Introduction of halt discomfort in the objective criteria of regulation for metro type railways

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Abstract

In general, train operators tend to regulate trains from the operational perspective and use criteria such as shorter delays or smaller deviations from an original timetable. These criteria may not be so important in metro type railways, where trains are quite frequent. Previous work has proposed a regulation algorithm from the passenger perspective, that is, using criteria based on waiting and travelling time, and train congestion. This algorithm, combined with classical optimisation techniques, has shown significant improvements in the objective criteria. This paper proposes to introduce a further criterion from the passenger perspective, which is called “halt discomfort”, that is the penalty for time during which trains are halted between the adjacent stations. Halt discomfort is important for metro type railways in particular, since many of them are underground railways, thus being halted between stations generally means that passengers have to wait in a tunnel and may feel severe discomfort. This paper first shows simulation results, in which all trains are suspended in the nearest station when a disturbance happens, and are resumed later when the disturbed train resumes. This method, namely a “stop-all-trains-at-once” philosophy, shows good results in terms of halt discomfort, though it is not effective for the other objective criteria. Then, this paper proposes a new regulation method, which is a mixture of the “stop-all-trains-at-once” philosophy and the classical optimisation method. This regulation shows a better result, in which halt discomfort is improved, while the other criteria do not deteriorate greatly.

Keywords: railway traffic control, computer simulation, optimisation.
1 Introduction

In metro type railways like the London Underground, once train operations are disturbed by, for example, a sudden increases in demand or signalling failures, some problems may happen, such as congestion, train delay propagation, train bunching, etc. Such problems may lead to decreased transport capacity. Under such conditions, the railway system may well be unstable, since the longer the trains are delayed, the less the capacity becomes. As Van Breusegem et al. have shown [3], metro type railways have an intrinsic instability. Thus, quick regulation is crucially important under disturbed conditions.

Train operators generally tend to regulate trains from the operational perspective and use criteria such as shorter delays or smaller deviations from an original timetable. These criteria may not be so important in metro type railways, where trains are quite frequent. Previous work by the railway research group at the University of Birmingham [1] has proposed a regulation algorithm from the passenger perspective, that is, using criteria based on waiting and travelling time, and train congestion. This algorithm, combined with classical optimisation techniques, has shown significant improvements in the objective criteria. This is briefly explained in section 2.

Though the criteria that the previous work has used are important factors to explain passengers’ discomfort under disturbed traffic, another important criterion does not seem to have been much discussed in past research. That is what this paper proposes to introduce, under the name of “halt discomfort”. This is the penalty for the time during which trains are halted between adjacent stations. Halt discomfort is important for metro type railways in particular, since many of them are underground railways, thus being halted between the stations generally means that passengers have to wait in a tunnel and may feel severe unease and discomfort. Halt discomfort is explained in section 4.

2 Classical optimisation

The research group at the University of Birmingham [1] has established an evaluation method for railway traffic from the passenger perspective, and developed an effective algorithm to “optimise” the traffic.

2.1 Objective criteria

The group has focused on three kinds of discomfort that passengers may feel when traffic is disturbed. They are waiting discomfort, travelling discomfort, and congestion discomfort.

(1) Waiting discomfort
Waiting discomfort $D_w$ is defined by eqn (1),

$$D_w = \frac{1}{(X_w - E_w)^2} \left(\max[0, A_w - E_w]\right)^2$$ (1)

Computers in Railways IX, J. Allan, C. A. Brebbia, R. J. Hill, G. Sciutto & S. Sone (Editors)
where

\( X_w \): normalising point for waiting time,

\( E_w \): expected waiting time,

\( A_w \): actual waiting time.

\( X_w \) is a linear function of \( E_w \), which means an acceptable waiting time for general passengers.

The expected waiting time (more accurately, the expected maximum waiting time) \( E_w \) may reasonably be set equal to the headway of the line in a metro type railway, where there are frequent train services, since passengers would come to stations without checking a timetable.

(2) Travelling discomfort

Travelling discomfort \( D_t \) is defined by eqn (2),

\[
D_t = \frac{1}{(X_t - E_t)^2} (\max[0, A_t - E_t])^2
\]  

(2)

where

\( X_t \): normalising point for travelling time,

\( E_t \): expected travelling time,

\( A_t \): actual travelling time.

The form of the equation is the same as eqn (1), with the only change in a suffix of parameters from \( w \) to \( t \). \( X_t \) is again a linear function of \( E_t \), which defines an acceptable travelling time for general passengers.

(3) Congestion discomfort

Congestion discomfort \( D_c \) is defined as eqn (3),

\[
D_c = \frac{1}{(X_c - N_c)^2} (\max[0, A_c - N_c])^2
\]  

(3)

where

\( X_c \): maximum congestion,

\( N_c \): nominal congestion,

\( A_c \): actual congestion.

Again, the form of the equation is the same as eqns (1) and (2), though in this case, \( X_c \) and \( N_c \) are independent. As is easily understood from eqn (3), a
nominal congestion $N_c$ represents a threshold beyond which passengers begin to feel discomfort from congestion in a train.

(4) Total discomfort
All the discomfort terms stated above are summed up as shown in eqn (4).

$$F_{obj} = D_w + D_t + D_c$$

2.2 Procedures of the regulation

The regulator developed by the group (called “the classical regulator” later in this paper) uses $F_{obj}$ in eqn (4) as an objective function. This needs to be minimised by changing decision variables, which are, in this problem, all arrival and departure times of trains at/from stations.

First, the regulator predicts the train movements and passenger flows. Secondly, it calculates the partial derivatives of $F_{obj}$ by slightly changing arrival and departure times of trains and calculating the difference of the discomfort values at that station. Thirdly, it amends arrival and departure times of the trains due to the results of the partial derivatives of $F_{obj}$ by the unit of 5 s. For example, if the partial derivatives of $F_{obj}$ by the departure time of Train $i$ from Station $k$ is negative, 5 s is added to the departure time, since this change leads to a smaller $F_{obj}$. Finally, it checks the constraints of arrival and departure times of trains, since there are several operational constraints such as minimum run time between stations, minimum headway at a station, and minimum dwell time at stations to allow all passengers to exchange (or passengers to exchange until a train is full), and amends the times if necessary.

3 Model of a real railway system

In order to test traffic regulators, a model of a real railway is necessary. Siu [2] has established a simulation program written in C++, called “Object-oriented Multi-train Simulator” (OOMTS). OOMTS can handle various types of railways, since it reads the data files describing the topology of the line, then constructs a model. In this paper, the model is based on the Hong Kong Island Line. The following are the main aspects of the simulation. The details are described in [1].

3.1 Line topology

The Hong Kong Island Line has 14 stations, all of which are equipped with two passenger platforms. The layout of the line is shown in Figure 1. At one terminus, expressed as Station 1 in the figure, there is a head-shunt; at the other terminus, expressed as Station 14 in the figure, trains turn around by crossings.
3.2 Signalling system, service and rolling stock

In this paper, the simulation model adopts a moving-block signalling system, due to its easiness to simulate, although the real railway uses a fixed-block signalling system.

Trains run every 90 s in the line. All of the trains stop at all stations, which means that there are 31 trains serving four round trips from station 1 to 14 and in the opposite direction within a simulated time of about 4 hours.

The nominal passenger load of the rolling stock is 1600 persons, while the maximum passenger load is 2000 persons.

3.3 Passenger flow

The passenger flow from one station to another is defined as OD, or origin-destination pair value. For example, 18 passengers per minute travel from station 1 to 7, while 3 passengers per minute travel from station 7 to 14, etc. Changing the set of OD pair value enables the simulation of various kinds of railways, such as underground lines in a city centre, city-to-suburbs lines, etc.
The passenger exchange rate at a station is defined as shown in Figure 2. This means that, if there are more passengers on a train than a nominal value, the more passengers are on a train, the slower the passengers alight from and board the train. This reflects congestion and conflict in the door openings of the train.

4 Introduction of halt discomfort

4.1 Outputs of the classical regulator

Before the introduction of halt discomfort, which has been briefly explained in section 1, the performance of the classical regulator is shown here. Figure 3 shows the results of the classical regulator when the headway of the line is 90 s and all the OD pairs are 18 persons/min, changing the initial disturbance (D) from 300 s to 1200 s by the unit of 300 s. The graph shows that this regulator has a good performance in reducing the three kinds of objective criteria (wait, travel and congestion discomfort).

4.2 Definition of halt discomfort

Halt discomfort is defined as shown in eqn (5).

\[ D_h = \left( \frac{\max[0, A_h - E_h]}{X_h} \right)^2 \]

where
- \( X_h \): normalising point for halt time,
- \( E_h \): expected halt time,
- \( A_h \): actual halt time.

Each objective criterion is set so that the four kinds of discomfort can be reasonably compared with each other. The comparison of each discomfort is shown in Table 1, in which each row is the set of conditions that show the same value of discomfort. For example, looking at the row in which Discomfort = 1, it can be seen that \( D_w = 1 \) when \( A_w = 630 \) s, \( D_t = 1 \) when \( A_t = 930 \) s, \( D_c = 1 \) when \( A_c = 2000 \), and \( D_h = 1 \) when \( A_h = 180 \) s. It is observed that halt discomfort is set to be the severest discomfort for passengers. This means that being halted between adjacent stations (usually in the tunnel) gives passengers the largest discomfort.
Figure 3: Discomfort comparison (Headway=90 s, OD=Flat 18).

Table 1: Discomfort comparison.

<table>
<thead>
<tr>
<th>Discomfort</th>
<th>$D_w$ ($E_w = 90$)</th>
<th>$D_t$ ($E_t = 300$)</th>
<th>$D_c$ (max=2000)</th>
<th>$D_h$ ($E_h = 60$, $X_h = 120$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$A_w \leq 90$ s</td>
<td>$A_t \leq 300$ s</td>
<td>$A_c \leq 1600$</td>
<td>$A_h \leq 60$ s</td>
</tr>
<tr>
<td>0.5</td>
<td>$A_w = 472$ s</td>
<td>$A_t = 741$ s</td>
<td>$A_c = 1883$</td>
<td>$A_h = 145$ s</td>
</tr>
<tr>
<td>1</td>
<td>$A_w = 630$ s</td>
<td>$A_t = 930$ s</td>
<td>$A_c = 2000$</td>
<td>$A_h = 180$ s</td>
</tr>
<tr>
<td>2</td>
<td>$A_w = 854$ s</td>
<td>$A_t = 1183$ s</td>
<td>($A_c = 2166$)</td>
<td>$A_h = 230$ s</td>
</tr>
</tbody>
</table>

4.3 Performance of the classical regulator including halt discomfort

Figure 4 shows the results of the classical regulator under the same conditions as in Figure 3. The graph shows that the performance of the classical regulator deteriorates by including halt discomfort, which is as expected, since the classical regulator does not consider halt discomfort at all.

4.4 “Stop-all-trains-at-once” philosophy

Instead of incorporating halt discomfort into the classical regulator, which is predicted to be difficult due to the structure and the procedures of the regulator, a simple regulation method is proposed here. It is (1) all trains are suspended in the nearest station when a disturbance happens, and (2) the trains are resumed later
when the disturbed train resumes travelling. Later in this paper, this regulation method is called the “stop-all-trains-at-once” philosophy.

Figure 4: Discomfort comparison (including halt discomfort).

Figure 5: Discomfort comparison (including the “stop-all-trains-at-once” philosophy).

As may be easily predicted, the “stop-all-trains-at-once” philosophy shows a good performance in reducing halt discomfort. Figure 5 shows the results of the simulations, in which no regulation is executed, the classical regulator is
activated, and the “stop-all-trains-at-once” philosophy is adopted. As can be observed in Figure 5, the “stop-all-trains-at-once” philosophy is effective in reducing halt discomfort, while it has a worse performance than the classical regulator in terms of the other discomfort values.

4.5 Combining the new philosophy with the classical regulator

From the results so far, combining the new philosophy with the classical regulator seems a possible way to construct a better regulator. Thus, the following procedures are proposed for a train dwelling at a platform:

1. If all the platforms of the next station are occupied, or the preceding train has not reached the next station, a train halted at the platform does not depart.

2. Otherwise, the train waiting at the platform operates according to the outputs of the classical regulator.

Figure 6 shows the results of the four kinds of regulation (no-regulation, the classical one, the “stop-all-trains-at-once”, and the combined one). As can be seen in Figure 6, the combined method shows the best performance.

5 Discussion and conclusions

The proportion of trains that are regulated by rule (1) in 4.5 to those regulated by (2) in 4.5 may determine whether the combined method stated in 4.5 is effective in reducing the total discomfort value. In the example shown in Figure 6, there are ten trains obeying rule (1), while three trains obey rule (2), out of thirteen trains already released in the line.

![Discomfort comparison](image_url)

Figure 6: Discomfort comparison (including the combined method).
As may be predicted by the discussion above, the performance of the proposed method may depend on the conditions of the line (headway, OD types, etc.). In this paper, only the results under the same conditions (Headway=90 s, all OD pairs=18) are shown. Other conditions such as other headways, various OD types, etc. are being examined.

It is also predicted that rule (1) in 4.5 needs to be improved when there is a train halted between adjacent occupied stations, since rule (1) cannot rescue the halted train, thus halt discomfort will rise sharply.

References