Train Operation/Passenger Behaviour Simulator under Moving Block Signalling Systems

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In recent years, various intelligent signalling systems such as moving block systems have been proposed and put into operation to increase transport capacity. Given the cost of replacing a signalling system it is important to be able to estimate the effectiveness of these new signalling systems. This research aimed to develop a method for simulating moving block systems. The simulation system can predict train traffic conditions and the passenger flows when the moving block system is in operation, while taking into account operational driving restrictions. The simulator was applied to an actual commuter line, to evaluate the effectiveness of the moving block system.

Keywords: timetable, train traffic control, signalling system, simulation

1. Introduction

Railway signalling systems based on the concept of blocks are used to prevent trains from colliding and to ensure operational safety. Recent years have seen the development and introduction of new signalling systems based on moving blocks. In these systems, train movements are controlled using position boundaries (limits) as opposed to the currently used speed restrictions. These boundaries move continuously according to the movement of preceding trains. Applying this method means that the minimum train headway can be reduced improving train frequency and punctuality. Moving block systems generally rely on radio based train control systems, which involves installation of a significant amount of new equipment. In addition, aspects of the system architecture, such as position of radio base stations, may affect the efficiency of train operations. Therefore, it is essential to accurately and quantitatively estimate the effectiveness of the moving block system from both a train operation and passenger perspective.

As a first step in this research, the function of a previously developed train operation/passenger behaviour simulator [1] was improved to be able to incorporate the simulation of train operations using a moving block system. A quick estimation and updating simulation method to obtain train speed profiles under a moving block system was developed and installed in the simulator. The simulator takes into consideration driver requirements for accelerating, coasting and braking. The simulator was then used for trial calculations of train operations and passenger behaviour for cases using the moving and fixed block systems during morning rush hour. The effects of train delay and recovery were evaluated by comparing passenger disutility values calculated using the results of the simulations for both the moving and fixed block systems.

2. Train control systems and moving block systems

2.1 Train control systems

In most railway signalling systems, block sections are defined by separating sections of track between stations. This is the principle behind the “fixed block system.” In other words, safety is secured by permitting only one train to enter each block section at a time. More recently however, new signalling systems have been developed where safety is guaranteed by ensuring a minimum distance between two successive trains, instead of defining fixed block sections. This is the principle underlying the “moving block system.” As radio communication based train control systems develop and are increasingly put into service, moving block systems are also increasingly being introduced (Fig. 1). Since the block sections are not fixed, moving block systems allow shorter headways without compromising safety.

Fig. 1 Fixed block system and moving block system

Installing a moving block system however, means replacing the whole signalling system. The capacity of the new control system, may influence train traffic, depending for example on the number of trains that can be covered by a single radio base. It is essential therefore, for the system to be designed with sufficient capacity to control train traffic. It is also important to quantitatively evaluate the cost effectiveness of the moving block systems over a whole rail line, taking into consideration the quantitative merits of decreasing headway and faster recovery from delays.

2.2 Related work

An example of a moving block systems that has been introduced in practice in Japan is ATACS [2]. One of the radio communication based train control system standards used for the moving block system is the European ETCS-Level 3.

Takeuchi et al. developed a train operation/passenger behaviour simulator that takes into consideration signal aspects and train operation curves for a fixed block system [1]. Kanda et al. evaluated the effects of a moving block system to examine the impact on reducing train delays [3]. These studies do not take into account however, detailed driving restrictions. Therefore, to obtain a more precise evaluation of these systems, it is important to incorporate driving parameters such as acceleration, coasting, and braking, and to estimate and update the speed profiles or train operation curves within a realistic computation time.

2.3 Purpose of the research

Based on the discussion above, this research therefore aims to develop a simulation method which satisfies the following requirements:

1. A simulation method that incorporates actual driving operations/conditions, and can produce results within a reasonable computation time.
2. Quantitatively evaluate the impact of the moving block system from a passenger transport service point of view.

To achieve these requirements, first of all, a train operation simulator for moving block systems was developed to take into account driving requirements/conditions. Then, a 10-minute delay due to disruptions on a certain commuter line was assumed. The simulator was then used to estimate train operations and passenger flows for both a fixed block system and a moving block system under these conditions. Finally, the results of the simulation were compared to identify the difference in the quantitative estimated impact on passengers when changing from the fixed block to the moving block system.

3. Train operation/passenger behaviour simulator

3.1 Outline

The overview of train operation/passenger behaviour simulator is shown in Fig. 2. The inputs are, timetable data, passenger Origin-Destination data collected through the automatic ticket barriers, and signalling equipment

Fig. 2 Outline of train operation/passenger behaviour simulator

data. The outputs are data for estimated train operation time, passenger train paths towards their destinations, and number of the passengers on board each train. The simulator also predicts train delays caused by congestion, and propagation of train delays. By estimating passengers' train paths, the number of passengers on board each train, and train delays successively, it is possible not only to evaluate timetables, but also various types of equipment, such as signalling systems. During morning rush hour on commuter lines in particular, the dwelling time of trains in stations is longer, because of the high number of trains being operated, and the extent of delay propagation depends on the design of the signalling system. The simulator can be used to design a signalling system to minimize train delay propagation.

Since the train operation/passenger behaviour simulator can estimate the route taken by passengers from the train operating timetables, it is possible to evaluate the timetable and signalling equipment design from the passenger point of view.

3.2 Function for estimating train operation curves in a fixed block system

The train operation/passenger behaviour simulator can be applied to all rail lines using fixed block systems. In the case of a fixed block system, the simulator first estimates the train operation curve when each train departs from a station, based on the signal aspect and any speed restrictions. Then, each train runs according to the estimated train operation curve. When the preceding train exits a block, and moves into the next block, the train operation curve is recalculated and updated (Fig. 3). The number of train operation curve recalculations is therefore equal to the number of blocks the train passes through. An approximate number of recalculations is given by the number of trains multiplied by the number of blocks. The overall simulation for an actual commuter line can be conducted within about 15 minutes with an ordinary personal com-

Fig. 3 Simulation of train operation curves for a fixed block system

puter.

The method for estimating train operation curves is the same as in SPEEDY [4], which was developed by RTRI and is used in practice for assessing train operating times. Train performance curves can therefore be rapidly estimated by predicting acceleration or deceleration of trains not only in the forward direction from the position of the train, but also in the opposite direction from where the train is stopped, which is determined by signal aspects. In addition, considering that it is difficult for trains to move from acceleration to deceleration, without coasting in between for a certain time, the train operation curve estimation method can take into consideration these driving restrictions.

4. Development of train operation/passenger behaviour simulator for moving block systems

4.1 Problems in applying simulator to lines controlled by moving block systems

If the fixed block system simulator was applied directly to a moving block system for evaluating train operation and passenger behaviour, then each train's operation curve would have to be recalculated with each movement of the preceding train. The fixed block system, by definition, uses blocks that do not move, therefore a train's operation curve was only calculated when it's preceding exited a certain fixed block. However, the moving block system by definition means that a train's operation curve would have to be recalculated with every movement of its preceding train. In order to adapt the simulator to suit the moving block system, it is necessary therefore to resolve two problems: the time required for each calculation, and how to estimate the operation curve according to a marginal position within which the train can stop.

4.2 Efficient recalculation method for train operation curves

If the train operation curves for a moving block system are recalculated using the conventional method for fixed

block systems, they would have to be recalculated for every simulation period (Fig. 4). If the simulation period is one second, the approximate number of recalculations would be the product of the number of trains and the simulation time (sec.), which would far exceed the number of calculations for the fixed block system.

This research therefore adopts a new estimation method for train operation curves (Fig. 5). In this method, when the first train operation curve is estimated, the time when the train starts coasting to decelerate and stop at the marginal stop point is also predicted. After that, the train operation curve is not recalculated until the train starts coasting. Recalculation is not necessary during this time because the train operation curve will not be influenced by the continuous change in position of the preceding train. When the succeeding train is already located in a position closer to the preceding train than to the position where coasting starts, then the whole train operation curve may be affected by the preceding train, and so recalculation is conducted for each simulation period.

In the proposed method, the number of recalculations is lower than in the conventional method. The effect of the proposed method depends on the number of trains, or the headway of trains. If there are no succeeding trains that begin to coast to decelerate and stop at the marginal stop point, the approximate number of recalculations is equal to the number of trains multiplied by the number of times a succeeding train reaches the recalculation points. This number is much smaller than that in the conventional method.

Fig. 4 Simulation of train operation curves under the moving block systems (conventional method)

Fig. 5 Simulation of train operation curves under the moving block systems (revised method)

4.3 Train operation curves to make trains stop at the marginal stop position

Under the moving block system, another problem is that the new train operation curve does not make the train stop at the marginal stop point. For example, as shown in Fig. 6, it is assumed that there is a speed restriction near the marginal stop point. When the preceding train moves forward a little, the marginal stop point for the succeeding train also moves forward a little and it is necessary to add braking, coasting and braking operations to the train operation curve so that the train operation curve makes the train stop at the new marginal stop point. This means that additional coasting operation is necessary, but, there are some cases where even if the coasting time is minimized, the new train operation curve cannot make the train stop at the new marginal stop.

To prevent such cases, no recalculation is made and the original train operation curve is applied to the succeeding train. By applying the original curve, the risk of the succeeding train exceeding the marginal stop point is avoided in the simulation.

This solution makes sense, since during real train operation, train drivers will not modify their driving pattern if the marginal stop point moves forward only a short distance. If the marginal stop point moves forward beyond a certain degree, drivers will eventually modify their driving pattern to ensure the train stops at the new marginal stop point.

Fig. 6 Change of train operation curve when marginal stop point moves forward a little

5. Test application to an actual commuter line

5.1 Method for evaluating effect of a moving block system

The method to evaluate the effects of installing a moving block system through a simulator is shown in Fig. 7. The train control systems that were compared were the fixed block ATS (Automatic Train Stop) system, the fixed block digital ATC (Automatic Train Control) system in which braking is controlled with a continuous curve, and the moving block system. In order to make a fair comparison

Fig. 7 Method for evaluating train control systems

Fig. 8 Evaluation method based on estimated passenger train paths

son of the train control systems, other conditions such as timetable, passenger train choice model, and track layout were kept the same, except for those that are specifically designed for each system, i.e. track circuits and signalling equipment. Assuming a situation where small delays occur, the scenario for the first delay was assumed to be the same for all systems.

The evaluation value indicating convenience was calculated for each passenger choice of train paths which was the output of each simulation. The evaluation value for each train control system was calculated by summing up all the passenger evaluations (Fig. 8). Comparison of the evaluation value for each train control system, makes it possible then to evaluate each train control system from a passenger point of view.

5.2 Description of railway line and preconditions used in the evaluations

In this paper, the effects of replacing the existing fixed block ATS system with the digital ATC system or the moving block systems were evaluated using the method described in 5.1. The railway line used in the evaluation had 19 stations, and about 1,000 trains in operation in a single day. The period used for the study was the morning rush hour between 7AM and 10AM, during which trains were running every 3 or 4 minutes.

208,335 passengers departing from origin stations between 7AM and 10AM were evaluated using the evaluation index. An average passenger evaluation was calculated for

each train control system. Based on the method described in the reference [5], the disutility value was used as the evaluation index for each passenger and was calculated with the following formula, taking into consideration the journey time, waiting time, number of transfers, and on-board congestion, for each traveler.

$$\text{Disutility} = \text{time} + 2 \times \text{wait} + 600 \times \text{trans} + \sum(\text{inter_time} \times \text{cong_formula}) \quad (1)$$

- Disutility: passenger disutility
- time: overall time from arrival at the origin station to the arrival at the destination station (in seconds)
- wait: sum of waiting time for the trains on the platforms at the origin station and the transfer stations (in seconds)
- trans: number of transfers
- inter_time: journey time for passenger on board a train between, two successive stations (in seconds)
- congestion: train congestion rate
- cong_formula: formula indicating level of passenger discomfort depending on congestion, as given below.
 - case 1: congestion is under 100%
cong_formula = $0.0270 \times \text{congestion}$
 - case 2: congestion is between 100% and 150%
cong_formula = $0.0828 \times \text{congestion} - 0.0558$
 - case 3: congestion is between 150% and 200%
cong_formula = $0.179 \times \text{congestion} - 0.200$
 - case 4: congestion is between 200% and 250%
cong_formula = $0.690 \times \text{congestion} - 1.22$
 - case 5: congestion is more than 250%
cong_formula = $1.15 \times \text{congestion} - 2.37$

5.3 Evaluation results

The simulator was first used to evaluate the fixed block systems and the moving block system, without any disruption. Using an ordinary PC, the time required for computing all the calculations for both the fixed block and moving block systems for a whole day was about 30 minutes. This demonstrated that even for the moving block system, train operations could be estimated within a reasonable time. In addition, with no disruptions, there was no difference in disutility values between the train control systems.

In the next phase it was assumed that a certain train was unable to depart from a certain station due to a problem between 8:00AM and 8:10AM. Passenger experiences were evaluated and compared to see if there was any difference between train control systems, which influenced the delay recovery time and resumption of services.

The results of disutility, journey time, riding time and so on are shown in Table 1. Little difference appears between the ATS and digital ATC systems. With the moving block system however, journey times were shorter, and the disutility value per passenger was 30 seconds lower than that for the ATS system.

Table 2 shows the number of trains or stations where the train delay was more than two minutes. The number fell from about 300 trains/stations with the ATS system to 140 with the moving block system that allowed faster recovery of service.

Figure. 9 shows the train traffic around 8AM in what is called a “train headway curve.” The position of trains is plotted on the vertical axis, while time series are shown on the horizontal axis. With the ATS system, 4 trains ran through a certain section within a certain time period. With the moving block system, 6 trains ran through the same section in the same time period. This demonstrates the shorter headway between trains with the moving block system, compared to the fixed block systems.

Table 1 Average evaluations per index (per passenger)

	ATS	Digital ATC	Moving block
Total journey time (sec.)	735	731	717
Riding time (sec.)	595	593	579
Dwell time (sec.)	138	142	143
Waiting time (sec.)	140	138	139
Average congestion rate (%)	73	74	74
Average rate of seating opportunity (%)	57	57	57
Disutility value (sec.)	928	923	898

Table 2 Number of trains delayed for more than 2 minutes

	ATS	Digital ATC	Moving block
Arrival delay (trains/stations)	314	240	146
Departure delay (trains/stations)	301	233	140

Fig. 9 Comparison of headway curves (Upper: fixed block ATS system, Lower: moving block systems)

6. Conclusions

This research introduces a method to improve train operation/passenger behaviour simulation to reproduce train traffic controlled by a moving block system. Test calculations were carried out for an existing rail line to evaluate the effectiveness of the moving block system.

The new train operation/passenger behaviour simulator, has the added feature of taking into account driving patterns and requirements, such as acceleration, coasting, and braking. In addition, an efficient calculation algorithm to obtain train operation curves was developed, making it possible to reduce the required computation time for a whole day's timetable to about 30 minutes, which is within a reasonable time limit for train control system evaluation. A method for comparing the effectiveness of train control systems was also developed, which uses passenger experience measured in terms of disutility, based on the train paths chosen by passengers. By using this index, train control systems can be evaluated from the passenger point of view. The test evaluation was carried out to compare ATS, digital ATC, and a moving block system on a commuter line in a large city. Results from this test evaluation showed that when a small delay (10 minutes) occurred, use of the moving block system could reduce the average passenger disutility value by 30 seconds.

Future work will focus on continued test evaluations of other scenarios, on other types of line. It is also hope that

this method will be used to evaluate other train control systems that are currently still in research and development.

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