A simulation method for rail traffic using microscopic and macroscopic models

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Abstract

In this paper, a combined approach of a simulation for rail traffic is proposed. This approach makes it possible to use suitable models of the simulation both microscopic and macroscopic, according to required details for each train traveling between stations. This approach makes use of a feature of the train motion, that does not directly depend on the preceding train motion like road traffic, but only depends on the speed limit in the block section belonging at the present time. Applying this approach to a system for train traffic, we can get a quick response of macroscopic simulation and a detailed result of microscopic one.

1. Introduction

Simulation models for train traffic can be classified as microscopic and macroscopic. The former model simulates the motion of each train between two stations, according to the dynamic equation for the motion of a train. This model can describe detailed motions of trains. Therefore, the model has been used to make a run-curve, a headway table etc. for railway scheduling. The latter model simulates the arrival and departure time of each train at each station as the train's travel is taken for a discrete-event system. This model takes much less time on simulating than the microscopic one. Therefore, we use it for a system adjusting a train schedule when rail traffic is disturbed, which requires quick response (Komaya[1]). However, as the speed of each
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When the speed and the density of train traffic become higher, the system also requires the precision of the simulation like a microscopic one.

In this paper, we propose a combined approach of the microscopic model and the macroscopic one, the purposes of which is to get a quick response of macroscopic simulation and a detailed result of microscopic one. Our approach is based on special features of train traffic, as follows:

One is that the train motion does not directly depend on the preceding train motion, but only depends on the speed limit in the block section belonging at the present time. Using the history of the speed limit in each block section, the simulation of each train between stations can be performed independently (Komaya[2]).

The other is that trains travel between stations according to standard traveling time defined in a railway schedule, when they travel normally. Hence, it is not necessary to apply the microscopic simulation to such trains to predict their detailed motions.

Based on these features, applying the macroscopic model to trains traveling normally and the microscopic one to others, our approach has achieved the purpose. Using our approach, we can develop a system not only for adjusting a train schedule, but also controlling routes and navigating trains.

2. A microscopic model

In this section, the microscopic model for rail traffic is summarized and a method that makes it possible to simulate each train independently is discussed.

Generally, each train’s motion is described by calculating a position and a velocity at intervals of fixed microscopic seconds, with dynamic equations below,

\[ \dot{x} = v \]

\[ \dot{v} = (f_1 - f_2 - f_3 - f_4)/W \]

Where, \( x \) is a position of the train, \( v \) is its velocity, and force \( f_1 \) is the accelerating or breaking force, which is determined from a driver’s operation and specifications of the train. Force \( f_2, f_3, \) and \( f_4 \) correspond to running resistance, grade resistance, and curve resistance, respectively. \( W \) is weight of the train.

If we take only one train’s motion into account, this model has no difficulty. Therefore, from now on, our discussion is focused on how we can simulate plural trains.

As far as other trains’ motions are concerned, the most essential factor to calculate the motion of each train is the driver’s operation, because the remainder is determined from the train’s own motion: \( f_2 \) is determined from \( v \) and specifications of the train, \( f_3 \) and \( f_4 \) are determined from \( x \) and
specifications of the track. Moreover, to operate the train, the driver follows two speed limits, one is the signal aspect and the other is the speed limit marker situated on the trackside. By only the signal aspect, other trains can affect on the simulated train. Accordingly, it is important how to implement the signal aspect information into the model.

Now, the “block section” principle, which the signal aspect is based on, is summarized in figure 1. Each block section has its own “block signal” at its entrance that indicates its aspect to a train in the following block section. And the aspect corresponds to a position of the preceding train. In figure 1, the preceding train X is in the block section D. Therefore, signal D, signal C, and signal B indicate red, yellow, and green, respectively. And the following train Y in the block section A is controlled by the driver in accordance with the aspect of signal B, green.

In this principle, we can see a special feature of the microscopic model for rail traffic. For example, in the case of road traffic, each driver always gets information of the preceding car, and he operates his car in accordance with the information (figure 2). Therefore, when we build the microscopic model for road traffic, we must simulate all cars on the road simultaneously, using the information of the preceding cars at intervals of fixed microscopic seconds. In contrast to this, each train's driver gets information from a signal that changes its aspect corresponding to the time of the preceding train's tail passing through each block section. That is, by storing the changing time of each signal, we can simulate each train independently.
In figure 3, suppose that the preceding train X has already been simulated and the time of its tail into each block section is stored as $T_a$, $T_b$, and $T_c$. If the following train Y is in the block section A at the time $T_y$ ($T_y > T_c$), clearly, the train driver gets a green aspect. In this manner, we can simulate each train independently with the time information of the preceding train.

**Figure 3: The history of aspect sequence**

Additionally, it should be noted that in compounds of a station, there are different kinds of signals, say “home signal” and “starting signal”, which correspond to routes defined by interlocking logic. They indicate proceed aspects when the routes are set, after all obstructing conditions have been cleared. Usually, the obstructing conditions are caused by trains' occupation of certain sections in compounds of the station.

From this, we can get the clear time of the obstructing conditions by storing the time of trains passing through the sections. And the route can always be set, if the time has passed, and it is thought that a route for a home signal is set when a train has passed through a certain position before the station, and a route for a starting signal is set some seconds before the time that a train will depart on.

Finally, by integrating this clear time for the route setting and the changing time of the signal aspect as we have seen, we can get complete information for simulating a train in accordance with the preceding trains' motions, which need not be simulated simultaneously, anymore. We call this integrated information the signal transition information.
3. A macroscopic model

In this section, the macroscopic model for rail traffic is summarized.

The model describes motions of trains as two kinds of events, say “arrival event” at each station and “departure event” from each station. And, each train has two status. One is “train stopping status” that takes place when the arrival event is processed, and the other is “train running status” that takes place when the departure event is processed. Also, each home track in a station has two status, “occupied status” and “cleared status” corresponding to two status of the train. And all events are processed according to restrictions due to operating conditions and a train diagram shown in table 1, database of which has been prepared for the model.

Table 1: Conditions for train motions and a train diagram

<table>
<thead>
<tr>
<th>Operating conditions</th>
<th>Train diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train</td>
<td>Station</td>
</tr>
<tr>
<td>• Minimum value of traveling time between two stations</td>
<td>• Minimum value of the headway at arrival or departure from each station</td>
</tr>
<tr>
<td>• Minimum value of stopping time at each station</td>
<td>• Minimum value of the time required for turning back at each station</td>
</tr>
<tr>
<td></td>
<td>• Maximum number of trains running at a time between two stations</td>
</tr>
</tbody>
</table>

Where, the minimum value of traveling time between stations is defined by a traveling time of each train when all signal aspects between stations are green. The minimum value of the headway at arrival (departure) is defined by a period of the enough time to make it possible for the train to travel without being indicated more restrictive aspects than green. The maximum number of trains running at a time between stations is defined by the number of block sections between stations, because only one train is permitted to pass into each block section at the same time.

Next, the macroscopic model has an event-queue table. In the table, events to be processed are registered in the order of predicted occurring time...
as follows:
(i) The predicted occurring time of the arrival event is the later time of 
(departure time from the backward station) + (minimum value of traveling 
time between stations) and the arrival time at the station defined in the train 
diagram.
(ii) The predicted occurring time of the departure event is the later time of 
(arrival time at the station) + (minimum value of stopping time at each station) 
and the departure time from the station defined in the train diagram.

The first event in the table is tested in accordance with the conditions, 
if it can be processed. If the test is not passed, the next event is tested. If 
passed, the event is processed, its following event is registered in the event-
queue table, and transition of the status takes place. Moreover, when the 
event is processed, the arrival (departure) time is calculated, considering the 
predicted occurring time and a possible time to arrive at (depart from) the 
station by the minimum value of the headway.

In this manner, the model can calculate the arrival and departure time 
of each train without considering details of the train motion between stations. 
Therefore, as long as processing time for the simulation is concerned, the 
macroscopic model is superior to the microscopic one. On the other hand, this 
model cannot describe the motion of a train precisely such that it is indicated 
more restrictive aspects than green.

However, at least, the model can determine which train will be 
indicated such aspects:

Supposing that rail traffic is disturbed, two kinds of arrival delay occur. 
(A) One is that arrival delay is due to departure delay. In this case, the 
preceding train is enough far ahead for the train to get the green (proceed) 
aspect. But, the following train cannot arrive at the station because of its own 
departure delay from the backward station, even if the train travels by the 
minimum time. In the macroscopic model, this case means that the predicted 
occurring time is more than the possible time to arrive at the station.
(B) The other is that arrival delay is due to a preceding train. In this case, 
whether the train departs from the backward station on time or not, the train 
cannot arrive at the station because signals indicate more restrictive aspects 
than green. In the macroscopic model, this case means that the predicted 
occurring time is less than the possible time to arrive at the station.

After all, in the latter case, the train should be simulated by the 
macroscopic model if the precision is required.

And as discussed in section 2, we can build the microscopic model to 
simulate each train between stations independently. It is that we can easily 
combine the certain arrival time by the macroscopic model and that by the 
microscopic model, which is applied only the certain train between stations as 
required.
4. A combined model of the macroscopic model and the microscopic one

Now, we can build a combined model of the macroscopic model and the microscopic model, using features described in previous two sections (figure 4).

This model is based on the macroscopic one. When the arrival event is processed, it compares the possible time to arrive at the station and the predicted occurring time. And as a result of the comparison, it calls the microscopic model, if needed.

When the microscopic model is called, first, it makes the signal transition information of the train, using the preceding trains' information. It should be noted that if the preceding trains have not been simulated by the microscopic model, there is no detailed information (the time to pass through each section) of them. Though, in this case, the trains have been determined by the macroscopic model that they can travel normally (travel with green aspects). Therefore, the microscopic model can use preserved typical information made by normal traveling pattern.

Next, using the signal transition information, it calculates the arrival time of the train and return the time to the macroscopic model. Also, it stores detailed information of the train.

Finally, the macroscopic model makes the transition of the system status according to the processed event, and registers the new event, which follows the processed event, to the event-queue table with its predicted occurring time.

In addition, we can use the microscopic model for not only trains that cannot travel normally, but also all trains traveling between certain stations. For example, in a terminal station, because many intersectional routes may be set, trains traveling to/from the station have a tendency to be delayed, even if the train traffic is not disturbed. Therefore, it is useful to analyze a cause of trains' delay that we always predict details of the trains' motions. Simulating such trains by the microscopic model is simply achieved by changing rules to call the model.
In this section, we discuss efficiency of the combined model. It is essential for the model to reduce the total processing time of the simulation. And, the processing time for the microscopic model accounts for the majority of the total time, because the macroscopic one takes few seconds to simulate.

To evaluate the efficiency, we have prepared a hypothetical railway that has 40 stations and a three-hour train diagram that has 200 trains. And we have simulated the train traffic, applying initial delay on a train (figure 5).

Where, the traveling time means that the value of (the arrival time at each station) minus (the departure time from the backward station). The value of the dotted line corresponds to the traveling time of trains in both the cases of (A) and (B) described in section 4. On the other hand, the value of the broken line corresponds to the case of (B).

From this figure, the following features are observed:
As the initial delay increases, the traveling time of delayed trains increase. Though, the time is less than 25% of the total traveling time, even if the initial delay is 90 minutes. This indicates that even if train traffic is disturbed severely, most of the trains can travel normally. Additionally, It is thought that processing time to simulate trains between stations by the microscopic model is proportional to the traveling time of them. Therefore, comparing the original microscopic model with the combined model, the latter model can reduce the processing time according to the rate of traveling time of trains that
get more restrictive aspects than red (that is less than 18% even if the initial delay is 90 minutes).

![Diagram showing traveling time of trains between stations in disturbed situations](image)

**Figure 5:** Traveling time of trains between stations in disturbed situations

### 6. Conclusion

This paper presents a combined model of the macroscopic and the microscopic model. By applying the model to a train traffic controlling system, we can get quick response of the macroscopic model and detailed results of microscopic one.

Additionally, using the signal transition information, we have examined an algorithm for the microscopic model to reduce its own processing time. In
contrast to the present algorithm that calculates the train motion at each interval of fixed microscopic seconds, the examined algorithm calculates the motion at each time that occurs transition of the speed limits. Because the transition does not happen so often, we will be able to reduce the processing time.

References
