A Mixed Encoding Genetic Algorithm for Train Platforming Rescheduling under Train Delays

Shuxin Ding, Tao Zhang, Rongsheng Wang, Yanhao Sun, Xiaozhao Zhou, and Chen Chen

Signal and Communication Research Institute, Train Operation Control Laboratory for High-Speed Railway, National Engineering Research Center of System Technology for High-Speed Railway and Urban Rail Transit, China Academy of Railway Sciences Corporation Limited

Postgraduate Department, China Academy of Railway Sciences

School of Automation, Key Laboratory of Intelligent Control and Decision of Complex Systems, Beijing Institute of Technology

The 10th International Symposium on Computational Intelligence and Industrial Applications (ISCIIA2022) Sep.23-Sep.25, 2022, Beijing, China

Outline

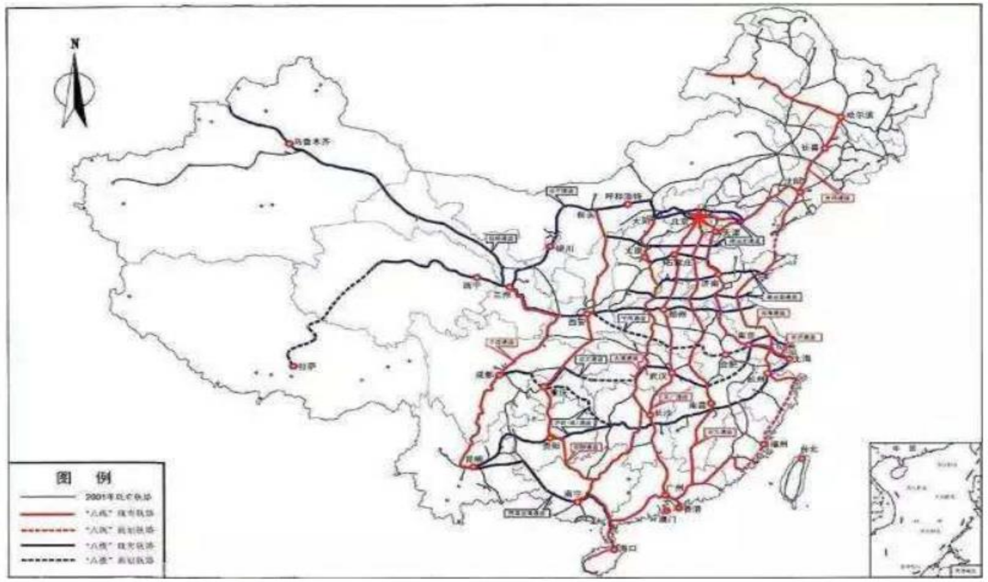
- Introduction
- Problem Formulation
- Proposed Method
- Computational Experiments
- Concluding Remarks

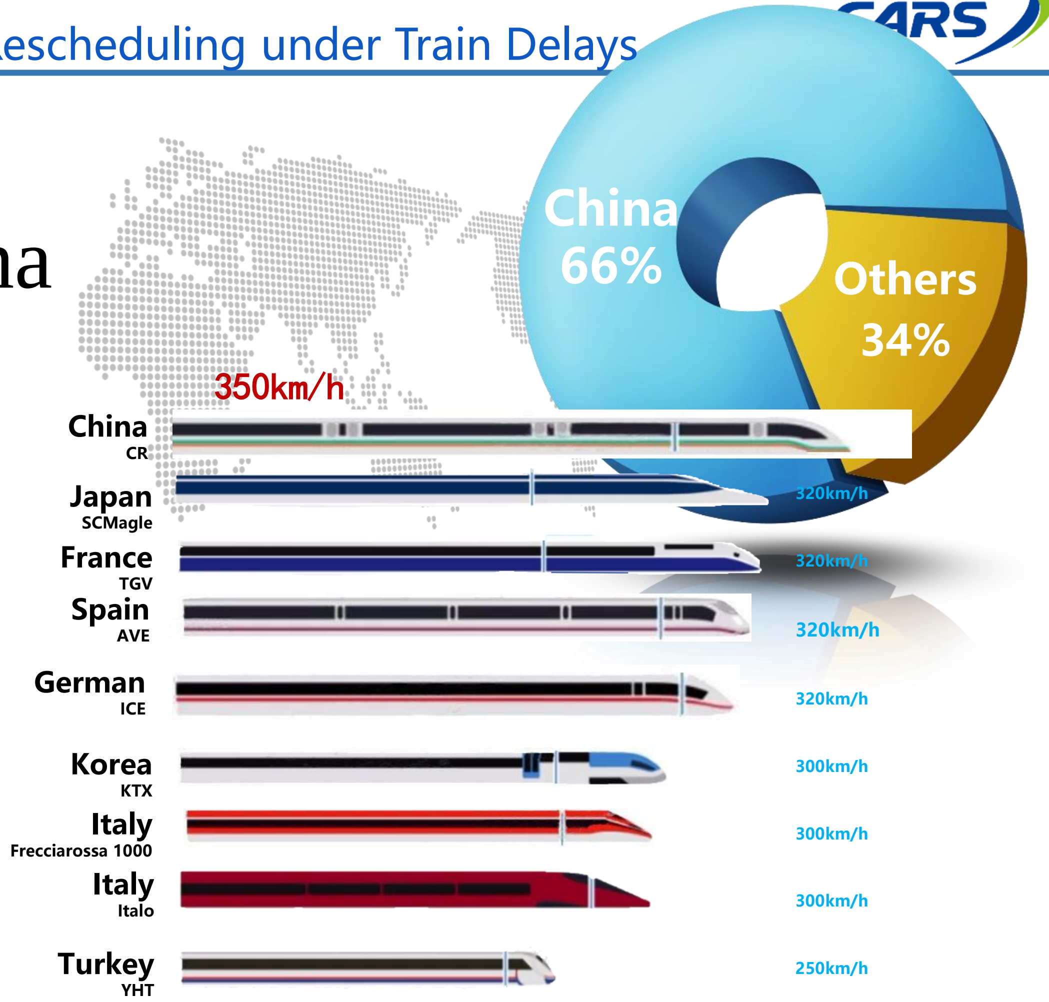
Introduction

China High-Speed Railway (HSR)——40000 kilometers

Operation as a network only in China

China High-Speed Railway Network





It is a great challenge to keep the HSR operate punctually

Large network size	High operation speed	High traffic density	Large amount of operation	Complex transportation organization	Diversified travel demand

Rescheduling is the key issue for emergency decision under disruption

- If the dispatching is not reasonable, once an emergency occurs, it is easy to cause a large area of train delay and other serious consequences, bringing inconvenience to passengers and reducing the operation efficiency of high-speed railway

2021.05

Beijing-Tianjin intercity high-speed railway with severe delay since overhead line with foreign matter

2018.12

Heavy snow cause multiple train delay in Changsha South Station

How to propose a simple and effective rescheduling model and a fast solution algorithm has become an urgent need for the efficient operation of high-speed railway in China!

Train dispatching system is the "brain" and "commander" of high-speed railway system

Real Application

Mainly handled by dispatchers based on their experience under emergencies

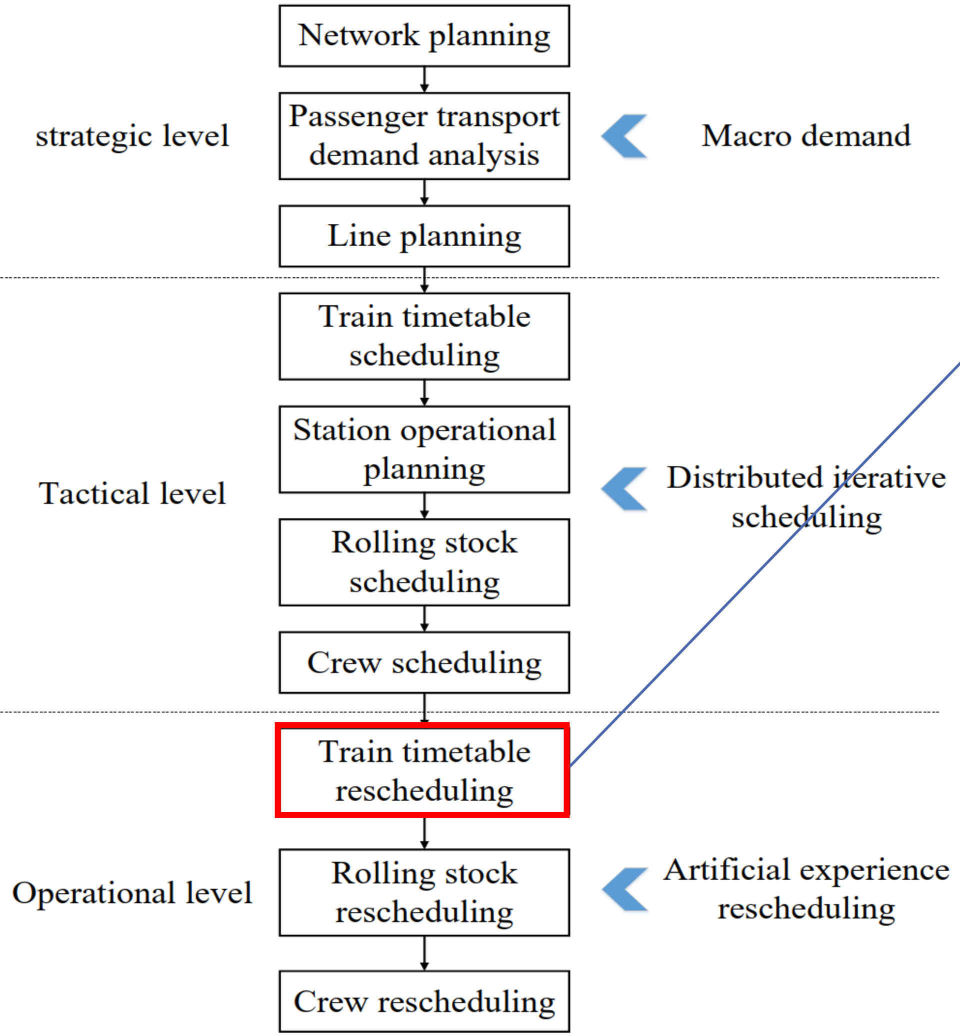
Manual scheduling decision is not optimal decision, which cannot guarantee high efficiency and precise operation

Theoretical research

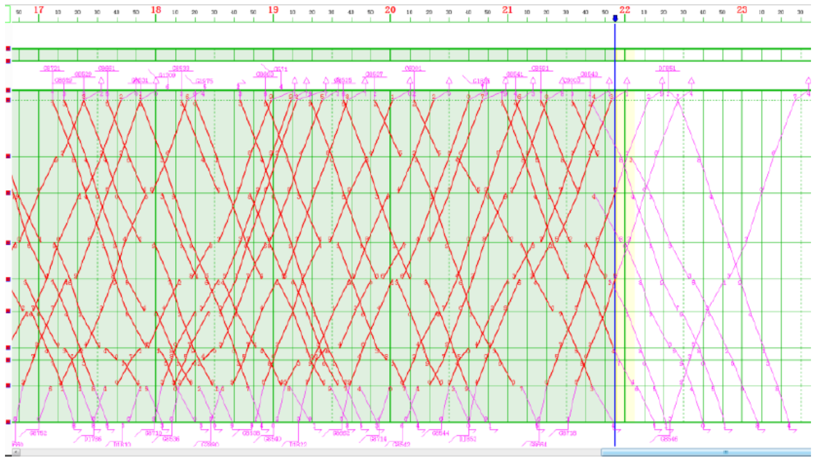
①Formulate mixed integer linear/nonlinear programming models (MILP/MINLP)
②Use exact method, metaheuristics, or AI technique

① NP-hard
② Time consuming and suboptimal

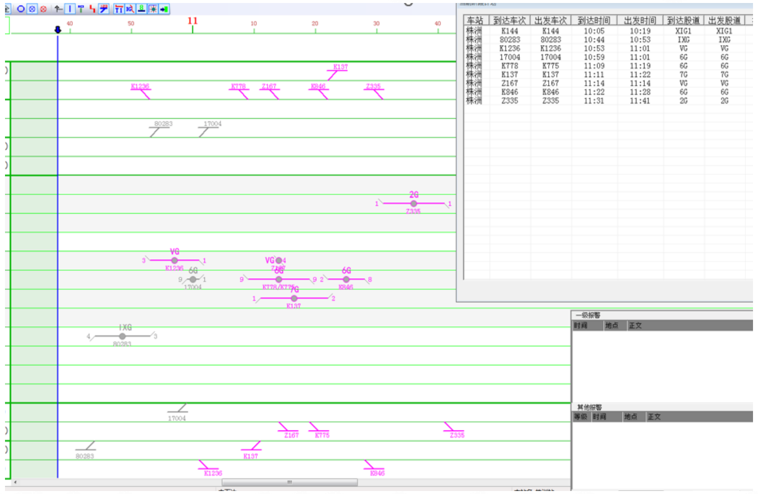
Different levels in railway planning and scheduling



Train Timetable Rescheduling



Train Platforming Rescheduling



Minimize total delay/total platform track assignment costs/…

Paper Contribution

- The train platforming rescheduling problem with train delays is proposed and modeled as an MINLP problem.
- An effective genetic algorithm is proposed, with a novel mixed encoding method with integer and permutation encoding schemes for solution representation and a rule-based decoding method to obtain a new train platform schedule. These encoding and decoding methods can manage the entire constraints and guarantee the feasibility of the solution.
- Experimental results show the efficiency and effectiveness of the proposed GA compared with other algorithms.

Problem Formulation

Decision Variables

Symbol	Description
$x_{l,i}$	actual platform track assignment of train *l*, 1 if train *l* occupies platform track *i*; 0 otherwise
t_l^a	actual arrival time of train *l*
t_l^d	actual departure time of train *l*
$q_{l,k}^d$	actual order for train departure, 1 if train *l* departures before train *k*; 0 otherwise

$$t_l^a, t_l^d \geq 0 \qquad x_{l,i} \in \{0,1\} \qquad q_{l,k}^d \in \{0,1\}$$

Formulation

Objective function

- Minimize the weighted sum of the total train arrival/departure delays and the rescheduling costs of the train platform schedule

$$\min Z = Z_1 + wZ_2$$

$$Z_1 = \sum_{l \in L} (t_l^a - T_l^a) + \sum_{l \in L} (t_l^d - T_l^d) \quad (1)$$

$$Z_2 = \sum_{l \in L} \mathrm{sgn}(t_l^a - T_l^a) + \sum_{l \in L} \mathrm{sgn}(t_l^d - T_l^d) + \sum_{l \in L} \sum_{i \in I} 0.5 |X_{l,i} - x_{l,i}| \quad (2)$$

Formulation

Constraints

- Platform track assignment constraint
- Headway constraint for departure headway and arrival headway
- Departure order constraint of two trains at the station
- Dwelling time constraint
- The arrival and departure times constraint

Formulation

Constraints

- Platform track assignment constraint

$$\sum_{i \in I} x_{l,i} = 1, \quad \forall l \in L \tag{3}$$

- Headway constraint for departure headway and arrival headway

$$t_k^a - t_l^d \geq Tsq_{l,k}^a - M(3 - x_{l,i} - x_{k,i} - q_{l,k}^a), \quad \forall l,k \in L, \; l \neq k, i \in I \tag{4}$$

$$t_k^a - t_l^a \geq h^a q_{l,k}^a - M(1 - q_{l,k}^a), \quad \forall l,k \in L, l \neq k \tag{5}$$

$$t_k^d - t_l^d \geq h^d q_{l,k}^d - M(1 - q_{l,k}^d), \quad \forall l,k \in L, l \neq k \tag{6}$$

- Departure order constraint of two trains at the station

$$q_{l,k}^d + q_{k,l}^d = 1, \quad \forall l,k \in L, l \neq k \tag{7}$$

- Dwelling time constraint

$$t_l^d - t_l^a \geq T_l^d - T_l^a, \quad \forall l \in L \tag{8}$$

- The arrival and departure times constraint

$$\tau_l^a = T_l^a + d_l, \quad \forall l \in L \tag{9}$$

$$t_l^a \geq \tau_l^a, \quad \forall l \in L \tag{10}$$

$$t_l^d \geq T_l^d, \quad \forall l \in L \tag{11}$$

The problem is an **mixed integer nonlinear programming** problem which belongs to **NP-hard**

Model Reformulation

$$Z_2 = \sum_{l \in L} \mathrm{sgn}(t_l^a - T_l^a) + \sum_{l \in L} \mathrm{sgn}(t_l^d - T_l^d) + \sum_{l \in L} \sum_{i \in I} 0.5 |X_{l,i} - x_{l,i}| \quad (2)$$

Nonlinear terms

$$\begin{cases} r_1^l = \mathrm{sgn}(t_l^a - T_l^a) \\ r_2^l = \mathrm{sgn}(t_l^d - T_l^d) \\ r_3^{li} = |X_{l,i} - x_{l,i}| \end{cases}$$

$$Z_3 = \sum_{l \in L} r_1^l + \sum_{l \in L} r_2^l + \sum_{l \in L} \sum_{i \in I} 0.5 r_3^{li} \quad (17)$$

$$\min\ Z = Z_1 + wZ_3 \quad (18)$$

$$\text{s.t. } Mr_1^l \geq t_l^a - T_l^a, \quad \forall l \in L \quad (19)$$

$$Mr_2^l \geq t_l^d - T_l^d, \quad \forall l \in L \quad (20)$$

$$r_1^l \leq t_l^a - T_l^a, \quad \forall l \in L \quad (21)$$

$$r_2^l \leq t_l^d - T_l^d, \quad \forall l \in L \quad (22)$$

$$r_3^{li} \geq X_{l,i} - x_{l,i}, \quad \forall l \in L, i \in I \quad (23)$$

$$r_3^{li} \geq x_{l,i} - X_{l,i}, \quad \forall l \in L, i \in I \quad (24)$$

$$r_1^l, r_2^l \in \{0,1\}, \quad \forall l \in L \quad (25)$$

$$r_3^{li} \in \{0,1\}, \quad \forall l \in L, i \in I \quad (26)$$

$$\text{Constraints } (3)-(14). \quad (27)$$

The reformulated problem is an **mixed integer linear programming** problem which belongs to **NP-hard**

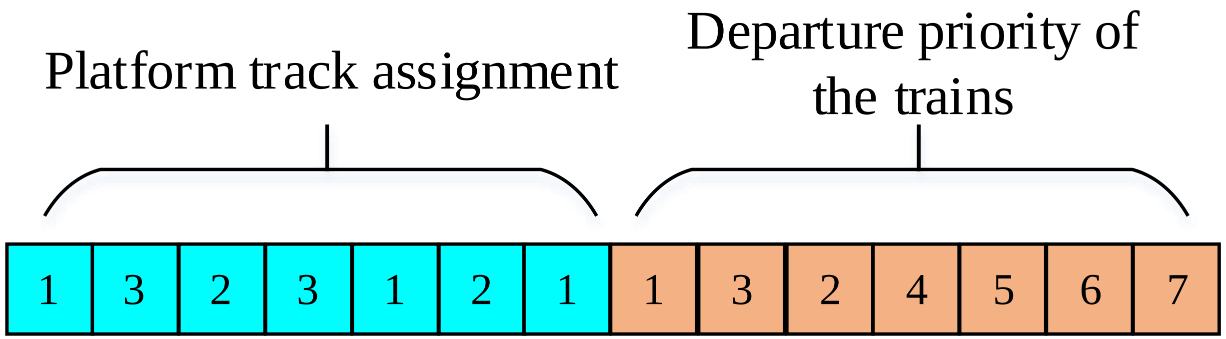
Proposed Method

Encoding and Decoding

- Using a mixed encoding with integer-value and permutation-value

I: Set of tracks L: Set of trains

  - e.g., 3 tracks 7 trains
  - Range [1, $|I|$]. ($|I| = 3$)
  - Range [1, $|L|$]. ($|L| = 7$)



- There are unfeasible region if we use real-value encoding to represent the adjusted arrival and departure time, and constraints handling should be designed
- The dimension and solution space is much smaller with the permutation-based encoding

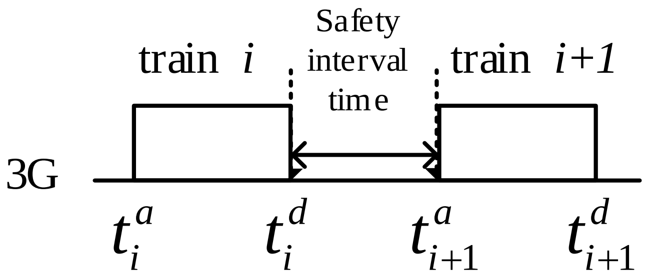
Encoding and Decoding

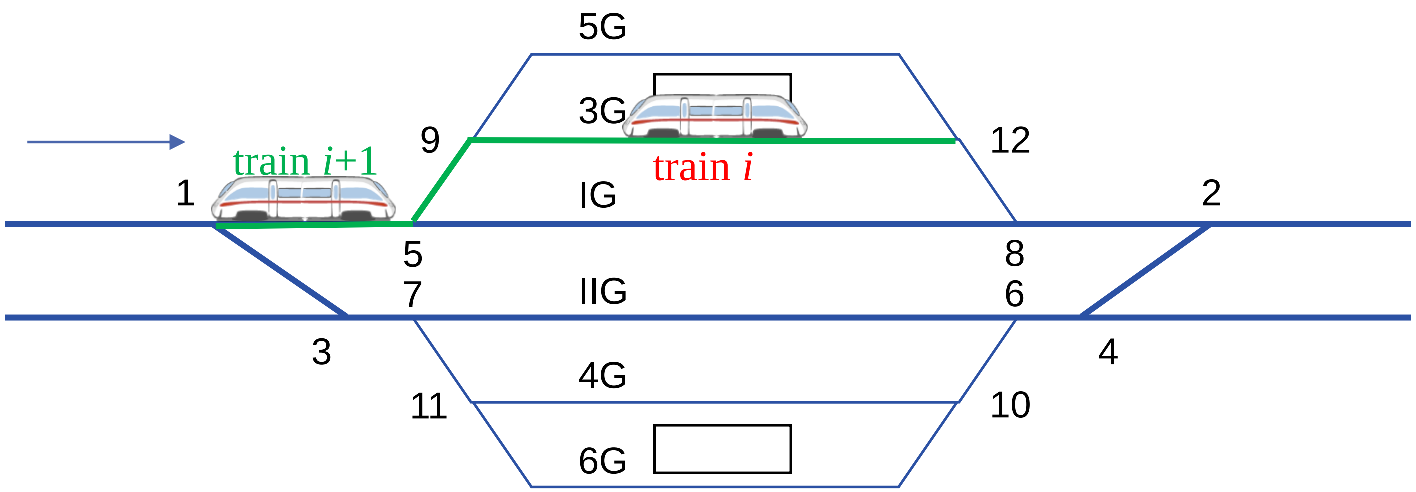
- Obtain the occupied track and arrival/departure time through the decoding procedure
  - Occupied track is obtained through the integer-based encoding
  - Departure order is obtained through the permutation-based encoding
  - Decide arrival/departure time satisfying different constraints

Encoding and Decoding

- Obtain the occupied track and arrival/departure time through the decoding procedure
  - Conflicts when trains occupy the same platform track

The arrival and departure time of the subsequent train is adjusted according to the safety interval time constraint

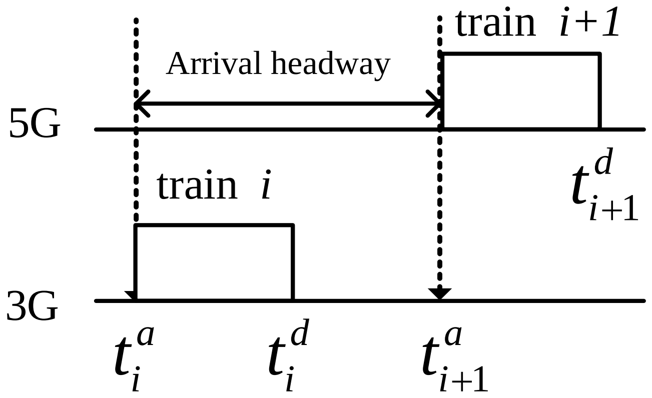


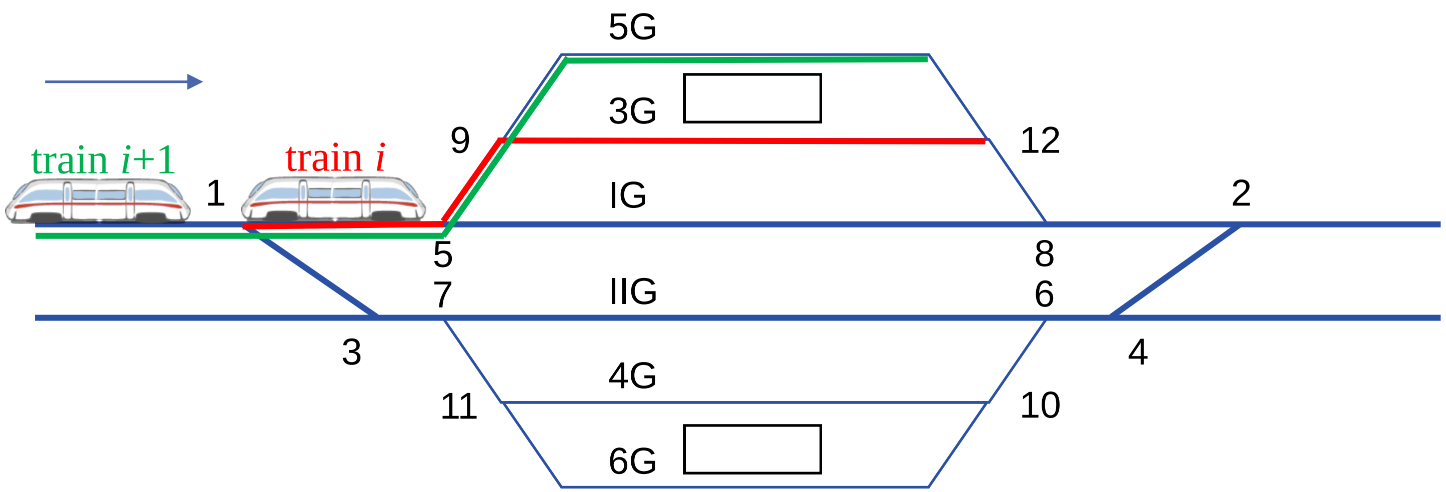


Encoding and Decoding

- Obtain the occupied track and arrival/departure time through the decoding procedure
  - Conflicts in the arrival routes

The arrival and departure time of the subsequent train is adjusted according to the arrival headway constraint

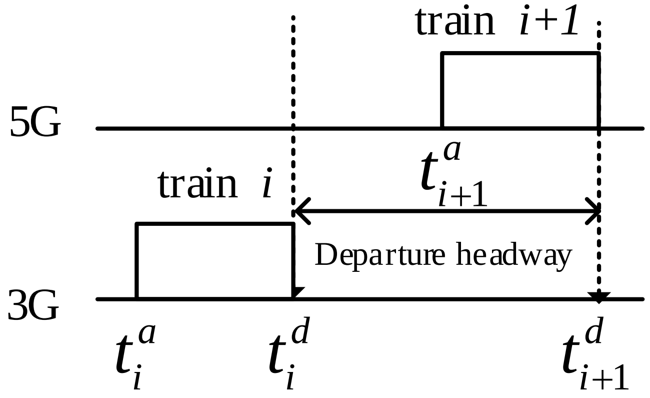


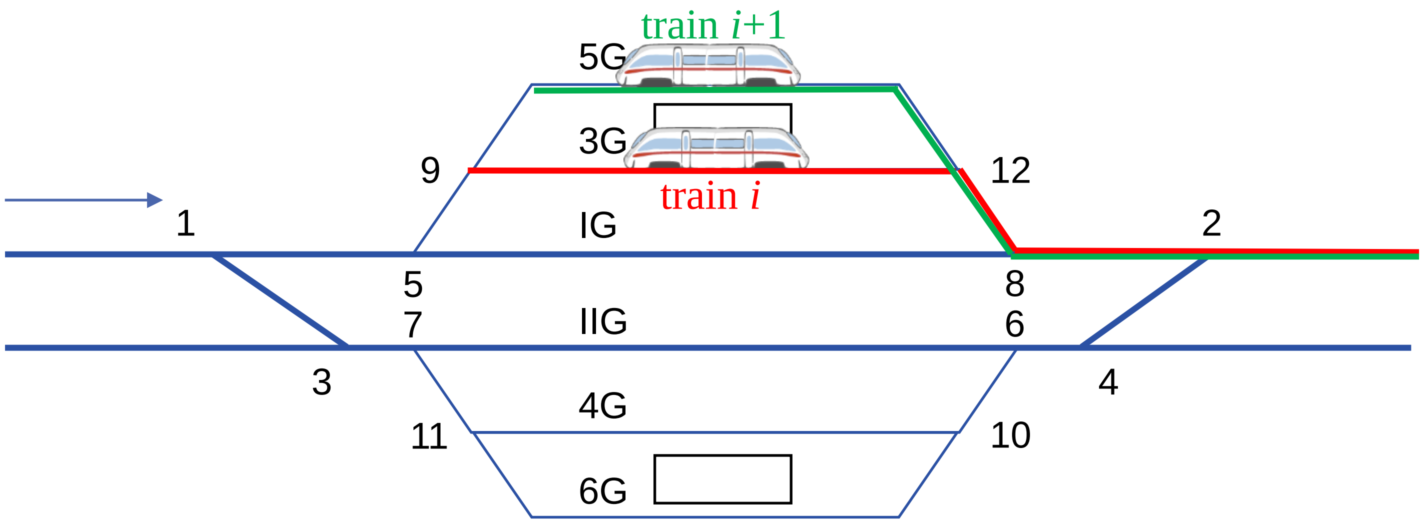


Encoding and Decoding

- Obtain the occupied track and arrival/departure time through the decoding procedure
  - Conflicts in the departure routes

The departure time of affected trains with lower priority is adjusted according to the departure headway constraint



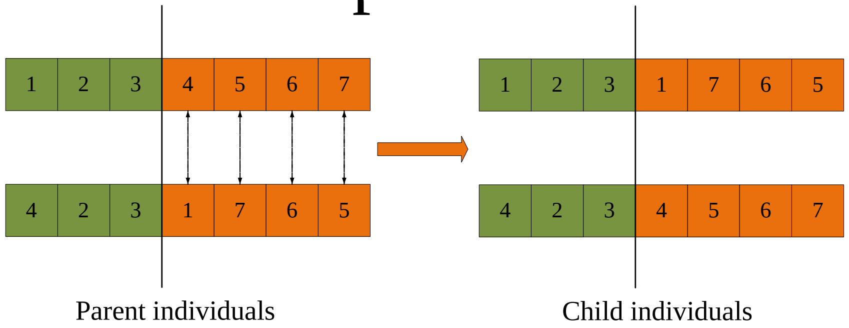


Proposed Genetic Algorithm

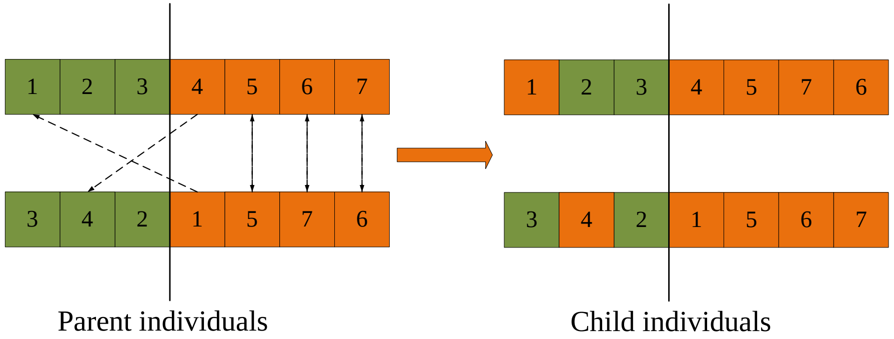
- Population Initialization
  - Platform track assignment randomly generated integer with the range [1, $|I|$]
  - Train departure priority randomly generated permutation with the range [1, $|L|$]
- Selection Operator
  - Roulette wheel selection
  - The individuals are selected with a probability according to their fitness values.

Proposed Genetic Algorithm

- Crossover Operator

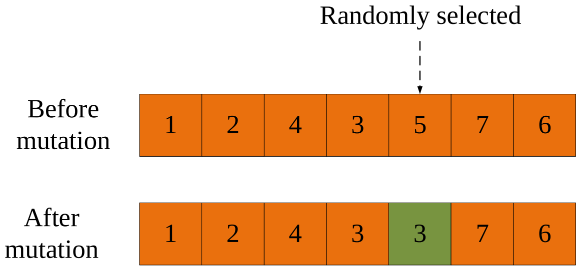


Single-point crossover for the integer value encoding



Modified order crossover for the permutation-value encoding

- Mutation Operator



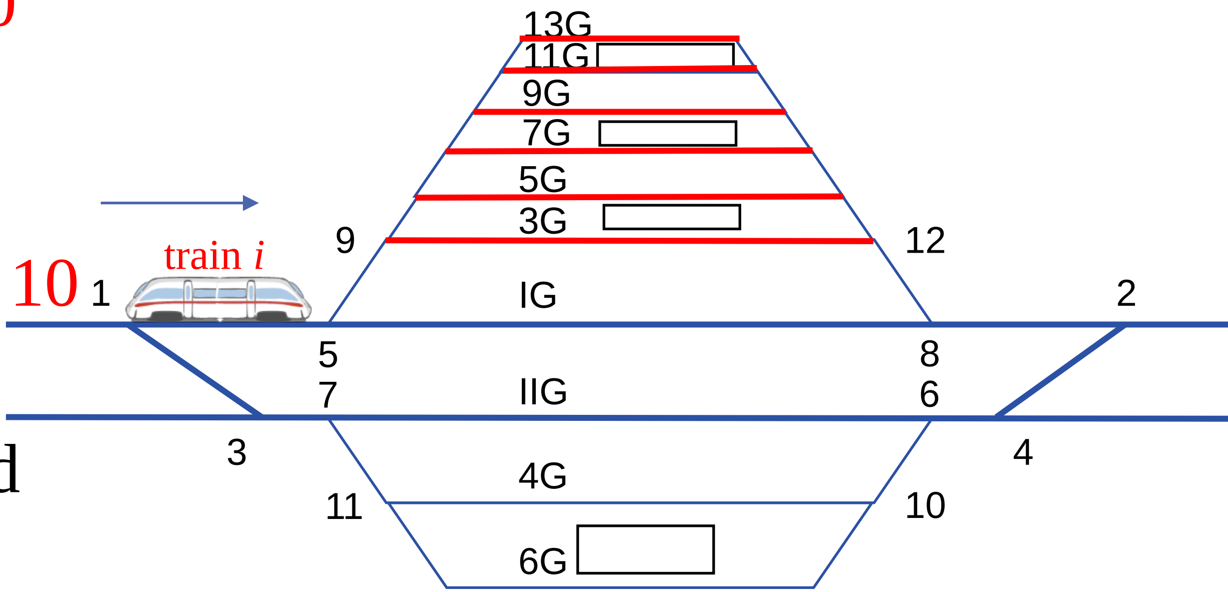
Single-point mutation for the integer value encoding

Swap mutation for the permutation-value encoding

Computational Experiments

Computational Experiments

- 6 platform tracks for downstream trains
- Trains downstream from 12:00 to 22:00
- Safety interval time: 3min
- Headway for arrival/departure: 4min
- Weight w in the objective function:1 & 10
- Number of trains $|L|$: 60/70/79
- The arrival delay is randomly generated between 1 to 20 min at a occurrence probability of 0.5
- Altogether 6 test instances
- Compared algorithms: SaDE、CLPSO、GA(Real-coded) with random key algorithm



Computational Experiments

Table 3. Results of the comparison on the objective value of different algorithms.

Instance	$\|I\|/\|L\|/w$/delayed trains	SaDE	CLPSO	Real-coded GA	The proposed GA	CPLEX
1	6/60/1/29	991.95 ± 7.05	977.30 ± 5.21	963.80 ± 6.10	**950.20 ± 6.01**	933.00
2	6/70/1/37	1100.35 ± 7.42	1079.95 ± 5.60	1059.15 ± 4.72	**1042.25 ± 7.79**	1021.00
3	6/79/1/39	1242.75 ± 14.62	1212.15 ± 10.47	1173.40 ± 5.61	**1145.00 ± 6.94**	1119.00
4	6/60/10/29	2163.50 ± 16.16	2069.00 ± 24.89	1991.00 ± 37.63	**1863.75 ± 47.95**	1738.00
5	6/70/10/37	2425.95 ± 20.91	2342.40 ± 26.68	2233.80 ± 36.98	**2079.90 ± 48.76**	1943.00
6	6/79/10/39	2774.55 ± 38.01	2642.10 ± 27.86	2525.05 ± 55.71	**2267.95 ± 56.97**	2111.00

- The proposed GA outperforms other three algorithms.
- The best value from the proposed GA approximates the exact value with a GAP between 1% to 4%.
- All the result are obtained within 40 seconds, which guarantees real-time rescheduling.

Computational Experiments

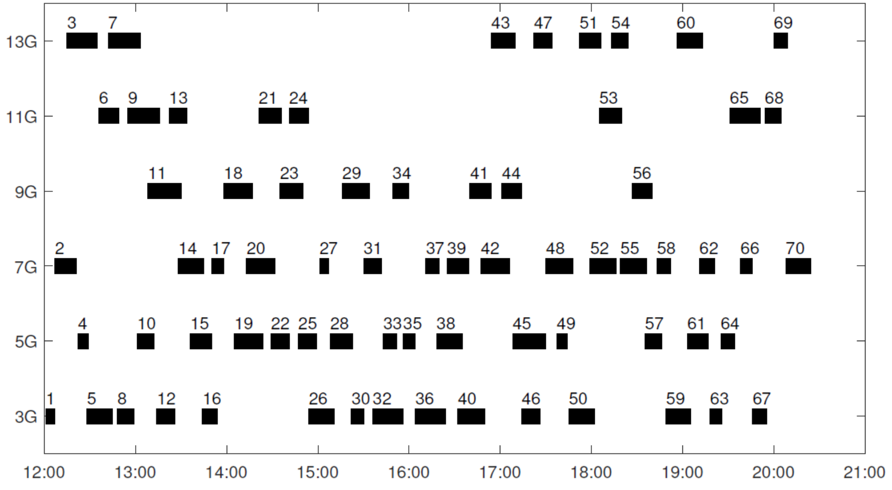


Fig. 1. Original train platform schedule for instance No. 2.

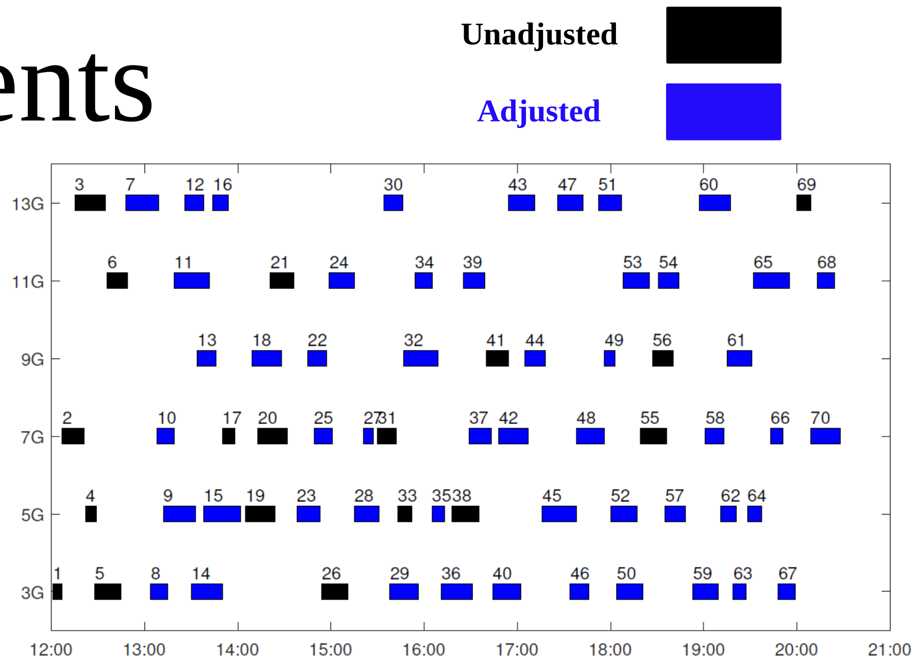


Fig. 2. Rescheduled train platform schedule for instance No. 2.

- For instance No. 2, the number of delayed arrival trains is 37. The number of total rescheduled trains is 52.
- It can be drawn from the figures that the unoccupied resources in the platform tracks (11G and 13G) are effectively used.
- For example, during 13:00 to 17:00 in track 13G and 15:00 to 18:00 in track 11G, tracks are unoccupied most of the time according to Fig. 1. While in the rescheduled train platform schedule, these tracks are more effectively used.

Computational Experiments

- Converge curves of the four algorithms on instances No. 3 and 6
- The proposed GA converges faster than other algorithms at the beginning
- Both the proposed and real-coded GA have a high convergence speed
- The final result of the proposed GA is better than those of the other algorithms.

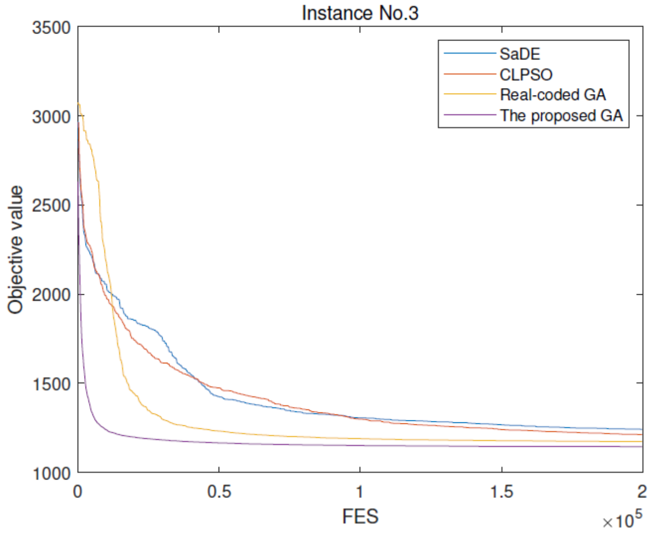


Fig. 3. Convergence curves of different algorithms for instance No. 3.

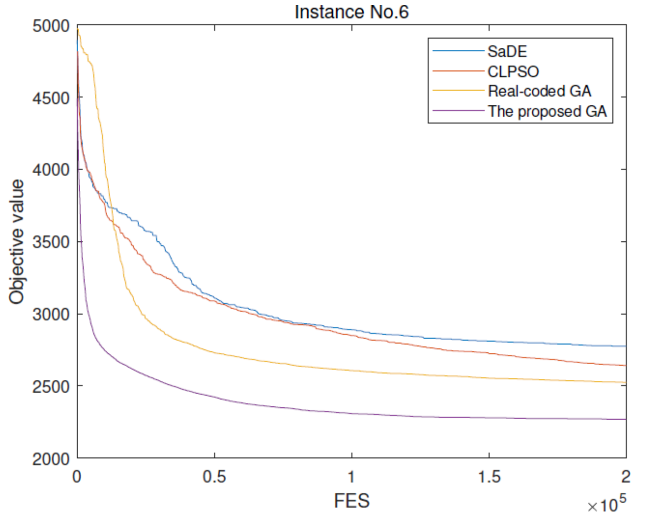


Fig. 4. Convergence curves of different algorithms for instance No. 6.

Concluding Remarks

- The train platforming rescheduling at a high-speed railway station is formulated as a MINLP problem.
- A mixed encoding GA is designed to solve the problem.
- A novel encoding and decoding method are specially designed.
- Obtained near-optimal solutions within one minute.

Future Research

- Consider a more complex railway station with more arrival/departure directions
- Consider the uncertainties in the dynamic environment
- Consider an integrated model with train timetable rescheduling and train platforming rescheduling

Thank you for your attention!

Q&A