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

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Outline

• Introduction

• Problem Formulation

• Proposed Method

• Computational Experiments

• Concluding Remarks
Introduction
A Mixed Encoding Genetic Algorithm for Train Platforming Rescheduling under Train Delays

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

<table>
<thead>
<tr>
<th>Large network size</th>
<th>High operation speed</th>
<th>High traffic density</th>
<th>Large amount of operation</th>
<th>Complex transportation organization</th>
<th>Diversified travel demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>China CR</td>
<td>Japan SCMagle</td>
<td>France TGV</td>
<td>Spain AVE</td>
<td>German ICE</td>
<td>Korea KTX</td>
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<td>Italy Frecciarossa 1000</td>
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|                    |                      |                      |                           |                                      | Turkey YHT               |}

China 66%
Others 34%
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.
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

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

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

- ① NP-hard
- ② Time consuming and suboptimal
Different levels in railway planning and scheduling

- Strategic level
  - Network planning
  - Passenger transport demand analysis
  - Line planning
- Tactical level
  - Train timetable scheduling
  - Station operational planning
  - Rolling stock scheduling
  - Crew scheduling
- Operational level
  - Train timetable rescheduling
  - Rolling stock rescheduling
  - Crew 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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_{l,i}$</td>
<td>actual platform track assignment of train $l$, 1 if train $l$ occupies platform track $i$; 0 otherwise</td>
</tr>
<tr>
<td>$t^a_l$</td>
<td>actual arrival time of train $l$</td>
</tr>
<tr>
<td>$t^d_l$</td>
<td>actual departure time of train $l$</td>
</tr>
<tr>
<td>$q^d_{l,k}$</td>
<td>actual order for train departure, 1 if train $l$ departs before train $k$; 0 otherwise</td>
</tr>
</tbody>
</table>

$$ t^a_l, t^d_l \geq 0 \quad x_{l,i} \in \{0, 1\} \quad q^d_{l,k} \in \{0, 1\} $$
Formulation

Objective function

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

\[
\min Z = Z_1 + wZ_2
\]

\[
Z_1 = \sum_{l \in L} (t_l^a - T_l^a) + \sum_{l \in L} (t_l^d - T_l^d) \tag{1}
\]

\[
Z_2 = \sum_{l \in L} \text{sgn}(t_l^a - T_l^a) + \sum_{l \in L} \text{sgn}(t_l^d - T_l^d) + \sum_{l \in L} \sum_{i \in l} 0.5 |x_{l,i} - x_{l,i}| \tag{2}
\]
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

\[ \sum_{i \in I} x_{l,i} = 1, \quad \forall l \in L \] \hspace{1cm} (3)

• Headway constraint for departure headway and arrival headway

\[ t_{k}^{d} - t_{i}^{d} \geq T_{s}q_{l,k}^{d} - M(3 - x_{l,i} - x_{k,i} - q_{l,k}^{d}), \quad \forall l,k \in L, \quad l \neq k, i \in I \] \hspace{1cm} (4)

\[ t_{k}^{d} - t_{i}^{a} \geq h_{k}^{a}q_{l,k}^{a} - M(1 - q_{l,k}^{a}), \quad \forall l,k \in L, l \neq k \] \hspace{1cm} (5)

• Departure order constraint of two trains at the station

\[ t_{k}^{d} - t_{i}^{d} \geq h_{k}^{d}q_{l,k}^{d} - M(1 - q_{l,k}^{d}), \quad \forall l,k \in L, l \neq k \] \hspace{1cm} (6)

\[ q_{l,k}^{d} + q_{k,l}^{d} = 1, \quad \forall l,k \in L, l \neq k \] \hspace{1cm} (7)

• Dwelling time constraint

\[ t_{i}^{d} - t_{i}^{a} \geq T_{d}^{i} - T_{l}^{a}, \quad \forall l \in L \] \hspace{1cm} (8)

\[ \tau_{l}^{a} = T_{l}^{a} + d_{l}, \quad \forall l \in L \] \hspace{1cm} (9)

• The arrival and departure times constraint

\[ t_{l}^{a} \geq \tau_{l}^{a}, \quad \forall l \in L \] \hspace{1cm} (10)

\[ t_{l}^{d} \geq T_{l}^{d}, \quad \forall l \in L \] \hspace{1cm} (11)

The problem is an mixed integer nonlinear programming problem which belongs to NP-hard.
A Mixed Encoding Genetic Algorithm for Train Platforming Rescheduling under Train Delays

Model Reformulation

\[ Z_2 = \sum_{l \in L} \text{sgn}(t_i^d - T_i^d) + \sum_{l \in L} \text{sgn}(t_i^d - T_i^d) + \sum_{l \in L} \sum_{i \in I} 0.5|X_{l,i} - x_{l,i}| \] (2)

\[ \begin{align*}
    r_1^l &= \text{sgn}(t_i^d - T_i^d) \\
    r_2^l &= \text{sgn}(t_i^d - T_i^d) \\
    r_3^{ij} &= |X_{l,i} - x_{l,i}|
\end{align*} \]

\[ Z_3 = \sum_{l \in L} r_1^l + \sum_{l \in L} r_2^l + \sum_{l \in L} \sum_{i \in I} 0.5r_3^{ij} \] (17)

\[ \min Z = Z_1 + wZ_3 \] (18)

s.t. \[ M r_1^l \geq t_i^d - T_i^d, \quad \forall l \in L \] (19)

\[ M r_2^l \geq t_i^d - T_i^d, \quad \forall l \in L \] (20)

\[ r_1^l \leq t_i^d - T_i^d, \quad \forall l \in L \] (21)

\[ r_2^l \leq t_i^d - T_i^d, \quad \forall l \in L \] (22)

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

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

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

\[ r_3^{ij} \in \{0, 1\}, \quad \forall l \in L, i \in I \] (26)

Constraints (3) – (14).

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

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 $[1, |l|]$  
  • 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

Parent individuals

Child individuals

Single-point crossover for the integer value encoding

• Mutation Operator

Before mutation

After mutation

Randomly selected

Single-point mutation for the integer value encoding

Before mutation

After mutation

Randomly selected two points

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

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.
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