



Train control method for high speed and high density railway systems

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Abstract

Many railway systems are moving toward high speed and high density railway systems for faster and more frequent intercity transit service. In such systems, it is very difficult to plan the timetable and to run each train according to it, because many kinds of trains are running at the same time with only a short headway. In this paper, we propose a new method to control trains effectively under these conditions. The proposed method is called a “Target Shooting Method” (TSM). In TSM, every train’s future movements are planned by ground-vehicle cooperation to get smooth and energy saving traffic control.

1. Introduction

Recently, the demand for faster and more frequent transportation service is getting higher, both within and between cities. Since, the innercity commuter lines usually have no sidings and the performance of each train is nearly the same, i.e. no pass/refuge between trains is necessary. On the other hand, long distance intercity lines have many sidings, and many kinds of trains run, which means much pass/refuge. So, in intercity lines, the timetables become very complicated as traffic density is getting higher. Several methods for easy planning and rescheduling the timetables for such lines have been proposed (Tsuruta[1], Komaya[2]). However, the problem of train operation in high speed and high density intercity lines has not received sufficient consideration. In this paper, first, we clarify the problem of now to operate each train without unnecessary deceleration. Then we propose the new train control method to operate each train by ground-vehicle cooperation, and discuss its advantages. Finally, we show the results of computer simulations to demonstrate the validity of the proposed method.

2 Problem of high speed and high density railway systems

High speed and high density railway systems are realized by introducing new high speed trains into long distance intercity lines, simultaneously with preparation of a higher density timetable. But the two requirements of fast and frequent are at odds in the timetable, because as trains run faster, the longer the minimum headway becomes while higher traffic density means the headway in the timetable must become shorter. A small headway margin, which is the difference between the headway in the timetable and the minimum headway, is one of the aspects of high speed and high density railway systems. Another aspect is the increase in the number of times that a faster train passes slower trains while traveling on its way. These two aspects make the timetable very complicated.

In such high speed and high density railway systems, train interference, which causes unnecessary deceleration of a train due to an Automatic Train Protecting (ATP) system or other signaling systems, becomes a problem. Here we say 'unnecessary' because deceleration can be avoided if all trains are being operated appropriately. Train interference results from the relationship between the headway margin and the running time margin, which means the difference between the running time defined in the timetable and the standard running time.

Usually, some running time margin is provided for various reasons. With some running time margin, there are many feasible paths in the time-distance plane which satisfy the departure time and the arrival time as defined in the timetable (Figure 1). And if there is a small headway margin, one of the feasible paths of the preceding train may interfere with one of the feasible paths of the following train as shown in Figure 2. In the figure, the transition of signal indication, which allows maximum speed to the following train, is shown, where a fixed block ATP is assumed for a signaling system.

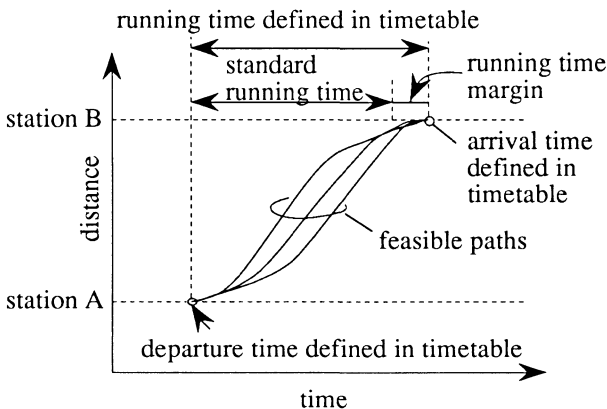


Figure1: Example of feasible paths in time-distance plane where there is a running time margin

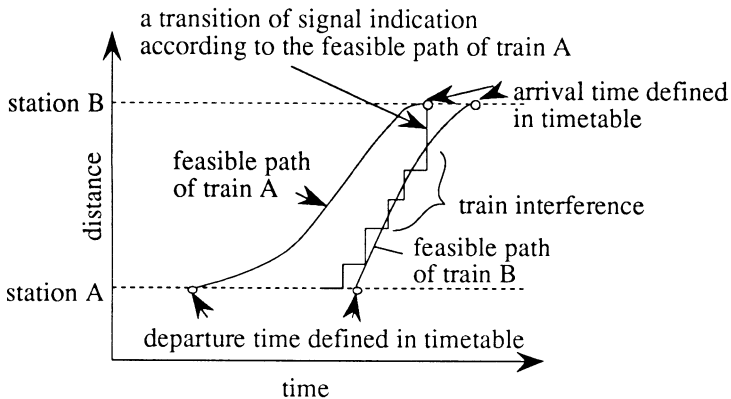


Figure 2: Example of feasible paths in time-distance plane with train interference

Train interference has many disadvantages especially for high speed and high density railway systems. First of all, train interference is a waste of energy and time. And, as many trains run with a small headway margin, even a slight delay of a train easily interferes with the following train and soon the delay may propagate until the timetable collapses. This does not happen where the traffic density is low, because there is enough headway margin. Therefore, to control trains smoothly with less energy consumption in high speed and high density railway systems, avoidance of train interference is the biggest concern.

3. Target Shooting Method

To solve the problem described in section 1, we propose a “Target Shooting Method” (TSM), which consists of the following three steps: 1) a detecting step, which detects the possibility of train interference, 2) a resolving step, which eliminates the possibility by calculating Train Targets, and 3) a shooting step, which controls each train according to Train Targets.

1) The detecting step

To detect the possibility of train interference efficiently, we introduce the concept of an occupied area in which all feasible paths exist in a time-distance plane, and which satisfies given constraints without considering train interference. An occupied area is easily calculated by simulating the movement of a train with a train model which is used to evaluate standard running time, because there is no need to consider the transition of signal indication. Figure 3 shows an example of an occupied area where the constraints are departure time and arrival time as defined in the timetable.

Because all feasible paths are included in the occupied area, a train must run within its occupied area to satisfy its constraints. So, using occupied areas of successive trains, it is easy to predict the worst case in which the preceding train interferes with the following train. In Figure 3, the worst path of train A, which may cause interference with the following train, is the right-most path P in the occupied area. Then the worst case is examined by overlaying the transition of

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signal indication along path P on the occupied area of the following train. Where and when train interference may occur is understood from the occupied area of the following train being cut off by the transition of signal indication. We call this area an interference area (Figure 4).

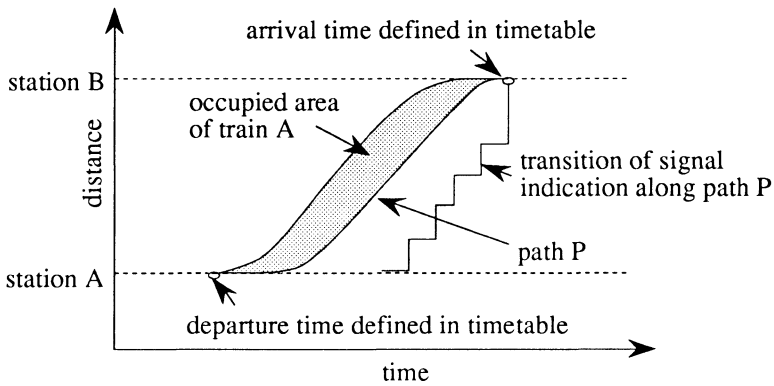


Figure 3: Example of an occupied area

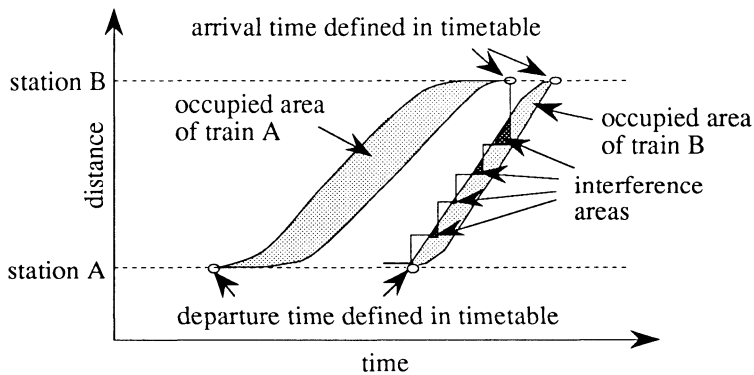


Figure 4: Example of interference areas

If there is no interference area, no train will interfere with others as long as they run satisfying their constraints. The detecting step calculates occupied areas of all trains and examines if there are any interference areas or not. If an interference area is found, the resolving step resolves the possibility of train interference.

2) The resolving step

The resolving step resolves the interference area by restricting the occupied area. An occupied area is restricted by additional constraints, i.e., the Train Target which consists of a target position, a target velocity and a target time of the train. The reasons for their choice are as follows: 1) Restricting the occupied area by a target point in the time-distance plane is reasonable 2) Because the signaling system indicates the maximum speed allowed, train interference depends on the velocity of the following train. So, specifying the velocity is a useful way to

avoid train interference. An example resolution of the interference area by using Train Targets is shown in Figure 5. After the interference area is resolved, no path which includes the Train Targets interferes with other paths.

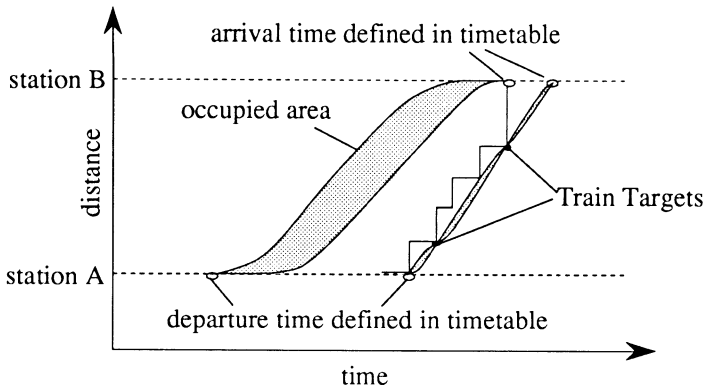


Figure 5: Example resolution of train interference

3) The shooting step

In the shooting step, a feasible path including Train Targets is calculated from an energy saving point of view. First, a fastest path which satisfies the position and the velocity in Train Targets is calculated. The fastest path is easily calculated by using a train model. Then the path is modified to satisfy the time constraints in energy saving criteria by using the method proposed in Kawashima[3]. After calculating all paths between Train Targets, they are connected at Train Targets. The connected path is continuous in velocity, because Train Targets specify (position, velocity, time). So, planning a path which includes all Train Targets can be decomposed into planning paths between Train Targets. After calculating a feasible path, the train is controlled by using conventional PID control or predictive fuzzy control (Miyamoto[4]).

4. Train Targets Generation

In this section, a Train Targets generating algorithm which can resolve train interference in some cases is described. In this algorithm, a fixed block ATP system is assumed and a width of interference is used. The width of interference at the transition point is defined as the width of the interference area measured in time at the transition point T_i (see Figure 6). Here, the transition point is the point where the signal indication changes.

[The Train Targets generating algorithm]

- 1) Calculate initial occupied areas.
- 2) Calculate interference areas.
- 3) Calculate the width of interference W_i at each transition point T_i .
- 4) Set Train Target at the transition point T_j where the width of interference W_j is maximum.
- 5) Calculate occupied areas with Train Targets.
- 6) Calculate interference areas.
- 7) Repeat 3)-6) until all interferences are resolved.

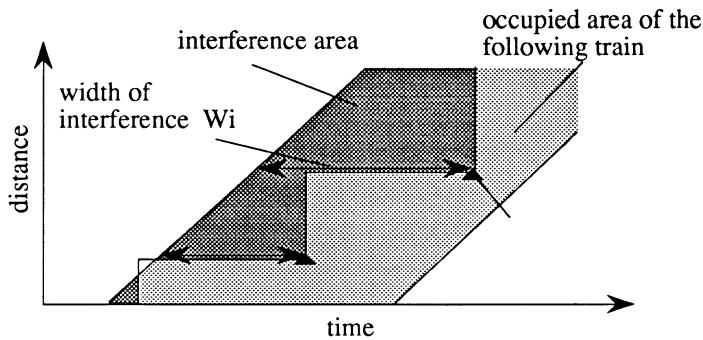


Figure 6: Definition of width of interference W

5. Advantages of TSM

In TSM, the traffic control system on the ground makes the Train Targets, which specify where and how fast a train should be at a specified time to avoid train interference, and then the train shoots the Train Targets (runs to satisfy the Train Targets). In other words, in TSM, path planning of a train is divided into two parts: 1) global planning on the ground (i.e. making Train Targets); and 2) local planning on the vehicle (i.e. making a path including Train Targets). There are three advantages of TSM are as follows.

1) Load distribution between the ground and the vehicle

In TSM, the system on the ground does not need to make precise paths of all trains to assure that there is no train interference. So, the computation load is low compared with the method which plans precise paths of all trains. Furthermore, in TSM, the system on the vehicle plans a path which includes all Train Targets, and such path planning does not require a huge computing power. Thus, in TSM, the computing load is distributed between the ground and the vehicle.

2) Small communication load between the ground and vehicle

In TSM, the information transmitted between the ground and the vehicle consists only of Train Targets, which consist of position, velocity, and time. So, TSM can be used where the capacity for communication is limited.

3) Easy to follow the rescheduled timetable

When the timetable is rescheduled, all trains must follow the new timetable immediately. In TSM, it is easy to follow the new timetable by re-calculating the Train Targets.

6. Computer Simulations

In this section, the results of computer simulations are shown. We simulate two trains run between two stations in the case where an express train passes a normal train with small headway margin. The conditions of the simulations are shown in Tables 1-3.

Table 1 Conditions of trains

length		200[m]
weight		280[ton]
acceleration		1.0-1.5 [km/h/s]
deceleration		2.0-3.0 [km/h/s]
maximum speed	express	130[km]
	normal	110[km]

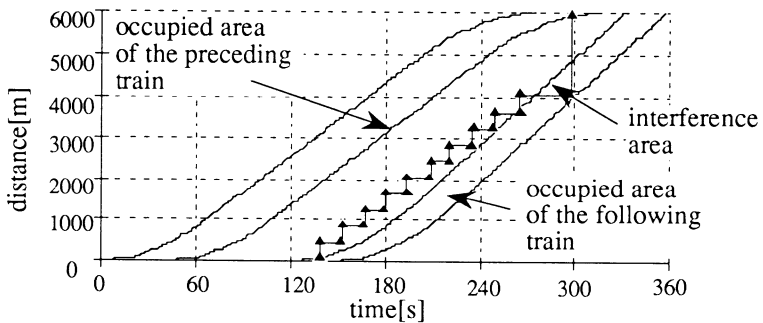
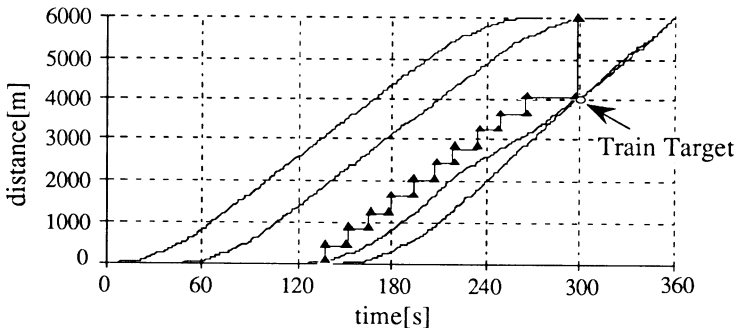
Table 2 Conditions of line

distance between stations	6[km]
length of block	400[m]
signalling system	ATP [indication pattern] 0, 25, 55, 90, 110, 130 [km/h]

Table 3 Conditions of timetable

standard running time	express	3'45"	running time in timetable	express	4'00"
	normal	4'45"		normal	5'15"
minimum headway		40"	headway in timetable		45"

Figure 7 shows the train interference and Figure 8 shows its resolution. Figure 9 shows the velocity curve of the following train when both trains run while consuming their running time margins uniformly. Figure 10 shows the velocity curve of the following train when the following train runs according to the Train Target shown in Figure 8. In Figure 9, the deceleration caused by the ATP is clearly seen, there is no deceleration in Figure 10.


Figure 7: Simulation of train interference

Figure 8: Simulation of train interference resolution

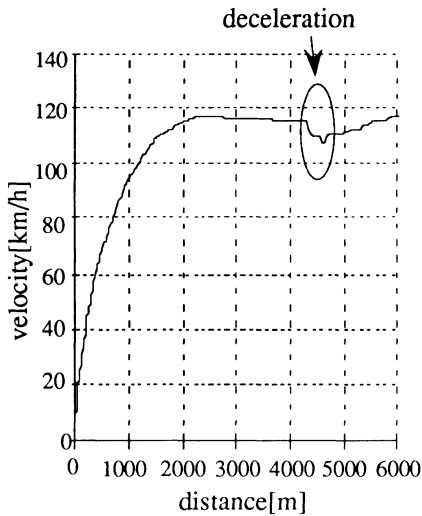


Figure 9: Velocity curve without Train Target

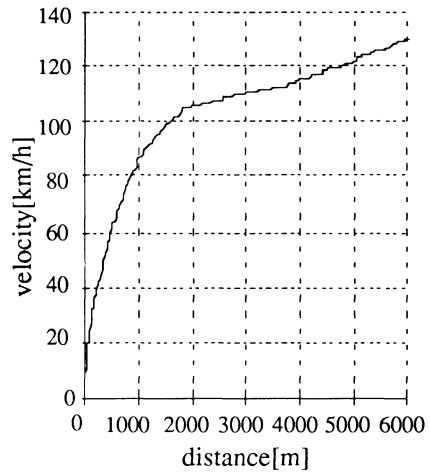


Figure 10: Velocity curve with Train Target

7. Conclusion

We proposed a new train control method, TSM. In TSM, the future movements of a train were expressed as an area in which all feasible paths are included. By using that area, the possibility of unnecessary deceleration was detected effectively. Then, the proposed method separated the path planning functions, so a better computer work load distribution was obtained between the ground and the vehicle, and easy path replanning was achieved.

We showed an algorithm which can resolve some train interference. And the results of computer simulations showed that using TSM, smooth and energy saving train operations could be obtained.

References

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