**Real-Time High Speed Train Rescheduling in Case of a Partial Blockage**

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**Abstract** This paper considers the problem of real-time train rescheduling on a double-track high speed railway line in a disrupted situation, where one track of a segment is temporarily unavailable for a long period of time. Due to the disruption, trains on the disrupted line are unable to run as planned. Therefore we need to reschedule trains constantly to reduce the influence of the disruption on passengers. In a partially disrupted situation, trains passing the disrupted segment have to share the residual capacity of the line. To this end, we have to decide the sequence of trains passing through the unblocked line in the blocked segment, the arrival and departure time of each train at each station, and the trains that have to be cancelled because of the reduced capacity. A Mixed Integer Programming model is formulated to minimize the total weighted train delay and the number of cancelled trains. Considering the uncertain duration of the disruption and the complexity of large real-time train rescheduling problem, a scenario-based rolling horizon approach is utilized to solve our problem. Finally, a real-world instance of the Beijing-Shanghai high speed line in China is used to test our model.

**Keywords:** High Speed Railway · Partial Blockage · Train Rescheduling

**1 Introduction**

Within a high speed railway system, trains are organized as planned in the normal situation. The original timetable is installed in the high speed railway dispatching system, and the short term plan, e.g., a plan for 3 hours, based on the original timetable is sent to the high speed railway station control system. To this end, trains are controlled by these systems and they run as planned. However, disruptions caused by external and internal factors, such as bad weather, bad condition of railway controllers and malfunctioning railway infrastructure, may occur in the daily operations. This requires trains to deviate from the original timetable. In such a disrupted situation, real-time train rescheduling is of great importance to reduce the impact of the disruption on passenger service quality.

Recently, real-time train rescheduling has attracted much attention, see the current survey by Cacchiani et al. (2014). However, most of the previous research focuses on real-time train rescheduling under small perturbations, namely disturbances. Furthermore, compared to solving train rescheduling problems at a macroscopic level, more research is based on a microscopic level, see Corman et al. (2011, 2012) and D'Ariano et al. (2008) for instance. In the current paper, we aim to reschedule trains in a large disrupted area at a macroscopic level. In our case, we assume that one track of a double-track high speed railway segment is unavailable for a relatively long period of time, e.g., 2 hours. Hence, trains have to share the residual track in the disrupted segment during the disruption. In such a situation, the vital decision is how to reschedule trains in both directions to pass the sole track in the disrupted segment in a proper order so as to reduce the influence of the disruption on train operations.

Brucker et al. (2002) have conducted research on this kind of train order decisions, based on the assumption that the order of trains in each direction passing the disrupted segment is fixed. Unfortunately, in our research, there are various types of trains running on a high speed railway line. Therefore the order of trains running in the same direction is not fixed in a disrupted situation. Trains of a higher priority may overtake trains of a lower priority to decrease the total weighted train delay. Hereby, our problem is more complex than that of Brucker et al. (2002).

Recently, Louwerse and Huisman (2014) have conducted research on timetable adjusting in a partially blocked situation. In their research, they mainly focus on how to form a disposition timetable in the situation where one track of a segment is blocked. However, they have not taken all the station capacity into account and they have not considered the transfer from the original timetable to the disposition timetable when the disruption occurs and from the disposition timetable to the original timetable after the end of the disruption. Based on Louwerse and Huisman (2014), Veelenturf et al. (2014) consider how to reschedule trains in a partially blocked situation. In their paper, they take the station capacity into account, and they also consider the capacity of rolling stock. However, both Louwerse and Huisman (2014) and Veelenturf et al. (2014) are based on a periodic timetable, and they only take a relatively short period of time into account. Furthermore, trains of the same type have the same stopping pattern in their consideration. In the current research, we take a more complicated train stopping pattern into consideration. In this, trains, even of the same type, may have different stopping patterns, and they overtake each other due to their various stopping patterns.

**2 Problem Description and Model Formulation**

## 2.1 Problem description

We mainly focus on double-track one way high speed railway lines with one line for trains running in each direction. There are various types of trains running on this line, both high speed trains with a speed of 300-350km/hr and medium speed trains with a speed of 200-250km/hr. Furthermore, long distance trains, local trains and cross-line trains (trains that half run on this high speed line and then cross to other related high speed lines) are operated together on the same high speed line.

In a partially blocked situation where one track of a segment is blocked, trains in both directions have to share the residual track in the blocked segment during the disruption. The following decisions should be made immediately to assist dispatchers by affording them a real-time disposition timetable.

1. The order of trains that pass the residual track in the blocked segment, both for trains in one direction and trains in two directions.
2. The order of trains that run in one direction. Due to the various types of trains and the different train stopping patterns, overtaking between trains is common in a disrupted situation, even after the end of the disruption. Therefore it is necessary to revise the order of the trains in a long time horizon.
3. The time for each train that arrives at or departs from each station that it visits. This decision is mainly related to the order decision above.
4. The stopping pattern of trains that dwell at stations to wait for the disruption because of the decreased capacity in the blocked segment.
5. The trains that need to be cancelled due to the limited track capacity in the blocked segment and the limited station capacity.

2.2 Model formulation

The event-activity network (which is used in our previous paper Zhan et al. (2014) to cope with real-time high speed train rescheduling in case of a complete blockage) is used to depict our railway system. A Mixed Integer Programming (MIP) model is formulated to solve our problem. In our objective, we minimize the total weighted train delay and the number of cancelled trains. However, since a seat reservation strategy is usually utilized in high speed railway system, it is relatively easy to know the passenger flow data. Therefore our model can be easily extended to reschedule trains from the passengers' perspective.

We assume that there is no anticipation on the occurrence time of the disruption. A scenario-based rolling horizon approach is used to handle our large-scale problem. This method also contributes to reducing the computation time. The rolling horizon approach is applied in rolling stock rescheduling, see Nielsen et al. (2012) and train rescheduling.

In our MIP model, the main constraints that we consider are as follows:

1. Railway segment capacity constraints (open track capacity constraints),
2. Station capacity constraints,
3. Train balance constraints (number of trains of the same type in each direction should be balanced),
4. Train cancelation constraints.

**3 Experiments and results**

3.1 Test instance

To test our model, a real-word instance of the Beijing-Shanghai high speed railway line is taken. This line is more than 1300 km long, and 23 stations divide it into 22 segments. There are approximately 260 trains running on this line during a whole day. These trains can be divided into several types. Thus it is a very busy and long high speed line. In each instance, we assume that there is one disruption. We test various disruption scenarios based on different locations, occurrence times, and durations of the disruption.

3.2 Results

According to our experiments, we obtain the following results:

* We found that different disruption scenarios have different impacts on the train operations. A disruption that occurs earlier on the day seems to have more serious influence on the train operations. Besides, a longer duration of a disruption causes more serious impact on the passenger service.
* If we give different penalty values to cancelling a train, either a high speed or medium speed train, and delaying a train, the number of cancelled trains and the total train delay differ. Hence, there is a trade-off for railway managers between cancelling a train and delaying a train.
* If we allow some trains to have larger delays, more trains are able to run in the disposition timetable. Trains just follow each other passing the disrupted segment in the same direction. This increases the capacity of the blocked segment, but disturbs the balance between trains in the two directions. However, to a certain extent this is acceptable in a non-periodic timetable.
* Our solution is better than the practical dispatching strategy that used on Chinese high speed railway in reducing the impact of disruption on train operations.

**4 Mathematical Formulas**

For the sake of completeness, we also add some mathematical formulas here:

$$a^{2}+b^{2}=c^{2} (1)$$

$$\sum\_{i\in I}^{}X\_{i,j}\geq 1 for all j\in I (2)$$

$$\sum\_{j\in I}^{}a\_{i,j}X\_{i,j}\geq b\_{j} for all i\in I (3)$$

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