Research on Railway Traffic Conflict Management Method in Onboard-centered Train Control System

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Abstract—In order to ensure the safety of train operation and improve the ability of train to deal with emergencies independently, this paper classifies and defines the possible conflicts in railway operation, and proposes a method of train conflict prediction and collaborative resolution. The feasibility of this method is verified by the establishment of timed automata model for different operation scenarios. Finally, a prediction method of station level resource occupation conflict is proposed, which is verified by a simulation example.

1. INTRODUCTION

In recent years, the research on on-board centered train control system has been widely carried out at home and abroad. This new train control system is currently in the preliminary stage of research, which can have different system structures and module functions. The on-board equipment is responsible for train movement authority calculation [2] and interlocking function. The traditional ground centralized control will be replaced by a onboard-centered distributed control mode, which puts forward higher demand for the automation and intelligence of the onboard equipment. In addition, the train should be capable of dealing with some of its own traffic scheduling, in order to further improve the ability to deal with traffic conflict independently.

Railway traffic conflict can be divided into section conflict in section and conflict in station. Trains can resolve conflicts by predicting future conflicts. Conflict in section refers to conflict in headway distance, which means when two trains are running in the section, the headway distance is less than the safe interval, and the speed of the rear train is higher than that of the preceding train. If the train operation is not adjusted in time, it may cause emergency braking or rear end collision of the trains, which will endanger traffic safety. Conflict in station and yard refers to resources occupancy conflict. In the process of train arrival and departure, there is a conflict between resources of two or more trains, which indicates that there is a conflict in approach mode [3]. At this time, if the route is not changed or the resource allocation is not adjusted in time, the train may have to stop outside the station. In both cases, the train may deviate from the train schedule.

It is very important to predict the occurrence of conflict in advance. Petri net is used to establish the train group operation model to predict conflict, but the station situation is not considered in detail. Literature [5] focused on the detection and resolution of station level conflicts earlier. The substitution diagram is used to model and detect the train operation at the micro level [6]. A conflict prediction
method based on spatiotemporal deduction of driving events needs a lot of historical data. According to the historical data, fuzzy time table can improve the prediction accuracy [7].

This paper puts forward the methods to solve these two types of conflicts. An automatic prediction method of station level conflict is proposed. The accuracy of the prediction results is verified by an example. Finally, UPPAAL is used to verify the feasibility of timed automata model in the solution of station conflict.

2. RAILWAY TRAFFIC CONFLICTS RESOLUTION

2.1. Section conflict management method
In the onboard-centered train control system, the train runs in moving block mode, and the information exchange of train position, speed and operation plan is completed through periodic communication between trains. Since a train only communicates with the adjacent trains, although the train can quickly change the dynamic plan to ensure the safety of the train, it is unable to timely inform other trains of the change of the train plan because the train is unable to obtain the train information of the whole line. In this case, when the train changes its dynamic plan to a certain extent, it is easy to produce a chain reaction, forcing each subsequent train to passively change its driving plan, resulting in extensive train delays and affecting the operation efficiency of the whole line [8]. Therefore, it is very important to predict the conflict between the tracing interval of trains and the operation plan, and guide the train to run according to the traffic plan.

The on-board train control system includes three levels: central equipment, on-board equipment and trackside equipment. The center equipment includes dynamic capacity decision (DCD) and train control resource management unit (Resource Management). DCD realizes the decision-making function of train dynamic operation, which is mainly responsible for the formulation and sending of traffic plan and the supervision of train operation; RMU is used as the ground database to assist the train to identify the train ahead and control route, and supports temporary speed limit and electronic map download. On board equipment is the core of train control system, which consists of train control module, route logic unit (RLU) and electronic map data base. Trackside equipment mainly includes balise and object controller OC. Balise is mainly used to assist train positioning. And OC is mainly used to realize state acquisition of route equipment and drive switch.

When a train begins operating, it will establish communication with the corresponding regional resource management center RMU and dynamic capacity decision subsystem DCD [9]. The train obtains traffic plan from DCD, the electronic map data from RMU, and requests the IDs of all trains within certain range from RMU. The train sends out information. After other trains return their status information, the train searches for the train in front of it and requests to establish communication to periodically obtain the position and speed information of the train ahead. In order to detect the running status of the train ahead, if the tracing intervals of the succeeding trains may exceed the fluctuation range set by the traffic plan, the warning information and suggestion for adjusting the operation conditions are generated to guide the trains to operate according to the traffic plan. When it is detected that the tracing interval is less than the minimum tracking interval, it is necessary to adjust the train control mode.
There are two control modes in the onboard-centered train control system, one of which is using onboard equipment for main control and DCD for monitoring. The second is using DCD as main control. The train judges and predicts the risk level of conflict. When the train is unable to handle the conflict by itself, the train driving instruction is transmitted to DCD by on-board equipment. DCD directly sends dispatching order to the train to ensure the safety and efficiency of the whole line. Because the adjustment scheme of the train to the conflict may affect the operation plan of the trains before and after the conflict train, these trains also switch to the DCD master control mode. Other trains will not be affected.

When the conflict is solved effectively, the train control needs to be switched back to the on-board master control. The switching process can follow two schemes. First of all, DCD judges that the train is back to normal operation, sends a switching application to the on-board equipment, and the train returns the confirmation information after checking its own running state, and accepts the authorization of DCD to complete the switching. Second, when the train detects that the train is running normally, it sends a handover request to DCD. When DCD determines that the train meets the switching conditions, it transfers the vehicle control right to the train. The specific process is shown in Fig. 1.

2.2. Station conflict management method
For onboard-centered train control system, the train route logic unit RLU is responsible for route control function, and the object controller is responsible for centralized management of station resources. Before the train enters or leaves the station, it has completed the analysis of driving plan transmitted by DCD, including destination station, parking track and departure time.

When preparing to enter the station, the train will establish communication with RMU and continue to request the location and ID of the train at the station. By matching the train location and electronic map, the train can judge whether there is line resource conflict. The train establishes communication
with the conflicting trains to obtain their timetable, delay time, resource information, passenger capacity, etc. The train comprehensively determines the train priority, determines the resource allocation sequence or changes the route information. The adjustment plan shall not deviate from the operation plan as far as possible. The plan adjustment information is sent to the conflict train. If the confirmation message is returned, it will be implemented according to the plan. The adjustment information is transmitted to DCD through RMU to provide macro control reference for dispatchers. If a scheduling command is received from the DCD, the scheduling command is executed first.

3. CONFLICT PREDICTION METHOD BASED ON TCPN

The Petri net analysis method[10] has been applied in many fields and also in the field of conflict prediction. Because this paper studies the onboard-centered conflict prediction method, which is a dynamic local conflict prediction that changes with the train, it focuses more on avoiding train collisions and reducing competition for infrastructure resources, and design a conflict prediction model based on petri network.

In the train control system, the process of train operation is the process of continuously occupying the resources on the track side. In the station, the track circuit was eliminated, and the tracks in the station were divided into virtual segments, each of which varied from tens of meters to hundreds of meters according to the different lengths of the station layout. The virtual segments of the track is stored as a data node in the station layout data structure which is stored in the electronic map for the train to match the occupancy of the track resources in the station.

Through the algorithm shown in Fig. 2, the TCPN structure of the conflict prediction can be obtained. The track data in the electronic map is used as the input to finally obtain the TCPN model of the train's conflict detection. Steps 2-6 set up a place and library for each virtual segment. The color set contains a global "start" and "end" virtual node. Steps 7-13 set the running process of the train in the virtual section as a transition, define the color set, and set the connecting arc between the transition and the place. Steps 14-23 take the driving plan or the route resource plan occupancy time as input, and calculate the initial mark of the model based on the actual position of the train at this time. Token represents the running train. Token is assigned a color to identify the train attributes. The set of colors represents the approach and direction of the train, and step 19 sets the time constraint parameters on each place for each train. Due to limited space, Figure 3 only shows the algorithm for generating the double track section. The schematic diagram of the input and output results is shown in Fig. 3. Fig. 3(a) shows the track topology of a certain range of the train, and Fig. 3(b) represents the corresponding conflict detection PN structure of the train.

After establishing a multi-train TCPN operation model within a certain range in front of the train, we can further obtain all reachable flags R(N, M0) under the initial mark M0, and perform conflict detection on the reachable signs one by one. The conflict detection method is through judging whether the token under the reachable mark meets the corresponding constraints.

This paper mainly considers the prediction of the possible competition situation of resources by trains, and stipulates that the capacity of each place is 1, that is, one track resource can only be occupied by one train for a period of time. So there are constraints (1).

\[ \forall p \in P \land m(p) \leq 1 \]  \hspace{1cm} (1)

If there are signs that do not satisfy the constraint (1), the train's conflict resolution module sends an early warning. Since the train operation is a typical controlled random process, and the size of the virtual segment is different, the operation of the train may deviate from the planned time in the future.
Automatic generation algorithm of PN structure for station conflict prediction

**Import:** virtual partition collection \( S \), Train collection \( V \), Train colorset \( A \), Run scheduled time collection \( T \);

**Output:** TCPN\( = (T,P,F,C,D,M_0) \)

1. \( T = \emptyset, P = \emptyset, F = \emptyset, D = \emptyset, M_0 = \emptyset \);
2. for all \( s_i \in S \) do
3. design a place, denoted by \( s_i \);
4. \( P \leftarrow P \cup \{s_i\} \);
5. \( C(p) \leftarrow C(p) \cup \{a_i,u\} \);
6. end for
7. for all \( (s_i, s_{i+1}) \in \mathcal{O} \) do
8. design a transition \( t_j \), denoted by \( (s_i, s_{i+1}) \);
9. \( T \leftarrow T \cup \{t_j\} \);
10. \( C(t_j) \leftarrow C(t_j) \cup \{b_i,h\} \);
11. design two arcs \((s_i, t_j)\) and \((t_j, s_{i+1})\);
12. \( F \leftarrow F \cup \{(s_i, t_j), (t_j, s_{i+1})\} \);
13. end for
14. for each place \( p \) do
15. \( m_0(p) = 0 \);
16. end for
17. for all \( v_m \in V \) do
18. for all \( p_i \in P \) do
19. \( D(p_i, v_m) = t_n \);
20. if \((s_i, \text{start} = v_m, \text{position} = s_{i+1}, \text{end})\)
21. \( m_0(p) = 1 \);
22. end for
23. end for

**Figure 2.** Algorithm of automatically generating PN structure

**Figure 3.** Station example and PN structure

In order to fully predict the conflict, a constraint on the tracking interval is added, such as constraint (2). The trigger time of token in place \( P \) minus the trigger time of token in the next place.

\[
\forall t_i \in \{e(M)\}, p \in t_i',
\tau_i - \min(e(M)) \leq \Delta t
\]

To verify the effectiveness of the method, take the station in Fig. 3 as an example for simulation verification. The operation plan information used in the simulation is shown in Table I. A total of 6 trains are involved. The headway between trains is not less than 3 minutes. The train can pass the station without conflict according to the driving plan. The C# language is used to develop a TCPN-based conflict prediction and resolution control module, which changes the actual train running time to simulate late behavior, analyzes the actual train conflicts and the conflicts predicted by the TCPN model. The simulation results are shown in Table II.

**TABLE I. TIMETABLE OF TRAIN**

| Train | Arrival time | Departure time | Parking track |
|-------|-------------|----------------|--------------|
| 1     | 7:10        | 7:12           | IG           |
| 2     | 7:06        | 7:09           | 3G           |
| 3     | 7:15        | 7:18           | IG           |
| 4     | 7:02        | 7:05           | IIG          |
| 5     | 7:08        | 7:17           | 4G           |
| 6     | 7:19        | 7:19           | IIG          |

**TABLE II. TRAIN CONFLICT RESULT**

| Actual deviation | Forecast result |
|------------------|-----------------|
| Train 1 arrives 5min late | Conf1 = (v1,v2,p22,5)  
Conf2 = (v1,v3,p23,13) |
| Train 2 arrives 3min late | Conf1 = (v1,v2,p24,12)  
Conf2 = (v5,v6,p8,20) |
4. CONFLICT RESOLUTION STRATEGY

The conflict warning information contains where the train e may conflict with some other trains. The train establishes communication with other trains in conflict, and exchanges information with other trains in the form of request and response. This information are synthesized to formulate corresponding collaboration strategies which mainly resolves conflicts by changing the route of the train or adjusting the order of the trains in front of and in rear of the train. The following provides collaboration strategies in several typical scenarios. The train can choose one or more of them for combination.

- The train that arrives first can use resources first.
- The train with the shortest resource usage time can use the resource first. For example, a train with a shorter length continuously takes up resources for a shorter time.
- Trains with important tasks can take up resources first. For example, passenger trains are prioritized before freight trains.
- The train receiving the dispatch command first can occupy the resources. The control command for the train to resolve conflicts autonomously is lower than the priority of the dispatching command.
- Trains with more passengers can pass first. This principle aims to reduce the impact of delay on passenger satisfaction.

Fig. 4 shows the situation in which three trains occupy resources in different orders and pass through the station.

5. VERIFICATION BASED ON UPPAAL

The conflict handling process needs to obtain the necessary basic information from the RMU and other trains in a timely manner, and it has high demand on real-time property. Because the train is constantly moving, conflict prediction is also a dynamic process. Time automata is one of the important forms of formal methods. Time automata is a conversion system with time constraints. A six-tuple can be used to define $\langle S, S_0, \Sigma, X, I, E \rangle$. UPPAAL is a commonly used modeling and simulation tool for time automata. The UPPAAL tool provides a standardized verification grammar—BNF (Backus-Naur Form) grammar for model verification of real-time systems:

$$\text{Prop} := A[\text{Exp}] \mid E \Leftarrow \text{Exp} \mid E[\text{Exp}] \mid \text{Exp}_1 \rightarrow \text{Exp}_2.$$  \hspace{1cm} (3)

Where Exp represents a logical expression of a certain property of the system being verified. The letter E and A are used to quantify the path. Letter A indicates for all paths. letter E indicates that there is at least one path. The symbols [] and <> are used to quantify the state on the path. The symbol [] represents all state sequences on the path. The symbol <> indicates that there is at least one state on the path.

Due to limited space, only the time automaton model and verification of the conflict handling process at the station are shown, including the Train1 time automaton model shown in Fig. 5, the RMU time automaton model shown in Fig. 6, and the other Trains time automaton models shown in Fig. 7. The verification results of BNF statement in UPPAAL are shown in Table III, and all properties are satisfied.
Figure 5. Time automaton model of train

Figure 6. Time Automata model of RMU

Figure 7. Time automata models for other trains

| Verification Content                                                                 | BNF                                                                 | Result |
|-------------------------------------------------------------------------------------|----------------------------------------------------------------------|--------|
| The train can predict conflict based on the train information in the station.       | $E<> (\text{Train.idle imply Train.Predict\_conf})$                   | ✓      |
| The train can determine the priority based on other train information in the station.| $E<> (\text{Train.idle imply Train.Dete\_Prio})$                     | ✓      |
| If the train sends out the request information in the station and the response is not received within T1 time, an alarm will be given. | $A<> (\text{Train.Wait\_DistInfo imply Train.Alarm})$ and $(t1>T1)$  | ✓      |
| If the train does not send the route adjustment plan to other trains, it may cause the train to be delayed. | $E<> (\text{Train.Dete\_Prio imply Train.late})$ and $(\text{otherTrains.Finish\_AttrSend imply otherTrains.late})$ | ✓      |
| When RMU receives the request information in the train station, it must respond within T1 time. | $A<> (\text{Train.Wait\_DistInfo imply Train.Per\_confPred})$ and $(t1<T1)$ | ✓      |
6. CONCLUSIONS
This paper discusses the method of train handling conflict events, and designs two conflict resolution processes. The effectiveness of the method is verified by an example. The functional requirements of the system are realized by using UPPAAL tool and timed automata model. The train is adjusted ahead of schedule to coordinate operation mode and resource allocation, so as to enhance conflict resolution ability and resource utilization ratio. This method further improves the intelligent level of the train and relieves the pressure of dispatching.

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