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Analysis of minimum train headway on a moving block system by genetic algorithm

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Abstract

A minimum headway on a moving block system is discussed. Two different control concepts of the moving block system are defined. To obtain an optimum driving pattern which realizes a minimum-headway and least running-time. a genetic algorithm (GA) is introduced. The result shows that the minimum train headway simply decreases to 40km/h and thereafter the same values is kept in spite of a speed increase. And multiple-step braking operation is required at train stopping to a station from high speed running.

1. Introduction

A moving block system is one of the most effective solution to realize high-density train running[1,2]. Supposing a train decelerates continuously from a maximum speed to a stopping point at a station, this operation is named a single-step braking, minimum train headway could be calculated uniquely under given train-running condition on a moving block system.

On a single-step braking, there is a minimum point of train headway at approximately 40km/h at maximum speed. Over 40 km/h, train headway is increasing with maximum speed. In order to minimize the train headway, two-step braking operation is very effective in spite of train speed increasing. But until now the optimum break operation pattern has been never determined. A simulation method is adopted with assumption of two-step brake operation. By the way, the most suitable result of simulation data could not be said the optimum solution but a relatively optimum solution in the simulated results.

In this paper to overcome this difficulty, a genetic algorithm (GA) is investigated. It becomes clear that the two-step brake operation provides an optimum solution at the case of maximum speed from 40km/h to 190km/h, and that braking steps shall be added to attain an optimum solution at the maximum speed of 190km/h or over. This paper outlines these results and details of the study.

2. Train headway on a moving block system

2.1 Definitions

The general concept of a block zone under a moving block system is defined as follows.

Def.1 : Block Zone of Moving Block System

> "A track area which is determined by the distance from the position of preceding train to that of succeeding train is defined as the *block zone of moving block system*".

According to Def.1, two different concepts of block zone are derived as shown in Fig.1. One is a general concept that a moving block zone is decided as an area from the tail of succeeding train to that of preceding train with some margin taken for safety. This system is named MB-STP type moving block system. In this system, a preceding train is always regarded as a wall.

The other is a more efficient concept which can be adopted only for a derailment-free railway system. In this concept, the front boundary of moving block zone is decided by the stopping position of preceding train with a safety margin at the current running speed with a maximum braking value. This system is named MB-RUN type moving block system. It offers a possibility

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to significantly shorten the train headway .

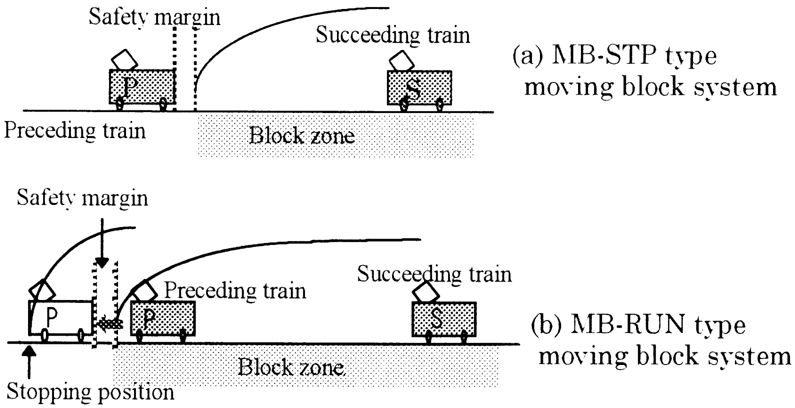

Fig. 1 . Two types of moving block

A train headway and a local-minimum train headway are defined by Def.2 and Def.3. (Note that all of the following definitions apply to both MB types.)

Def.2 : Train Headway

The *train headway* is defined as the smallest time-interval between two trains at which any train can run by keeping an established driving pattern without any restriction caused by the preceding train at a target station or on a line.

Under a moving block system, the train headway is affected by the train running curve. Then, the definition of a local-minimum headway at a target station is an important measure for system-efficiency analysis.

Def.3 : Local-Minimum Train Headway and Minimum Headway Driving Pattern

The *local-minimum train headway* (LMIH) is defined as the train headway obtained by an optimum driving operation at a target station to satisfy the minimum train headway and the least driving time. The *minimum headway driving pattern* (MHDP) is defined as a driving pattern which realizes optimum driving to satisfy LMIH.

This paper analyzes the LMIH with an assumption that every train stops at the halt which means a small station with no side tracks, and the distance between two stations has enough length to allow train speed-up.

2.2 Minimum train headway in single step braking

Fig.3 outlines the running curves of two trains on the MB-STP type system. An occupied zone is defined as an area extending from the train tail to the stopping point which means the front of the braking distance. In a distance-time diagram of Fig.2 the occupied zone forms a closed region L_2. The L_2 of succeeding train is able to approach to the tail of preceding train on line L_1 keeping at least 25 meters for safety margin. Then, the train headway is obtained as a time interval T_h between the two trains. Eventually, we get a train headway by an analytical approach or a simulation method for each driving pattern.

Table1. Assumed values for simulation.

Parameter	Value	Symbol
Train length	200m	L
Deceleration (normal)	2.8km/h/s	B_n=2.8/3.6 (m/s^2)
Deceleration (maximum)	4.7km/h/s	B_e=4.7/3.6 (m/s^2)
Acceleration	2.4km/h/s	A=2.8/3.6 (m/s^2)
Stoppage time at a halt	40 second	t_0
Brake delay time	2 second	t_B

Using train running parameters in Table 1, train headway is calculated in Fig.3. It shows following results.

(1) On both moving block types, there is a minimum point of headway at approximately 40km/h at the maximum speed.

(2) The headway of MB-RUN type is smaller than that of MB-STP type. But, the difference of headway, only three seconds or so, is not so large between two types.

It shows that the MB-RUN type system does not yield the intended result.

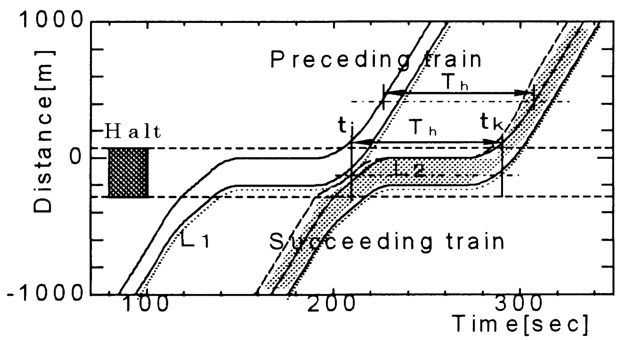

Fig.2. Train headway on D-T graph.

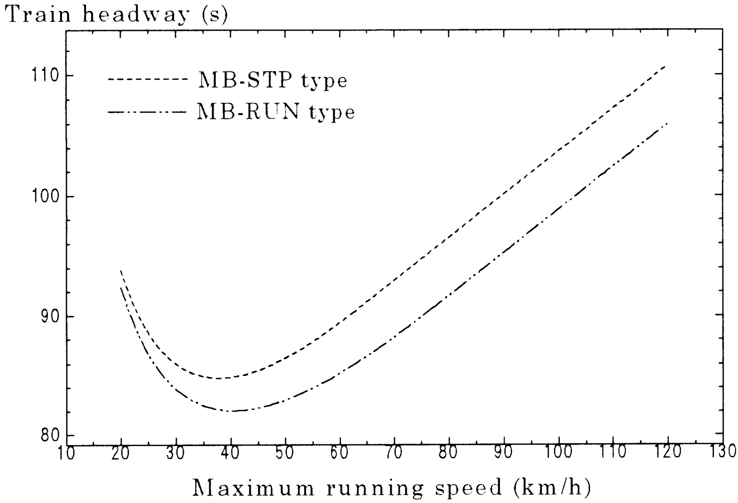

Fig.3. Train headway at single step braking.

3. Local-minimum train headway on multiple step braking

According to the above study and Fig.3 on the single-step braking system, it is inferred that, if a train were decelerating from maximum speed to 40km/h far from the station and entering into the station area at a constant velocity of 40km/h before a station-stopping operation, then the train headway could be minimized to the same value in spite of the train maximum speed. This driving run-curve shapes a two-step braking figure.

The local-minimum train headway (LMIH) by Def.3 must satisfy the least driving time condition. In order to search LMIH, a number of train driving patterns in a two-step brake operation must be introduced into the simulation. If the optimum data were selected from the simulated data, it could not be regarded as the optimum solution in general. Because until now it has not known whether a two-step brake operation gives a shorter train headway than a multiple-step brake operation.

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3.1 Genetic algorithm and LMIH

To solve this difficulty, introduction of a genetic algorithm (GA) which is one of the most convenient tools to search a minimum and/or maximum solution is considered. It is essential for applying GA to define correlation with a gene. For a gene, the brake operation pattern is applied as follows.

A train driving pattern illustrated with a narrow line from a given maximum speed to stopping is shown by a time vs. velocity diagram in Fig.4. The dashed line in Fig.4 means a driving pattern which is calculated under a two-step brake operation. In Fig.4 a gene corresponds to brake ON/OFF operations. Assuming a deceleration ratio as 2.8km/h/s, it takes 29 seconds for a train to stop from a maximum speed 80km/h. When a brake handle in a two-step brake operation is released at a middle speed V_r and the same speed position V_r is kept for T-seconds, total stop time would amount to 29+T seconds. If we prepare 240bits for a gene whose binary digit 1 means brake ON, any 29-out-of-240 codes can correspond to the pattern of a train arriving at the station.

An architecture of the GA method is composed of forty individuals, an equality gene-crossover method and selecting conditions which are decided that is a better minimum train headway and a minimum arrival time. And a mutation is generated by a partial-replacement of bits and a bit-inverse method.

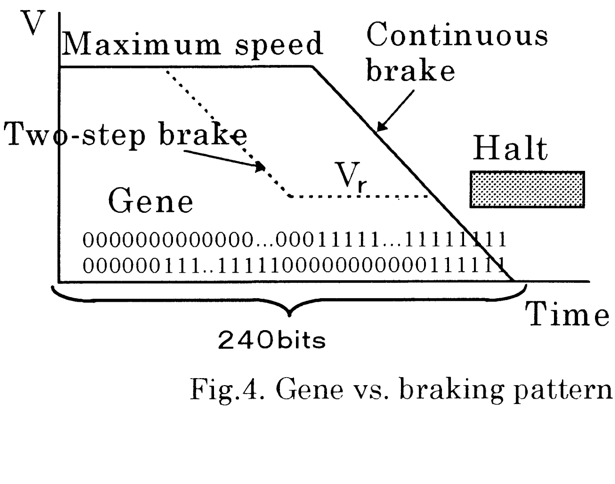

Fig.4. Gene vs. braking pattern.

3.2 Maximum speed vs. local-minimum train headway.

The relation of a local-minimum headway (LMIH) driving pattern vs. maximum speed and the effect of train length on LMIH are investigated utilizing the GA method. Selecting conditions for individuals are decided as follow.

1) The brake handling times is less.
2) The driving time between two stations is short.
3) The headway is small as far as possible.

At first, the influence of maximum speed on LMIH is analyzed. According to the result, LMIH simply decreases to 40km/h and then keeps the same value in spite of speed increase as shown in Fig.5. This result means that even if the train speed is increased more, the train headway is maintained at about 85 seconds under the condition of MB-STP type, while under that of MB-RUN type, it keeps 83 seconds at the speed of exceeding 40km/h.

By the way, it is nonsense to increase the driving time, even if train headway might be minimized. A driving time between two stations according to an MHDP is compared with that in a single-step brake operation whose driving time is the shortest. The difference between them increases in proportion to speedup. But the difference is no more than 15 seconds for LMIH, in spite

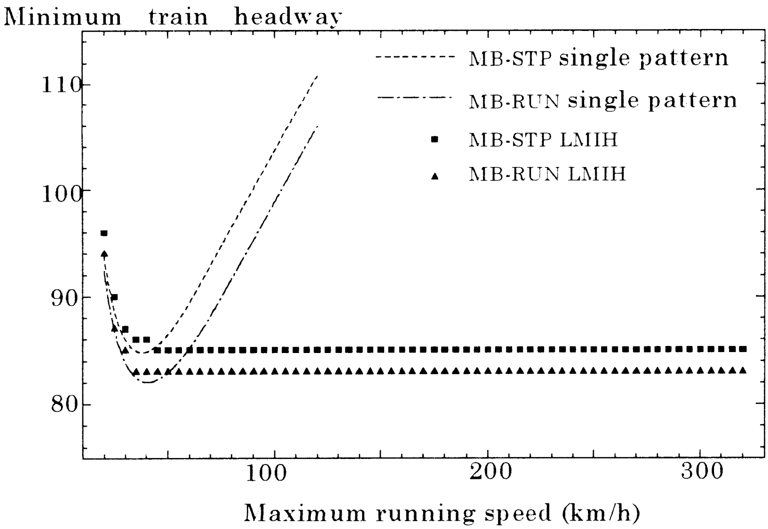

Fig.5 Maximum train speed vs. LMIH.

of 200km/h of train speed as shown in Fig.6. On the other hand, the train headway of LMIH is 55 seconds shorter than that by a single-step brake operation as shown in Fig.6. When this result is roughly applied to train and traffic operation, in the case of driving according to a single-step brake operation 25.7 trains are able to run per hour, while 42.3 train runs are possible under a driving pattern of LMIH, if an increase in the operation time of 15 seconds is permitted for each train. From the view point of an increase in the carrying capacity, the efficiency of train operation according to an MHDP and intrinsic superiority of a moving block system are demonstrated by these results.

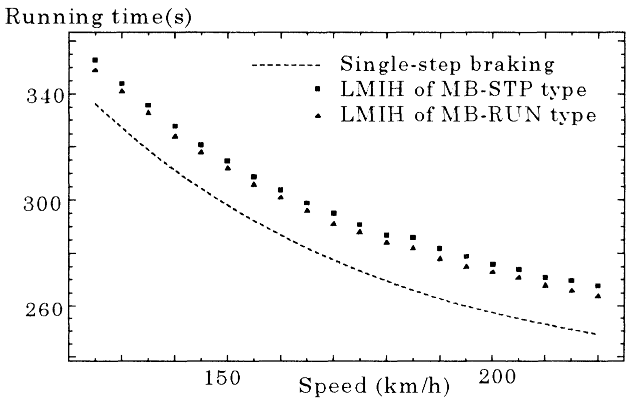

Fig.6 Running time loss of LMIH

3.3 Maximum speed and brake steps

A distance vs. time curve corresponding to LMIH at the train speed of 200km/h under the condition of MB-STP type is illustrated in Fig.7. In it an outline of the curve forms a three-step brake operation. As mentioned already, deceleration is assumed to be a normal brake value in this analysis. Therefore, the dashed line in Fig.7 forms a horizontal line during a brake operation of succeeding train. Similarly, a train-driving pattern at 250km/h forms a figure of four-step brake operation at MB-STP type. According to these results a heuristic knowledge that the two-step brake operation brings about the optimum headway for traffic capacity increase, applies only to about 190km/h or less, and multiple-step brake operation had better be applied to high-speed running over 200km/h as shown in Fig.8. The relation between optimum brake handling steps and train speed is affected by various conditions such as a stoppage time at the station, maximum train speed, deceleration, acceleration and train length. But the phenomena generally apply as universal facts.

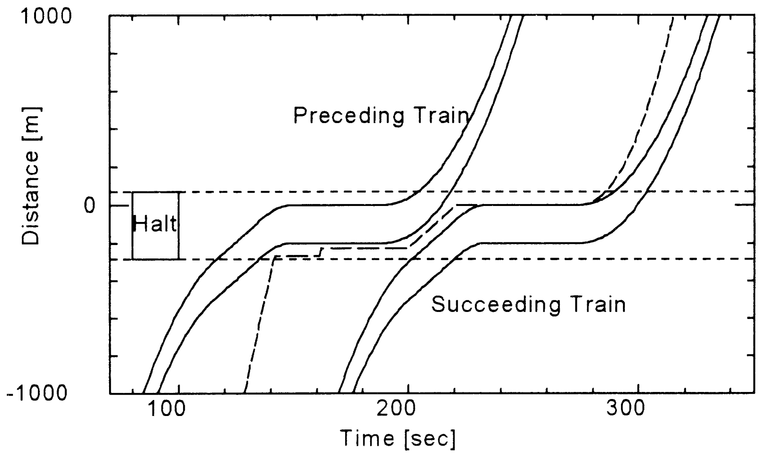

Fig.7 Distance-Time diagram of LMIH at 200km/h

4. Conclusions

Selecting a halt which is one of the bottlenecks for train headway, the train headway under two types of moving block system has been investigated. A train driving under a moving block system has larger flexibility of driving so that train headway cannot be calculated by means of an analytical approach except for the case of a single-step brake operation. To solve this difficulty, a more efficient method applying GA has been produced. The relation of a Local-minimum headway (LMIH) driving pattern vs. Maximum speed has been analyzed. Under the assumed running conditions the effect-analysis of maximum speed on LMIH has shown an important result that LMIH simply decreases to the value at 40km/h and then keeps the same value in spite of speed increase.

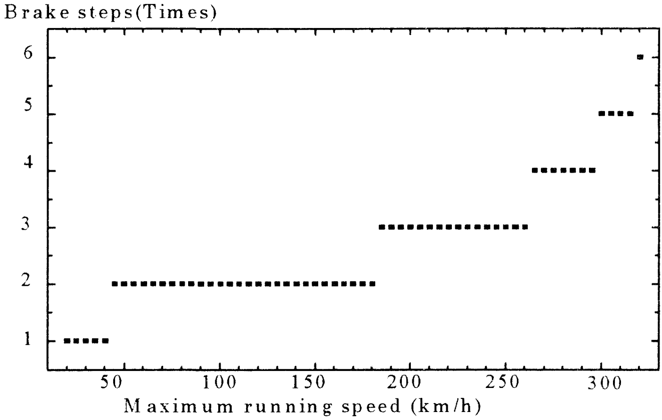

Fig.8 Braking steps vs. maximum speed on MB-STP.

When this result is roughly applied to train and traffic operation, in the case of driving according to a single-step brake operation 25.7 trains are able to run per hour, while 42.3 train runs are possible under a driving pattern of LMIH, if an increase in the operation time of 15 seconds is permitted for each train. It increases train capacity 64 per cent more than the conventional train operation does. From the viewpoint of increasing the carrying capacity, the efficiency of train driving according to an MHDP and intrinsic superiority of a moving block system have been revealed by these results. As a result of this study minimum and optimum train headway driving patterns corresponding to any train-speed under given train and track conditions can be produced easily by utilizing the GA method.

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