Evaluation of Facility Improvement for Turn-back Operations from a Passenger Service Viewpoint

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When an operational disruption occurs, it is often the case that all trains on that line are suspended. This may significantly decrease services available to passengers, because even passengers who need not go through blocked sections are forced to wait until the cause of the suspension is removed. Deploying additional turn-back facilities and providing shuttle services can localize the negative effect of such disruptions. This research establishes a method for estimating the effectiveness of turn-back facilities from a passenger viewpoint. A series of case studies were compiled, which included experiments to evaluate the effectiveness of additional turn-back services.

Keywords: operational disruption, train rescheduling, temporary shuttle services, turn-back facilities, simulation

1. Introduction

Recent years have seen an increase in through-train connections along railway routes, allowing passengers to reach their destination without changing train.

If there is a disruption, train operating companies will roll out measures to try to maintain the train operations as many as possible. Turn-back services for example, which provide temporary shuttle services to the intermediate stations, or perhaps they will predetermine train rescheduling patterns, which include such temporary shuttle services.

However, as it is costly to establish or maintain turn-back facilities, it is desirable to conduct cost-benefit analyses, to ensure that the most effective solutions are adopted. This type of analysis can help estimate the costs of installing or maintaining turn-back facilities. It is hard to grasp however, the quantitative effects of turn-back facilities, because they aim to improve services when traffic is disrupted. As a result, it is necessary to consider not only the number of passengers, but also the time required by passengers to complete their journey, their waiting time, congestion, and so on.

This research sought to develop an evaluation method which would examine turn-back facilities from a passenger viewpoint. The method is based on the premise that there is an operational disruption, and estimates train traffic and passenger flows both before and after launching turn-back services, by virtue of a train operation and passenger flow simulator [1]. Turn back services are evaluated from a passenger viewpoint by using the results of the simulation. This method not only gives insight into the service frequency of disruptions, but also indicates behaviour adopted by passenger to avoid the negative effects of the disruption, with using other rail routes.

The method was used on an actual rail line in an urban area. The effects of additional turn-back facilities at a station were evaluated, and the effectiveness of the method was approved.

2. Effects of installing additional turn-back facilities

2.1 Occurrence of operational disruptions and turn-back services

When operations are disrupted, and part of a line is blocked, train dispatchers decide to suspend all trains along that rail line, and may initiate temporary shuttle services between unaffected stations with turn-back facilities. From a passenger viewpoint, rather than all trains being suspended, it is preferable to have limited services operating where it is possible. Introducing temporary shuttle services however, does have drawbacks, such as congestion on platforms in stations where temporary services are not being offered, and time required before ordinary services can be resumed.

Figure 1 illustrates an example of a disruption to services in Sta.6, where trains have been suspended. Without turn-back facilities between intermediate stations, no trains can run at all until the cause of the blockage is removed. If turn-back facilities are installed at Sta.4, trains between Sta.1 and Sta.4 can operate, and services in this limited section can resume. This paper aim to answer the questions of how to evaluate the turn-back services provided at Sta.4 ? Are they worthwhile ? Moreover, between which stations will turn-back facilities make the biggest difference, if only one station can be selected ?

The sole means to answer these questions and establish whether these temporary services should be introduced, is to find a suitable method to evaluate the options by comparing the advantage to passengers of a temporary shuttle service and its drawbacks, i.e. high cost and congestion on platforms.
2.2 Conventional way to evaluate turn-back services

The conventional way to evaluate turn-back services is either to compare train rescheduling or to examine the number of passengers who will wait for operations to resume. Schedule comparison is used mainly for lines operating with cyclical timetables. It compares differences in train rescheduling before and after the deployment. Comparing new rescheduling makes it possible to confirm whether the temporary shuttle service is possible or not, as well as understanding the movement or service frequency of trains. It does not allow though estimation of how many passengers can be transported to their destinations, or how many will have to wait for operations to resume after rescheduling. Investigating the number of passengers passing through each section before and after the deployment is compared by using Origin-Destination data (Fig.2). This shows the number of passengers who would be able to reach their destination through turn-back services. It does not show however the number of passengers exposed to heavy congestion or forced to make a detour via another railway line. Moreover, the frequency of disruptions in each section is not incorporated in this method, even though it is critical for appropriate evaluation.

These methods have a common problem. That is, although turn-back services should be evaluated based on the detailed movements of passengers and the transport services they receive, they only compare rescheduling plans, or only evaluate the particular line in question. Evaluations need to be based on detailed passenger behaviour, including detour routes.

2.3 Related works

Concerning the evaluation of turn-back facilities, Oza-wa et al. [2] proposed a method for estimating passenger demand for certain Origin-Destinations in case of disruption, and the distribution of transport needs. His method estimated the effects of additional turn-back services according different deployment plans. This method, gives some insight into the behaviour of passengers making detours by taking other rail routes, but as evaluation values are based on the average passenger delay, it cannot consider the inconvenience to passengers due to the increase in required transfers or added congestion. Additionally, it does not show the frequency of disruptions.

Tomii et al. [3] propose a fast train rescheduling algorithm by simulating the movements of disrupted trains with program evaluation and review technique (PERT). Under this algorithm, the number of sources of passenger dissatisfaction to be reduced is set as the evaluation value. Given the emphasis on passenger satisfaction however, the method does not directly consider passenger services, such as total journey time, the number of transfers, or congestion.

Kunimatsu et al. [4] meanwhile, proposed a method for evaluating timetables or train rescheduling plans considering passenger flows, by using a train operation and passenger flow simulation technique. It incorporates a passenger detour route choice model, and can estimate the number of passengers using detour rail lines. This research establishes an evaluation method for turn-back facilities based on this principle.

3. Method for evaluating turn-back services

3.1 Outline of the method

The workflow of the proposed turn-back service evaluation method is shown in Fig.3. This research focuses on lines and time periods with cyclic timetables. First, the basic rescheduling is set both for before and after the deployment of turn-back facilities. For example, ordinarily when the section between Sta. A and Sta. B is blocked, rapid trains turn-back at Sta. D, while local trains do so at Sta. C. If turn-back facilities are introduced at Sta. B however, this means that local trains can go to and from Sta. B using the turn-back facility. Second, operational disruption scenarios and corresponding rescheduling plans are made. Several
scenarios are compiled varying time, location, and duration of the disruption. Then, the train operation and passenger flow simulator is applied to the rescheduling plans under the conditions both with and without turn-back services, to estimate the corresponding train traffic and passenger flows. Finally, corresponding values, indicating disutility to passengers, are calculated by using the estimated behavior of passengers, and these factors are summed up to produce a set of evaluation values corresponding to the periods before and after the deployment of turn-back facilities.

3.2 Automatic generation of scenarios

Scenarios with different time, location, and duration of disruption are generated as follows: the probability of disruptions per day for each section and time period is calculated based on past disruption records. According to this probability, the corresponding operational disruptions are generated stochastically. For simulation of 1000 days of operations on a rail line with a cyclic timetable of 15 minutes, for example, 20 scenarios are made based on the information that the probability of disruptions between Sta. A and B during the period from 10am to 3pm is 0.02. Each scenario has an equal time interval to another succeeding scenario within the target time period, like “10:45-11:45, between Sta. A and Sta. B” or “13:00-14:00, between Sta. A and Sta. B.” Similar information about disruptions is generated for other sections and time periods. The scenarios applied before and after the deployment are the same.

3.3 Automatic generation of rescheduling plans and detour routes

The procedure for making train rescheduling plans is as follows. Rescheduling policy is defined, including setting of the section where the blockage occurs and where traffic is suspended, for conditions both before and after the deployment. The data of train rescheduling alternatives necessary for the simulation are automatically generated for each scenario by mechanically applying the operations of partial suspension or shuttle trains according to the policy (Fig.4).

The detailed procedure is as follows. First, the user defines the section and duration of the blockage. The duration is defined as an integral multiple of cycle time in the timetable. Hereafter, the rate of the integral multiple is represented as \( \alpha \). Next, partial suspensions are applied to \( \alpha \) trains in the same family, considering the rescheduling policy. In other words, the destinations of trains are changed to the station which was defined in the policy as being the terminal station if that section had traffic suspended. At the same time, new trains are added which originate at the station which was defined as the terminal station on the other side of blocked section. When partial suspension of trains is impossible because the trains in question have passed the terminal station on either side of the suspended section already at the time traffic was stopped, they are halted at the nearest station until operations can resume, and are rescheduled later as part of the same batch in the timetable. Trains which depart at the origin station after the occurrence time are fully suspended. These procedures are applied to all inbound and outbound trains passing the blockage section during the disruption. Following this first analysis, a decision is then made to determine whether the turn back operation can be completed within the allocated time. If there is not enough time, then the turn back operation is cancelled, since it could not be completed in time. Detour possibilities available to passengers are calculated using ordinary schedule data for neighbouring lines (Fig.5). Total journey times both for the detour and original route are calculated considering information about time, location, and duration of the disruption. As the time distances on the original route increase after services resume as a result of the timetable disruption, the total journey time value for the original route is set as longer than what it would be in.
3.4 Train operation and passengers’ behaviour simulator

Kunimatsu et al developed a train operation and passenger behaviour simulator at RTRI [1]. Both passenger origin-destination data and timetable data are used as input in this method, and each passenger route choice, congestion of each train, and train delay are estimated (Fig. 6). At the same time, the number of passengers getting on or off at stations is estimated, and dwell time necessary for getting on or off is predicted. This enables the reproduction of certain phenomena, such as passenger-congestion generated delays, which in turn induce greater concentrations of passengers. The simulator can also predict detour-behaviour whereby passengers migrate to another rail line in case of disruption. When suspension or estimated time of resumption is announced, passengers can decide whether or not to make a detour, based on the estimated time required to arrive at a destination [5].

This research offers detailed insight into passenger behaviour including the choice to make a detour, by conducting scenario-based simulations, introducing the condition of turn-back services, rescheduling alternatives, and detour routes, automatically produced in the manner described in Sections 3.2 and 3.3.

3.5 Turn-back evaluation based on the expected value of the sum of the disutility

The disutility value for each passenger for each rescheduling plan is calculated on the basis of a detailed log of passenger behaviour in each scenario and turn-back service conditions. The disutility value is defined as the conversion of the inconvenience to each passenger, including total time, waiting time, the number of times of transfers, and congestion, into an increase in total journey time. Passengers migrating to another rail line are included, by adding the inconvenience of the detour, like walking time required for transfer, journey time of the detour line, and time of transfers. The disutility value is calculated as follows [6].

\[
Disutil = time + 2 \times wait + 600 \times trans + \sum (\text{ride}_\text{time} \times \text{cong } \text{formula})
\]

※ Each variable is as follows.
Disutility value

- **time**: Total journey time from the origin station to the destination (seconds)
- **wait**: Waiting time for trains at the origin station or the transfer station (seconds)
- **trans**: The number of transfers (times)
- **ride_time**: Total time on board a train from the origin station to the destination (seconds)
- **cong_formula**: The following formula is applied according to the congestion rate

\[
\cong_{\text{formula}} = \begin{cases} 
0.0270 \times \cong & : \text{congestion is under 1.0} \\
0.0828 \times \cong - 0.0558 & : \text{congestion is between 1.0 and 1.5} \\
0.179 \times \cong - 0.200 & : \text{congestion is between 1.5 and 2.0} \\
0.690 \times \cong - 1.22 & : \text{congestion is between 2.0 and 2.5} \\
1.15 \times \cong - 2.37 & : \text{congestion is over 2.5}
\end{cases}
\]

The evaluation value of a particular scenario and turn-back service conditions are set as the sum of all passenger disutility values calculated following the procedure described above. The calculation process is applied to all disrupted and normal operation scenarios. Then, the expected disutility value for each day is calculated by taking the weighted average of disutility in each scenario, considering the number of times each scenario appears and the number of days of normal operation. The difference in expected value of each turn-back service condition is considered as the expected extent of the improvement of transport services per day.

4. Application to an actual line

4.1 Outline of the studied line and turn-back facility deployment plan

The outline of the studied line and turn-back facility deployment plan is shown in Fig. 7. Without the deployment of the turn-back facility, when an operational disruption occurs at Sta. D, semi express trains turn-back at Sta. A and Sta. I, and local trains turn-back at Sta. B. No trains are operated between Sta. B and Sta. I until the cause of the blockage is removed. In the deployment plan, additional turn-back facilities are introduced at Sta. E and Sta. F. Accordingly, semi express trains turn-back at Sta. F, and local trains turn-back at Sta. E. As a consequence, the only remaining section where no trains operate is between Sta. B and Sta. E. As a result, passengers from Sta. K to Sta. A are able to reach their destinations by transferring to another rail line at Sta. F. The quantitative effects of turn-back services were evaluated during cyclical timetable periods (from 10a.m. to 3p.m.).

The temporary shuttle services introduced with this turn-back facility only function if the operational disruptions occur from Sta. A to Sta. E. Research found that 28 blockages ranging from 30-90 minutes had occurred here between the hours of 10 a.m. to 3 p.m. over the past three years. This means that the probability of disruptions is about 2.55% per day. Scenarios were thus created according to this rate, and the occurrence time was set at a random every 15 minutes from 10a.m. to 3p.m. The target number of passengers to be evaluated and supposed to arrive at the origin station on the target line was 216,181.
4.2 Results of the evaluation and discussion

The results of the evaluation are shown in Table 1. The precondition that operational disruptions would occur with a probability of 2.55% per day, meant that there would be 974 days of ordinary operation and 26 days with disruptions over 1,000 days of operation. Each of the 26 disrupted days is shown under the 2nd line of the table. The corresponding disutility values are shown on the right-hand side of the table.

Analysis of the weighted average of all scenarios showed that the difference in disutility between the periods before and after the provision of turn-back services was 864,572. This demonstrates that the effect of installing turn-back facilities at Sta. E and Sta. F is equal to the case in which the journey time of all passengers is decreased by 4 seconds per person per day.

<table>
<thead>
<tr>
<th>NO days</th>
<th>Occurrence time</th>
<th>Sum of the disutility value (216,181 passengers)</th>
<th>Without</th>
<th>With</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>974</td>
<td>Normal Operation</td>
<td>364,959,980</td>
<td>364,976,633</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>10:28</td>
<td>454,566,067</td>
<td>409,043,806</td>
<td>45,522,261</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>10:58</td>
<td>458,018,144</td>
<td>441,581,088</td>
<td>46,437,056</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>11:13</td>
<td>459,968,708</td>
<td>414,645,167</td>
<td>45,323,541</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>11:43</td>
<td>456,024,055</td>
<td>415,936,685</td>
<td>40,087,370</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>11:58</td>
<td>453,507,620</td>
<td>413,425,772</td>
<td>40,081,848</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>12:13</td>
<td>455,628,928</td>
<td>415,175,666</td>
<td>40,453,262</td>
<td></td>
</tr>
<tr>
<td>1</td>
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<td>450,252,887</td>
<td>410,500,783</td>
<td>39,752,104</td>
<td></td>
</tr>
<tr>
<td>4</td>
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<td>453,428,749</td>
<td>413,497,874</td>
<td>39,930,875</td>
<td></td>
</tr>
<tr>
<td>2</td>
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<td>451,358,257</td>
<td>413,181,594</td>
<td>38,176,663</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>13:58</td>
<td>442,433,188</td>
<td>408,621,536</td>
<td>33,811,652</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>14:28</td>
<td>415,506,838</td>
<td>395,954,892</td>
<td>19,551,946</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>14:43</td>
<td>396,726,027</td>
<td>389,032,488</td>
<td>7,693,539</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>14:58</td>
<td>377,850,285</td>
<td>376,166,355</td>
<td>1,683,930</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>Weighted average</td>
<td>366,948,677</td>
<td>364,084,105</td>
<td>864,572</td>
<td></td>
</tr>
</tbody>
</table>

4.3 Comparison of two turn-back facilities deployment plans

As the next step, another deployment plan at another station along the same line was evaluated in the same way. The purpose was to clarify which plan was most effective, from a passenger perspective. The results are shown in Table 2. Analysis of the weighted averages of all scenarios, showed a difference in disutility before and after installation of turn-back facilities of 106,201. This is significantly smaller than the previous result, 864,572. This indicates that the deployment plan of Sta. E and Sta. F was better for passengers. Similar evaluations and comparison of deployment plans and quantitative analysis of the impact of turn-back services by location can be done in advance of any installation.

5. Conclusions

A quantitative evaluation method was developed to examine the deployment of turn-back facilities, providing temporary shuttle services, from a passenger viewpoint. The benefit of this method is that it offers aggregate and detailed insight into the level of convenience to passengers, taking into account train timetables or rescheduling alternatives both with and without turn-back facilities. The method was used on an actual line confirming its applicability for evaluating the deployment of turn-back facilities.

Future work will seek to apply the method to lines and time periods with non-cyclic timetables. Work will also focus on improving timetable rescheduling. The final purpose of this research is to develop an evaluation system to assist decision-making in matters regarding operational equipment.

References

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