A cooperative strategy framework of train rescheduling for portal junctions leading into bottleneck sections

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Abstract

On main line railways, bottleneck sections in urban area usually have high intensity traffic flows because of trains converging from different origins through portal junctions. As a result, a small delay to one train can cause long knock-on delays to following trains because of the limit margin time and recovery time in the nominal timetable in bottleneck sections. This paper proposes a cooperative strategy framework for train rescheduling of portal junctions leading into bottleneck sections to decrease the overall delay and recovery from the unpredictable event of disturbances. The strategy is mainly based on an improved Differential Evolution algorithm for the Junction Rescheduling Model (DE-JRM), which is proved to be suitable for solving train rescheduling problems for both individual fly-over junctions and flat junctions.
Keywords: train rescheduling, differential evolution, bottleneck sections.

1 Introduction

In practical railway operations, most train delays occur in junction areas, where trains from different origins converge. Because of the conflict at the junction point, a delay to one train can cause unplanned stops and consequential delays for the trains on other converging routes. A typical example is shown in Figure 1. Train 1 and train 2 approach the station ahead from different routes, via

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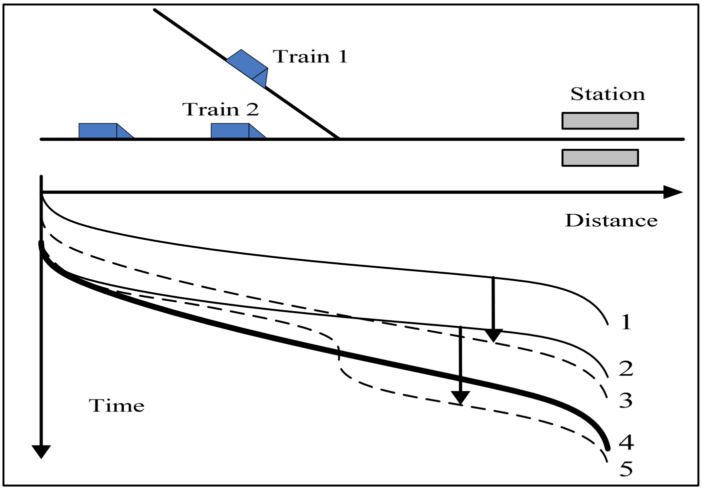

Figure 1: Example of train rescheduling.

the same junction point. The nominal train trajectories for the two trains are shown as curve 1 and curve 2 in Figure 1, respectively. For instance, if train 1 is delayed from curve 1 to curve 3 because of some disturbance, it will cause conflicts with train 2 at the junction point. Without timely traffic management, train 2 has to take an unplanned stop before the junction point, as shown with curve 5. This consumes more time and increases energy consumption. If the conflict can be detected and train 2 can acquire a new train rescheduling decision from the traffic management system in advance, the driver of train 2 can slow down the train when approaching the junction point, as shown with curve 4, and the unplanned stop caused by the delayed train 1 can be avoided. This will reduce train delay and energy consumption in the event of disturbances. Considering all approaching trains to the junction point in a time window, the rescheduling problem refers to the optimisation of route setting sequences and train arrival time at junction points.

On many railways, sections of the infrastructure with junctions at the portals are described as bottlenecks. These usually have the highest traffic flows in railway networks. A typical urban railway configuration, with a bottleneck section and the associated approach tracks, is shown in Figure 2. Generally, bottleneck sections are located at the heart of networks, between portal junctions where many trains converge from a range of origins and diverge to a variety of destinations. In this scenario, a relatively short delay to one train may cause long consequential delays for following trains, because of resource conflicts at junctions and dense traffic flow in bottleneck sections. Conventional train service management approaches cannot achieve reliably a level of timetable adherence that permits accurate presentation of trains at portals. A great deal of effort has been devoted to the train rescheduling in these areas, to ensure optimal use of the available capacity and to minimise the disruption to services from some unpredictable incidents [1-3].

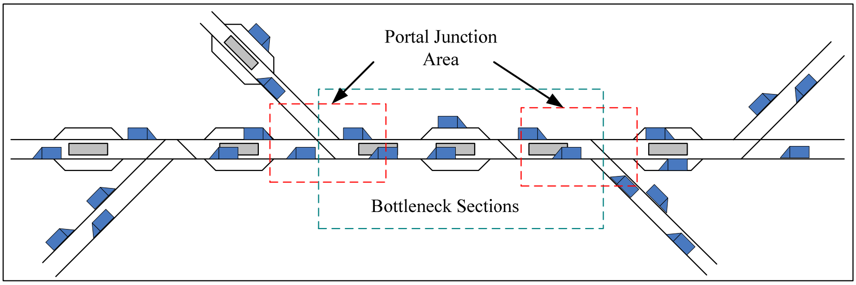

Figure 2: Layout of generic bottleneck sections.

The prediction of approaching train movement and the detection of potential conflicts are essential for train rescheduling in junction areas. The prediction mainly depends on the rescheduling decisions in the adjacent junctions. So the rescheduling decisions in adjacent junctions could have influence on each other. The decision making for individual junctions needs to know the decisions made in the adjacent junctions in advance. That means if there are no any cooperative mechanism applied into the decision making process for junctions, the local optimal decisions generated by each junction may not be optimal solutions to other junctions, even cause conflicts between each other and eventually have feedback to the initial rescheduling decisions. It could make the local optimal decisions infeasible. Because of the limit of recovery and margin time in bottleneck sections, the cooperative rescheduling of approaching trains for portal junctions of bottleneck sections is an efficient approach to maintain high service quality and gain better associated cost expressed in different aspects like monetary terms, weighted delay minutes and energy consumption etc., as well as the particular definition of passenger satisfaction (Tomii *et al.* [4]).

Relevant papers have been published on different aspects of railway traffic management and control with different modelling methods (Alternative Graph, D'Ariano *et al.* [1], Discrete Event Modelling, Dorfman and Medanic [3], Object-oriented Modelling, Goodman and Takagi [5], Description Language for rescheduling patterns, Hirai *et al.* [6], etc), solution algorithms (Intelligent Search [1, 2], Dynamic Programming Ho *et al.* [7] etc), and also collaborative rescheduling for distributed railway traffic control based on a heuristic search for optimisation of train sequences (Chou *et al.* [8]).

Earlier studies on optimisation of rescheduling decisions mostly focused on solving combinatorial optimisation problems like train sequences change, trains connections combination, trains re-routing, while disregarding the train running time optimisation issues together. The rescheduling strategy in this paper is focused on the retiming and re-sequencing of perturbed trains approaching portal junctions of bottleneck sections. A cooperative strategy framework for train rescheduling of portal junctions leading into bottleneck sections is proposed. The strategy is mainly based on an improved Differential Evolution algorithm for Junction Rescheduling Model (DE-JRM) which is proved to be suitable for solving train rescheduling problems for both individual fly-over junctions and flat junctions, based on a quantitative statistical evaluation method.

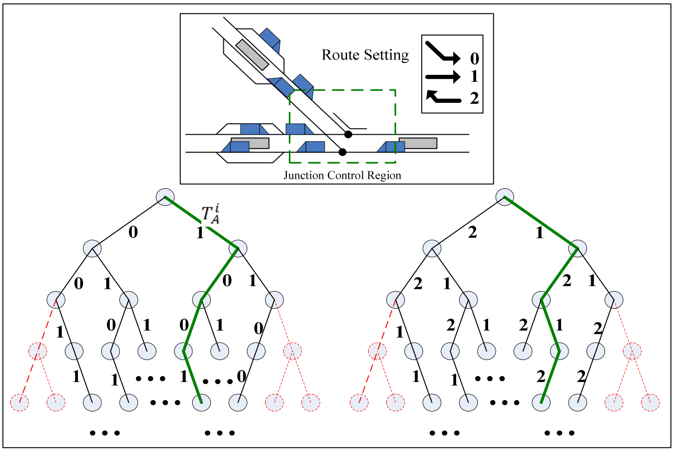

Figure 3: Sketch map of junction rescheduling decision making.

This paper is organised as follows. In section 2, an individual junction rescheduling methodology is briefly introduced. Section 3 describes the quantitative statistical evaluation of DE_JRM for both flyover junctions and flat junctions. Finally, a cooperative strategy framework for train rescheduling of portal junctions leading into bottleneck sections is proposed.

2 Train rescheduling for individual junctions

2.1 Junction rescheduling model (JRM)

The basic JRM principle can be represented as shown in Figure 3. Binary Decision Trees can be used for the graph based modelling of the process of rescheduling trains through a two tracks junction. For a fly-over junction, the route 1 and route 2 shown in Figure 3 are grade separated by bridges or tunnels. There will be one potential conflict point caused by the trains on approaching route 0 and 1. The rescheduling decision making process can be graphically modelled with the decision tree shown in the bottom left. Every branch of the decision tree(s) denotes a route setting for the trains on different routes approaching the junction. The train arrival time can be denoted with the length of branches. For a flat junction, two potential conflict points are created by approaching trains on three different routes (Route 0 and Route 1, Route 2 and Route 1), so that two decision trees with a common branch (Route setting 1) are used for the graph based modelling. The optimisation objective is to find the optimal decision tree branch routes with the optimal duration (train arrival time) complying the constraints of operation and signalling systems. The objective function in this paper is defined as Weighted Average Delay, which reflects the deviation of rescheduled timetable with nominal timetable and the effects on the passengers on board. The details of the mathematic formulation of JRM were presented in Chen *et al.* [9].

The presented optimisation problem for train rescheduling in junction areas is a typical NP-hard problem, as well as a hybrid optimisation problem. It is unlikely to find a classic optimisation algorithm that solves such a problem in a polynomial time. However, it is possible to find near optimal or acceptable solutions in a reasonable time using an efficient algorithm.

2.2 Differential evolution algorithms for JRM

To solve the presented hybrid optimisation problem including continuous variables (train arrival time) and discrete variables (route setting decisions), an improved Differential Evolution (DE) algorithm is proposed to optimise the continuous train arrival time, taking discrete route setting decisions as constraints for the algorithm. DE algorithms are proposed to be simple and efficient evolutionary approaches for handling continuous variable optimisation problems by Storn and Price [10]. The improved Differential Evolution algorithm for Junction Rescheduling Model (DE-JRM) presented here is based on the DE algorithm "JADE" presented by Zhang and Sanderson [11]. An additional operation "Modification" is added in the process of DE_JRM, compared with traditional DE algorithms. The pseudo-code of DE-JRM is shown in Figure 4.

The main function of Modification is to adapt invalid solution individuals generated by stochastic Mutation and Crossover operations based on the Greedy Rules so that they become valid in terms of the constraint rules of JRM because of the train operation and control constraints like train headway control, train running time limit etc. The details of algorithms DE_JRM can be seen in Chen *et al.* [9]. On the basis of large numbers of valid individuals in every generation, DE-JRM can evolve improved solutions from generation to generation and converge after numbers of generations.

```
Initialize first generation;
Calculate the initial cost (WAD);
While ( ! current best solution convergence)
        Mutation;
        Crossover;
        Modification;
        Calculate the current cost;
        Selection;
        Calculate the current best solution;
End.
Output the best solution;
```

Figure 4: Pseudo-code of DE_JRM.

3 Evaluation of DE_JRM for both fly-over junction and flat junction

To validate the efficiency of DE_JRM for both fly-over junction and flat junction, a method based on Monte-Carlo simulation methodology is used to evaluate the performance of the algorithm DE-JRM quantitatively, in terms of a Statistical WAD (SWAD). The First-Come-First-Served (FCFS) strategy, which has been widely used for junction control in British railways, was chosen as the bench mark for performance comparison.

A sketch map of the layout for the case study with two types of scenarios is shown in Figure 5. The left graph shows the configuration with a typical fly-over junction and the right one shows the configuration with a typical flat junction. These two main types of scenarios were studied for the evaluation of the proposed algorithm for train rescheduling. In each scenario, DE_JRM and FCFS rescheduling strategies will be applied and the performance will be compared for both fly-over junction scenarios and flat junction scenarios where 24 trains from different origins approach.

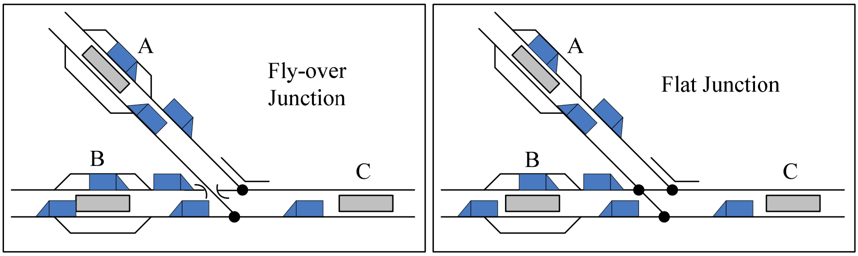

Figure 5: Sketch map of two types of scenarios for case study.

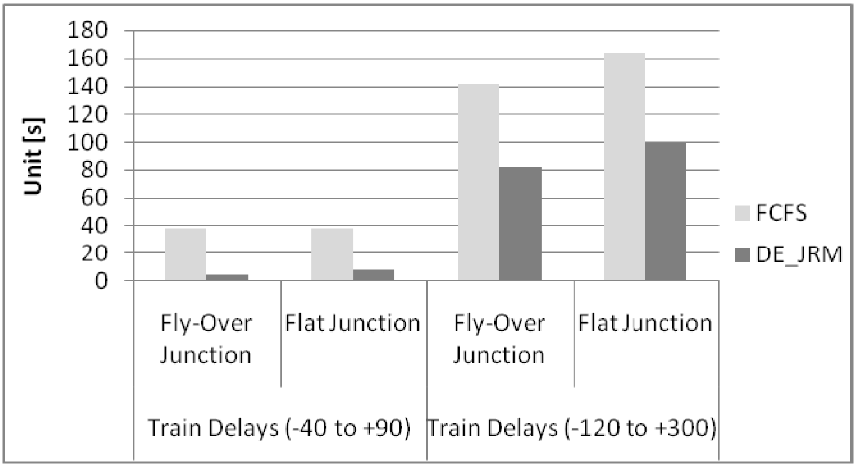

Figure 6: Comparison of SWAD for fly-over junction and flat junction.

As required by the Monte-Carlo simulation methodology, large numbers of perturbed scenarios are generated for simulation experiments based on the train delay probability distribution of boundary arrival time, and Statistical WAD (SWAD) can be gained from simulation results of 10000 independent experiments for DE-JRM and FCFS. SWAD represents the overall performance value, and the comparison is shown in Figure 6. SWAD is expected to be smaller when better train rescheduling algorithms or strategies applied. It can be seen that, for both fly-over junction and flat junction, the WAD can be significantly decreased by rescheduling with DE_JRM compared with FCFS.

4 Framework of cooperative strategy for portal junctions of bottleneck sections

The presented rescheduling methodology can be used for train rescheduling of individual junctions. For bottleneck sections, there are usually two junctions located at the portals where many trains converge from different origins. As shown in the Figure 7, the output train flow of one portal junction will be the input train flow of another portal junction. If the two portal junctions are located far away from each other that the train running time between two portal junctions is much longer than the rescheduling time window. That means the rescheduling decisions making in one portal junction do not need to know the rescheduling decisions making in another portal junctions in advance because the prediction of trains' movement from another portal junction in one rescheduling time window will not be affected by the new rescheduling decisions of another portal junction. If the two portal junctions are located not far away from each other, the rescheduling decisions made in one portal junction will depend on the rescheduling decisions made in another one and have influence to each other. In addition, if there is no cooperative mechanism between two portal junctions, it is unlikely to get optimal decisions for both two portal junctions and could generate

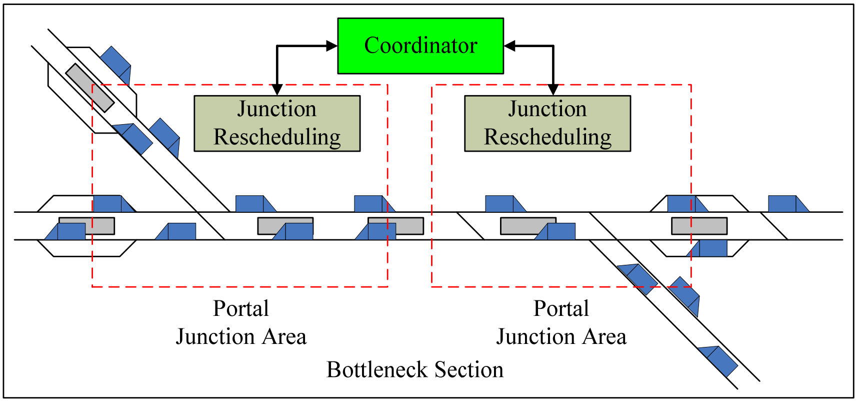

Figure 7: Coordinator for train rescheduling of portal junctions.

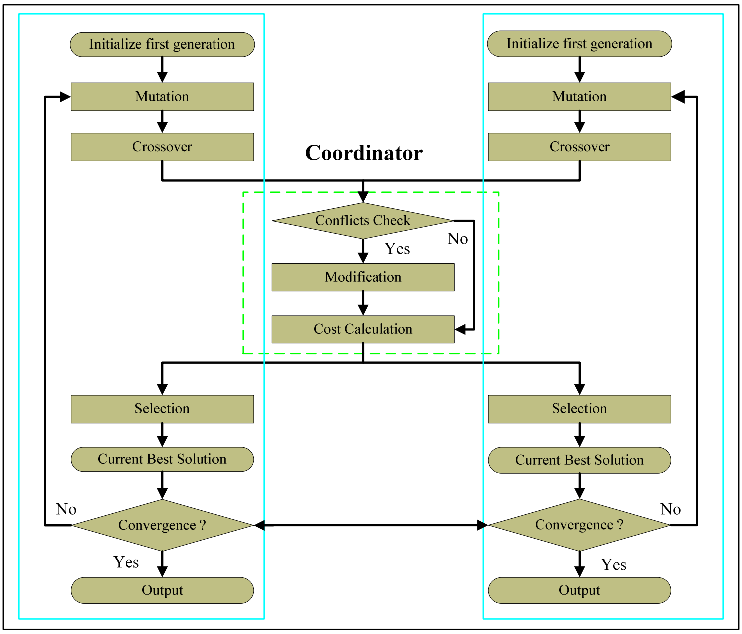

Figure 8: Flow chart of the cooperative strategy.

conflicts in the rescheduling decisions each other. To avoid the possible conflict decisions and try to get optimal decisions for both two portal junctions, a 'coordinator' is introduced as shown in Figure 7. The main task of the coordinator is to check the conflicts of the rescheduling decisions from two portal junctions and modify the decisions if necessary in the process of decisions making. The aim of modification operation in the coordinator is to adapt the invalid solutions to be valid in terms of signalling and operation constraints in bottleneck sections.

The flow chart of the cooperative strategy is shown in Figure 8. Based on the DE_JRM algorithm for individual junction rescheduling, the modification operations in rescheduling process of two portal junctions are integrated into the coordinator. All of the generated decision solutions will be sent into the coordinator for conflicts check and modification. As well, the total cost of the decisions for two portal junctions will be calculated in the coordinator. The updated decision solutions without conflicts and the total cost of the decision solutions will be sent back to the rescheduling decision units of two portal junctions. The current best solution is the best solution for all trains approaching the bottleneck sections combining the best solutions from two portal junctions in current generation.

Based on the proposed cooperative strategy framework for the train rescheduling of portal junctions, the train rescheduling problem for bottleneck sections can be divided into distributed individual junction rescheduling problems with cooperative mechanism between each other. This framework gives a parallel rescheduling decision making approach for two portal junctions of bottleneck sections. Compared with centralised rescheduling decision making for bottleneck sections, this framework can decrease the dimension of rescheduling problem by half and also ensure that the rescheduling decisions have no conflicts. The data transmission between the coordinator and rescheduling decision units of two portal junctions will not take long time by local area networks as the decision data amount is not large and can be transmitted within only several data frames in one generation of the algorithm.

5 Conclusions

Since both the margin time and the recovery time in the timetable for trains in bottleneck sections are limited, train rescheduling on the converging routes is a useful approach to achieving recovery from disturbance in railway operation in junction areas. A cooperative strategy framework for train rescheduling of portal junctions leading into bottleneck sections is proposed in this paper based on an improved Differential Evolution algorithm for Junction Rescheduling Model (DE-JRM) which has been proved to be suitable for solving train rescheduling problems for both individual fly-over junctions and flat junctions. The ongoing research is focused on the validation of the proposed cooperative strategy in terms of computation time, goodness of rescheduling solutions etc.

Acknowledgements

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