A Genetic Simulated Annealing Algorithm for Real-Time Track Reallocation in Busy Complex Railway Station

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Track failure at a railway station is a common disruption in the station area caused by abnormal weather or frequent use. This paper focuses on the real-time track reallocation problem to recover the affected track utilization plan and minimize the total train delays and passenger inconveniences. Train platforming operations in busy complex passenger stations are generally conducted according to fixed track utilization rules. In this paper, we presented a mixed-integer linear programming model for train platforming problems with constraints relevant to fixed track utilization rule and objectives of balanced usage of tracks. Furthermore, we proposed an improved genetic simulated annealing algorithm based on improved crossover and selection methods without breaking the fixed track utilization rule constraint. An experiment of Guangzhou East Station with fixed track utilization rules shows the effectiveness of the proposed model and algorithm. The model and algorithm provide efficient approaches for track reallocation problems based on fixed track utilization rules in busy complex passenger stations.

1. Introduction

Complex passenger stations as bottleneck areas of the network require high efficiency of train operations. Its widely acknowledged that station operation scheduling coordinates several different subproblems at strategical, tactical, and operational levels of a railway system. Capacity management at the strategic level is crucial for the safe reception of a greater number of trains in busy complex stations. At the tactical level of the railway planning process, an assignment plan of routes through station areas is after the train timetabling stage. The daily plan is made by train dispatchers based on current information of station topology, track occupation, passenger carriage turnover plan, operation process time standards, timetable, and so on. The daily plan can be divided into two shifts. Based on current information, the shift plan is manually compiled by station dispatchers 1 hour earlier before it is carried out. The shift plan will be further divided into three to four stage plans. Therefore, it is challenging and tedious work for station dispatchers to make train operation plans. Train routing problem (TRP) was first introduced by Zwaneveld et al. [1], and it refers to making a macroscopic feasible routes plan. Train platforming problem (TPP) was introduced when some researchers put more emphasis on the allocation of platforms and tracks. Extensive overviews related to TRP and TPP are given by Sels et al. [2], Cacchiniani et al. [3], and Zhang et al. [4].

In recent years, many researchers studied TPP which is proven as NP-complete by Zwaneveld et al. [1]. At the strategical level, Zwaneveld et al. [1] incorporated shunting decisions and preferences for allocation of trains to certain desired platforms and routes. At the tactical stage of TPP, Carey and Crawford [5] presented a greedy heuristic solution to the TPP and introduced “lexicographic” cost functions or decision
rules to overcome the difficulty in adding up the costs or penalties imposed on deviations from preferred train arrival and departure times and costs of choosing less preferred platforms. Caprara et al. [6] proposed a binary quadratic program and solve TPP with a pattern incompatibility graph and developed the branch-and-cut-and-price method. Billionnet [7] formulate TPP as the graph coloring problem without considering routes from platforming decisions and solved the integer programming model with backtracking and heuristic technique. Sels et al. [2] presented mixed-integer linear programming (MILP) model by minimizing the total cost function, which comprises of penalty for assignment of a nonpreferred (real) platform and an even higher penalty for assignment of a dummy platform. Dewilde et al. [8] introduced an approach to improve the robustness in a complex station zone and designed a three modules algorithm to tackle routing, timetabling, and platforming aspects of planning. Sama et al. [9] studied the ant colony algorithm for real-time train schedule and route problems and considered relaxation of train routing constraints. Lusby et al. [10] formulated the resulting TRP as a set packing problem to minimize the total deviation from the schedule for all trains and develop a branch and price algorithm. Liujiang et al. [11] proposed a bottleneck optimization model to enhance the carrying capacity by reasonably arranging routes and groups of turnouts and solved by a tailored simulated annealing algorithm. Zhang et al. [12] proposed a teaching and learning optimization algorithm, which is improved to solve the track platforms and throat area routes allocation model. Although several aforementioned research papers considered platform preferences, most existing studies mainly focused on the independence rule (e.g., introduced by Zhang et al. [13]) that separates the track allocation plan into an outbound track allocation plan and inbound track allocation plan and flexible track utilization rules are not considered from a problem complexity perspective. However, the flexible track utilization rule is more applicable to complicated operations (e.g., turn-around movement and shunting work) in multidirection complex stations that have cross-line trains and turnaround trains. In practice, station dispatchers in busy complex stations usually developed fixed track utilization rules that considers track or platform preference constrained by train directions (e.g., cross-line trains with locomotive changing operation should be assigned to tracks near the locomotive depot), train types (e.g., high-speed railway trains and normal-speed railway trains should be assigned to different platforms for passenger alighting and boarding) and operation chain management (e.g., stop trains with static operations such as water-supplying and sewage-suction should be reassigned to tracks with static operation equipment) in platform track assignment decisions.

Regarding the TPP in a real-time level, disruptions such as switch and signal failure, or track failure caused by abnormal weather or frequent use are common in busy complex stations. In recent years, few researchers focus on real-time track reallocation problem (RTRP) when track allocation plan or train platform assignment plan should be re-optimized quickly to prevent potential conflicts without reschedule the timetable. Chakroborty and Vikram [14] proposed an MILP model that minimizes the weighted sum of the total delay, the cost of using a nonpreferred platform and the cost associated with last-minute platform reallocation. Liu et al. [15] pointed out that the trains originally assigned to those failed tracks will have to be reallocated to a new time point either on its initial siding track or other siding tracks. Thus, it is essential to reallocate track utilization at a real-time level to reduce consecutive delays and passenger inconveniences. Most current research on real-time rescheduling or rerouting problems about disruptions or track accidents are focusing on segment blockage (e.g., Zhang et al. [16]). Although the real-time rescheduling problem is a popular research field, few of the studies concentrate on the issue of reallocating trains that are affected by switch failure, signal failure, or track failure in busy complex passenger stations. Liu et al. [15] introduced virtual trains to occupy the accident tracks and developed a mathematical programming model which aims at minimizing the total occupation time of station bottleneck sections to avoid train delays. Chakroborty and Vikram [14] proposed a mixed-integer linear optimization model based on minimizing total delay time and the difference between initial reallocation and optimized reallocation. However, the aforementioned studies did not consider the cost associated with platform reallocation or track reallocation based on the fixed track utilization rule specific to the busy complex passenger station. Given station topology and track information, operation process and time standard, fixed track utilization rule, original schedule and emergency information, real-time RTRP call for rescheduling a conflict-free track assignment plan to recover the impacted schedule and reduce the time deviation of the original plan in the complex station area.

In this paper, we aim to bridge the research gaps lying in the TPP and RTRP under track failure based on the fixed track utilization rule. More specifically, we optimize the TPP under the framework of the fixed track utilization rule, which is more applicable for train operation plans in busy complex stations. Besides, we also generate a coherent train reallocation plan under the framework of the fixed track utilization rule in case of track failure. The penalty cost for real-time track reallocation is also considered in the heuristic algorithm for RTRP.

The contributions of this paper are listed as follows:

1. We enriched methodological support for the TPP and RTRP with the fixed track utilization rule specific to busy complex passenger stations.
2. We developed an improved genetic algorithm for TPP and simulated an annealing algorithm for RTRP with consideration of the fixed track utilization rule in the mutation operations, and we also designed a special selection operation to eliminate unfeasible solutions.
3. We considered the inconvenience and risk level of changing tracks as part of the penalty costs due to
violating the original track assignment plan in the objectives of RTRP.

The remainder of this paper is organized as follows. In Section 2, the definitions and assumptions are given. Section 3 presents mixed-integer programming models for TPP and RTRP. Section 4 introduces a GA algorithm for TPP and an SA for RTRP. In Section 5, a case study is conducted on Guangzhou East Railway Station in China. In Section 6, the paper concludes with a summary and discussion of further research.

2. Problem Description

Chakroborty and Vikram [14] pointed out that abnormal weather such as heavy wind, heavy rainfall, or heavy snowfall may directly lead to switch failure, signal failure, or track blockage in the complex station areas. For instance, a station track is blocked when its overhead contact wires are hung with something blown by heavy wind. Under such emergency incidents, dispatchers usually take the following measures to generate new train operation plans to recover the impacted train schedule and reduce total delay:

(1) Track reallocation without adjusting arrival and departure times in the original schedule. Rearrange the arrival and departure operations of trains (e.g., Train 1 in Figure 1) originally assigned to the failed track (e.g., Track 3 in Figure 1(a)) to other tracks (e.g., Track 5 in Figure 1(a)) and maintain their arrival and departure time in the original schedule. Generally, the upward direction trains are assigned with upward side tracks and the opposite side tracks usually accommodate trains in downward direction according to station safety regulations and rules. Under emergency incidents, the fixed track utilization rule can be broken and downward side tracks are allowed to accommodate upward side trains. The cost of changing tracks to its opposite sidetrack is higher than changing tracks to the same sidetracks because it increases the risk of interfering with the arrival and departure operations in the downward direction.

Usually, dispatchers assign tracks to trains according to the fixed track utilization rule as explained by Zeng et al. [17]. For instance, terminating passenger trains (TEPTs) and originating passenger trains (ORPTs) are assigned to tracks and platforms that are close to the waiting room in busy complex stations because they will alight or board a huge number of passengers. As for those trains that have important passenger transfer concerns, dispatchers usually place two trains at tracks beside the same platform or assign their platforms close to each other. If the tracks are changed, the walking distance of passengers alighting TEPTs or boarding ORPTs increases if those trains are reallocated to tracks far from the waiting room. The station worker and passenger’s inconvenience and risk of additional dwelling time increase if original close tracks are assigned to tracks far from the waiting room. Therefore, we present a penalty cost table (e.g., Table 1) to better formulate inconvenience and risk level of changing tracks in different positions. The schematic layout for Guangzhou East Railway Station is shown in Figure 2. Track 18G can only be used for locomotive running operations. Passenger servicing operations should be conducted in track 6G, 8G, 10G, 12G, 14G, 16G, 20G, IIIIG, and 5G. Track 4G without a platform is not suitable for passenger service operations. 6G and 8G are mainly used for intercity railway trains; track 5G and IIIIG are mainly used for reception and departure of single direction track railway line (the third direction line) in order to improve the station throat capacity. Track 1G and IIIG are mainly used by nonstop through passenger trains or trains without passenger service operation.

(2) Time adjustment without changing original track assignment plan. Dispatchers adjust the arrival time of trains originally assigned to the track by coordinating its speed in the open track out of the station and waiting until the occupied track is available. Variations in arrival and departure times within allowable time windows can be viewed as an interaction between TTP and TPP under emergencies.

(3) Reallocate the arrival and departure operations of trains originally assigned to the failed track to other tracks and adjust the arrival and departure time of trains in the original schedule at the same time.

In this paper, we consider the problem of real-time rescheduling of train platforming at busy complex passenger stations with both track reallocation and arrival and departure time adjustment under disruptions. To better formulate the model, we assume that:

(1) A pair of mapped arrival turnaround trains (ATUPTs) and departure turnaround trains (DTUPTs) usually share the same carriage formation according to the rolling stock turnover plan. Also, they share the same assigned track and turn around their direction by changing locomotive positions. We integrate the mapped ATUPT with arrival time and DTUPT with departure time into one fictive TUPT with arrival time and departure time in our preparation work.

(2) We do not consider the route occupation of placing-in operations for TEPTs, taking-out operations for ORPTs or locomotive-changing operations for turnaround passenger trains because the arrival and departure operations are given higher priority.

(3) Initial train delays are predicted in advance and station workers made all emergency preparations in advance. If part of the trains that are assigned to the failed track cannot be reassigned to any other track, these train reallocations shall be combined with timetable adjustments in case of emergency.
3. Model Formulation

3.1. Notations

Table 2 presents notations used in this paper. Table 3 describes decision variables.

3.2. Constrains

3.2.1. Uniqueness Occupation Of Tracks. The constraint that each train can be assigned with only one track and one route is denoted as

\[ \sum_{j=1}^{n} x_{ij} = 1. \]  (1)

3.2.2. Unary-Resource Nonoverlap Constraints. Similar to other researchers such as Sels et al. [2], we also adopt unary-resource nonoverlap constraints. The occupation time interval of the train \( f \) claiming track \( j \) and the occupation time interval of the following train \( s \) claiming the
same track $j$ should be nonoverlapping. The aforementioned conflict-free constraint is denoted as

$$\left( x_{f,j}^{dep} - x_{s,j}^{arr} \right) \left( x_{f,j}^{arr} - x_{s,j}^{dep} \right) \geq 0, \quad \forall f, s \in Tr. \tag{2}$$

3.2.3. Safety Time Interval Constraints. The occupation time interval of track corresponds to minimum separation times between two adjacent occupation time intervals of train $f$ and train $s$, which are enforced by track occupation constraints in interlocking. The constraint is denoted as follows:

$$x_{f,j} + x_{s,j} \leq 1, \quad \forall f, s \in Tr,$$

$$t_{f,j}^{dep} + T_g \geq t_{s}^{arr}, \quad \forall f, s \in Tr. \tag{3}$$

3.2.4. Headway Time Interval Constraints. The headway time interval between two adjacent trains in the same direction should meet minimum headway time to ensure the safety of train operations. The constraint is denoted as follows:

$$x_{f,j} + x_{s,j} \leq 1, \quad \forall f, s \in Tr,$$

$$t_{f,j}^{dep} + T_g \geq t_{s}^{arr}, \quad \forall f, s \in Tr. \tag{3}$$

Table 2: Notations for general subscripts and input parameters.

| Symbol | Description |
|--------|-------------|
| $t_{arr}^i$ | Arrival time of train $i$ in original schedule |
| $t_{arr}'^i$ | Arrival time of train $i$ in a new schedule |
| $t_{dep}^i$ | The departure time of the train $i$ in the original schedule |
| $t_{dep}'^i$ | The departure time of the train $i$ in the new schedule |
| $Tr$ | Set of passenger trains indexed by $i \in Tr$. $m$ denotes the total number of trains within a given fixed period |
| $G$ | Set of all tracks indexed by $j \in G$. $n$ is the total number of tracks |
| $K$ | Set of all alternative track sets in fixed track utilization rule indexed by $k \in K$. $l$ is the total number of tracks. |
| $T_g$ | The minimum separation time interval of two adjacent track occupation |
| $I_z$ | Security headway time interval between two neighboring trains that occupy the same track |
| $T_i$ | Total operation time of the train $i$ in station area |
| $\omega_i$ | Weight of train $i$ |
| $c_{jj'}$ | Penalty cost if train’s assigned track is changing from track $j$ to track $j'$. If track remain unassigned, we have $c_{jj'} = 0 (\forall j = f')$ |

Table 3: Notation for decision variables.

| Symbol | Description |
|--------|-------------|
| $\tau_{arr}$ | 0-1 binary variable. If train $i$ has arrival operation in station, then $\tau_{arr}^i = 1$; otherwise $\tau_{arr}^i = 0$ |
| $\tau_{dep}$ | 0-1 binary variable. If train $i$ has a departure operation in station, then $\tau_{dep}^i = 1$; otherwise $\tau_{dep}^i = 0$ |
| $x_{ij}$ | 0-1 binary variable. If the train $i$ is assigned with the track $k$, then $x_{ij} = 1$; otherwise $x_{ij} = 0$ |
| $\omega_i$ | 0-1 binary variable. If the train $i$ is assigned with the special capacity track $k$, then $\omega_i = 1$; otherwise $\omega_i = 0$ |

Figure 2: Schematic layout for Guangzhou east railway station.
3.3.2 Objective of RTRP

3.3.1 Objective of TPP

Objective of TPP is track usage proportionality, which requires a global searching ability for global solution space of all the track allocation combinations. The objective of RTRP is to achieve a feasible and coherent track reallocation plan when some tracks failed, which requires a local searching ability to reallocate those trains that were originally assigned to the failed tracks only and maintain all the other trains’ track allocation. The genetic simulated annealing hybrid algorithm not only takes advantage of the strong global searching ability and fast convergence speed of GA when searching for an initial track allocation plan with proportionality in TPP but also uses SA’s good ability in jumping out of local optimal solutions when searching solution for RTRP. The purpose of the genetic algorithm is to provide a good-quality initial solution for the simulated annealing algorithm. A good-quality track allocation plan with high proportionality will reduce the workload of track reallocation under track failure. An unbalanced track allocation plan will increase the probability that a track with a large workload failed and cause a high track reallocation cost for many trains originally assigned to the failed track. The framework of the genetic and simulated algorithm is demonstrated in Figure 3. Details for the components are illustrated as follows.

4. Genetic Simulated Annealing Algorithm

In this section, a genetic and simulated annealing algorithm is designed to solve the RTRP model effectively. The objective of TPP is track usage proportionality, which requires a global searching ability for global solution space of all the track allocation combinations. The objective of RTRP is to achieve a feasible and coherent track reallocation plan when some tracks failed, which requires a local searching ability to reallocate those trains that were originally assigned to the failed tracks only and maintain all the other trains’ track allocation. The genetic simulated annealing hybrid algorithm not only takes advantage of the strong global searching ability and fast convergence speed of GA when searching for an initial track allocation plan with proportionality in TPP but also uses SA’s good ability in jumping out of local optimal solutions when searching solution for RTRP. The purpose of the genetic algorithm is to provide a good-quality initial solution for the simulated annealing algorithm. A good-quality track allocation plan with high proportionality will reduce the workload of track reallocation under track failure. An unbalanced track allocation plan will increase the probability that a track with a large workload failed and cause a high track reallocation cost for many trains originally assigned to the failed track. The framework of the genetic and simulated algorithm is demonstrated in Figure 3. Details for the components are illustrated as follows.

4.1 An Improved GA for TPP

Step 1. Initialization of parameters and encoding: the algorithm starts with set initial parameters: population size is 30; crossover rate is 0.8; mutation rate 0.25; maximum iteration times is 300; and $T_g = 2 \text{ min}$. Read the timetables and change the arrival or departure time into an integer between 0 and 360 (e.g., $t_{i\,\text{arr}}$ and $t_{i\,\text{dep}}$ in Figure 4). The mapping relationship between train number and assigned track can be regarded as a chromosome. Since the tracks are numbered as a natural sequence, binary coding commonly used in GA not only increases the complexity of coding work but also may not be conducive to the subsequent crossover and mutation operation. Therefore, the natural number encoding form is adopted in this paper for chromosome encoding. Genetic sequencing is carried out according to the arrival and departure time sequence of the train. Let the length of the chromosome be $m$, and the chromosome is a three-dimensional array $(1 \times m \times 4)$. The first page represents the mapping relationship between train $i$ and track $j$, and the arrival time, departure time, and fixed track utilization rule number of the train $i$ are encoded in the first, second, third, and fourth pages of chromosome genes. Then, the individuals’ chromosome is shown in Figure 4.

Step 2. Creating new chromosome and evaluation:
the roulette wheel selection operation is conducted based on calculated and ranked individual fitness values. Track number in the chromosome (Track No. 2 in Figure 4) should be unified mutated randomly according to track utilization rule (Rule S003 in Figure 4), and objective value of $Z_1$ could be very large. Therefore, the fitness value should be set as $1/Z_1$ to approach 0. If an individual does not satisfy safety time interval constraints, its fitness value will be set as $1/Z_1 - 1$ and ranked to the end of fitness value list. Unfeasible track allocation plans will be gradually eliminated through iterations. Parents for
**Figure 4: Illustration of individuals’ chromosome.**

**Table 4: Parameters of GA algorithm.**

| Parameters                                      | Values |
|------------------------------------------------|--------|
| Population size                                | 30     |
| Crossover rate                                  | 0.8    |
| Mutation rate                                   | 0.25   |
| Maximum iteration times                         | 300    |
| The minimum separation time interval of two adjacent track occupation | 2 min  |

**Table 5: Timetable information.**

| No. | Train Number | Arrival time | Departure time | Fixed track utilization plan | Initial TAP | Optimal TAP |
|-----|--------------|--------------|----------------|------------------------------|-------------|-------------|
| 1   | D814 ∗ D815  | 1            | 7              | 7                            | 2           | 14          |
| 2   | T810 ∗ T811 | 1            | 15             | 1                            | 10          | 4           |
| 3   | K310 ∗ K309 | 1            | 70             | 3                            | 7           | 5           |
| 4   | D825         | 11           | 26             | 3                            | 5           | 3           |
| 5   | T822 ∗ T821 | 13           | 62             | 1                            | 12          | 10          |
| 6   | T97          | 13           | 58             | 3                            | 3           | 7           |
| 7   | D740         | 18           | 25             | 7                            | 2           | 20          |
| 8   | T99          | 19           | 58             | 3                            | 4           | 2           |
| 9   | D716 ∗ D717 | 23           | 40             | 7                            | 6           | 16          |
| 10  | D793         | 26           | 29             | 7                            | 2           | 8           |
| 11  | D836 ∗ D837 | 31           | 50             | 7                            | 2           | 6           |
| 12  | D826 ∗ D827 | 44           | 57             | 7                            | 6           | 16          |
| 13  | D782 ∗ D783 | 49           | 87             | 7                            | 8           | 14          |
| 14  | T812 ∗ T817 | 61           | 153            | 7                            | 10          | 12          |
| 15  | D741         | 68           | 73             | 7                            | 2           | 16          |
| 16  | D760         | 69           | 72             | 7                            | 6           | 8           |
| 17  | D804 ∗ D805 | 83           | 100            | 7                            | 2           | 8           |
| 18  | D728         | 92           | 94             | 7                            | 6           | 20          |
| 19  | D761         | 107          | 110            | 7                            | 2           | 20          |
| 20  | 0919         | 110          | 125            | 3                            | 7           | 2           |
| 21  | D750         | 112          | 117            | 7                            | 2           | 6           |
| 22  | D704 ∗ D705 | 122          | 145            | 7                            | 2           | 20          |
| 23  | D729         | 128          | 130            | 7                            | 6           | 14          |
| 24  | T802 ∗ T803 | 133          | 197            | 7                            | 12          | 4           |
| 25  | D772 ∗ D773 | 139          | 172            | 7                            | 6           | 8           |
| 26  | D816         | 147          | 152            | 7                            | 2           | 20          |
| 27  | T162         | 148          | 158            | 3                            | 7           | 7           |
| 28  | D751         | 154          | 162            | 7                            | 2           | 14          |
reproduction are selected and crossover with random chromosomes to create new off springs. Also, unified mutation operations based on fixed track utilization rules are adopted to create new off springs. A new generation of the population is created and evaluated to select the best chromosome at the current iteration. If the new solution is better than the best-so-far chromosome, then replace the best-so-far chromosome with the new best chromosome. Otherwise, the deteriorated solution is accepted with certain possibilities.

Step 3. Judgment of termination criterions: repeat Step 2 until algorithm termination criteria are satisfied, the algorithm stopped and outputs the best-so-far solution and objective values.

Major steps of the SA algorithm will be briefly presented:

**Step 1.** Input the number of track that is broken down, and search the information of trains that are assigned to the failed track in the optimized TAP.

**Step 2.** Generate an initial solution of reallocated TAP after track failure within constraint in Section 3.2. Adjust the initial solution by changing tracks within the alternative track set of fixed track utilization rules.

**Step 3.** Check the feasibility of adjusted TAP. If all the constraints are satisfied, go to Step 5; otherwise, go back to Step 2. If all the tracks within the alternative track set of fixed track utilization rules are exhausted, no feasible solution are found, go to Step 4.

**Step 4.** If some trains assigned to track that is broken down cannot be reallocated to any other tracks, those train adjustment should be integrated with adjustment of train operation diagram under emergencies.

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### Table 5: Continued.

| No. | Train Number | Arrival time | Departure time | Fixed track utilization plan | Initial TAP | Optimal TAP |
|-----|--------------|--------------|----------------|-----------------------------|-------------|-------------|
| 29  | D794 * D795  | 166          | 183            | 7                           | 2           | 6           |
| 30  | T806 * T807  | 178          | 229            | 1                           | 10          | 3           |
| 31  | D718         | 183          | 186            | 7                           | 6           | 16          |
| 32  | D817         | 187          | 190            | 7                           | 2           | 20          |
| 33  | D838         | 193          | 200            | 7                           | 2           | 2           |
| 34  | D828 * D829  | 200          | 214            | 7                           | 6           | 6           |
| 35  | D742         | 214          | 224            | 7                           | 2           | 20          |
| 36  | N582         | 220          | 228            | 3                           | 7           | 7           |
| 37  | D719         | 221          | 224            | 7                           | 6           | 6           |
| 38  | D784 * D785  | 223          | 240            | 7                           | 8           | 16          |
Step 5. If initial feasible solution is found, we can optimize the solution with SA algorithm and set minimizing penalty cost $Z$ as optimization objective. Given initial temperature, iteration mark $k$, maximum iteration times $L$ at each temperature and cooling coefficient $\alpha$.

Step 6. Generate new solution with mutation operation similar to the aforementioned GA algorithm and check its feasibility. For each change, a new objective value $f_{\text{new}}$ is obtained.

Step 7. Calculate $\Delta f = f_{\text{new}} - f_{\text{old}}$. If $\Delta f \geq 0$, go to Step 8; otherwise, accept with a small probability $\rho = \exp(-\Delta f/T)$ and go to Step 8.

Step 8. At each temperature, repeat Step 6 to Step 7 until iteration times reaches $L$. The temperature is gradually decreased by function $T = \alpha \cdot T$. SA terminates when temperature iteration times reaches $k$.

5. Experimental Result and Discussion

This section illustrates the effectiveness of the proposed model and algorithms for a case study of Guanzhou East Station in China. The timetable, the fixed track utilization rules and the penalty cost table are accessed through field research of station dispatcher’s experiences in certain period. Experiments are tested on a ThinkPad T570 with Matlab.
The fixed track utilization rule is shown in Figure 3. Parameters for GA algorithm are shown in Table 4.

5.1. Track Utilization Plan of TPP. The arrival and departure times of each train is transferred to integers between \([0, 360]\), and the detailed timetable and track allocation plan (TAP) are given in Table 5.

The initial solution is created by selecting tracks within the corresponding alternative track set of fixed track utilization rules randomly. Figure 5 shows the track utilization scheme of the initial solution. Figure 6 illustrates the optimized track utilization scheme by using the improved GA. The optimized track utilization scheme in Figure 6 is more balanced than the track utilization scheme of the initial solution in Figure 5. The track allocation optimizing results are shown in Table 6.

A convergence test is shown in Figure 7 to demonstrate the efficiency of GA to solve TPP in Guanzhou East Station. The horizontal axis represents the objective values, and the
vertical axis represents a number of iteration times. It takes more than 100,000 iterations and reaches the objective of 141.1. Therefore, the GA is an effective tool to solve the proposed TPP model for complex and busy railway stations.

5.2. Track Utilization Plan of RTRP. If track No. 16 broken down within time window [10:00, 14:00] due to emergency incidents, dispatchers need to generate appropriate track reallocation plans to recover train operations and minimize the total train delay time. The rescheduled track utilization plan when track No. 16 is failed is shown in Figure 8. Parameters for SA algorithm are shown in Table 7.

Figure 8 depicts the reallocated track occupation plan intuitively. The reallocated occupation plan shows no secondary delays and optimized penalty cost reaches around 7. The average computation time is 9 s, which can serve fast response time requirement of real-time rescheduling under track failure situation. Figure 9 demonstrates the efficiency of SA to solve RTRP in Guanzhou east station.

6. Conclusion

In this paper, we presented mixed-integer model formulations for RTRP in busy complex passenger stations and proposed an GSA approach based on the fixed track utilization rule to make a balanced track assignment plan with minimum secondary delay. First, we propose a model formulation of RTRP with constraints including fixed track utilization rule and with objectives of balanced usage of tracks, minimum total secondary delay, and minimum penalty cost. Second, we propose an improved GA for TPP and GSA for RTRP. A case study of a typical busy complex station area that uses fixed track utilization rules in China shows the model and algorithm have great potential in improving the balanced usage of tracks within fixed track utilization rule constraints and fast track reallocation plan under track failure situation. The model and algorithm enable a rational approach for efficient rescheduling of track utilization plans based on fixed track utilization rules and track failure situation in busy complex passenger stations.

Subsequent research should explore a model that integrates track allocation and rescheduling of train operation diagram. More attention should be focused on time and track adjustment to ensure the TAP's feasibility under other disruptions.

Data Availability

The data and algorithms used in this paper can be accessed in the attached files: File 1. Fixed track utilization rule File 2
Core codes for simulated annealing algorithm
File 3
Core codes of improved genetic algorithm.

Conflicts of Interest
The author(s) declare that there are no conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Supplementary Materials
File 1. Fixed track utilization rule. File 2 Core codes for simulated annealing algorithm. File 3 Core codes of improved genetic algorithm. (Supplementary Materials)

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