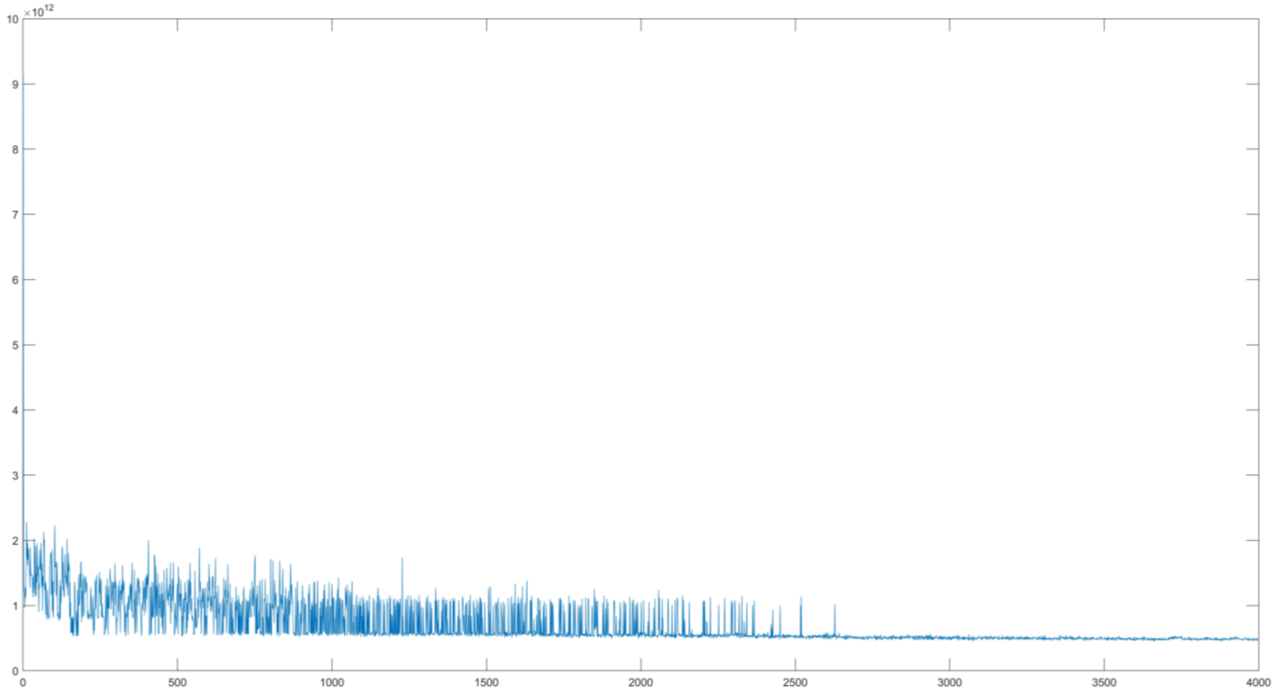
Case Study

Primary delay of 300s



Case Study

Convergence process



Conclusion

- By taking speed profiles in ATO system, time varying passenger flow into consideration, an integrated train and rolling stock rescheduling model is developed.

- an efficient algorithm based on Q-learning approach is designed.

- A tradeoff solution between operational cost and service quality can be generated within a short time.

Thank you for your attention!