An Approach to detect Bottlenecks of Timetable Stability based on Visualization of Historical Train Traffic Records

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For railway companies in metropolitan areas of Japan, it is a major issue to find solutions to reduce delays during morning rush hours. In this paper, we introduce an approach to detect bottlenecks of timetable stability based on an idea to visualize the historical train traffic records. We have devised three types of diagrams and two types of graphs suitable for the purpose of each step of analysis. As a case study, we applied the proposed approach to an actual railway line. As a result, we found that the direct cause of delays is that at one station, a significant extension of running times is occurring very often. Then the reason is departure delays occur and the delay is not recovered by the buffer time. Finally, we found this is because the buffer time at this station is smaller than that of other stations. From this analysis, we concluded that the bottleneck of the timetable is the headway time of this station.

Keywords：historical train traffic records, running time, dwell time, headway, departure difference

1. Introduction

In metropolitan areas of Japan, there is a massive demand for railways, especially in the morning and evening. As such, trains are running approximately every two minutes to meet this demand. The effects of an initial delay caused by minor incidents (such as the crowd, medical emergency) roll over onto following trains (secondary delays). Such delays tend to increase during the morning rush hours and because railway companies receive complaints for delays from the passengers, they are keen to improve stability of timetables[1]. Before the spread of COVID-19 (January 2020), there were often days on which a large number of trains had these secondary delays. Because of COVID-19, the volume of passengers decreased drastically, which in turn lead to a reduction of delays[2]. It is likely, however, upon recovering passenger volume, these delays will resurface. Therefore, it is necessary to find solutions to delay.

Within urban railways, minor incidents are mainly associated with the increase of dwell times. In general, the diagrams of railways are created with slight margins (running time margins, buffer time of headway times and dwell time margins). However, if these margins are not set properly or are too small, minor delays may surpass the prediction and no longer be included. Hence, these margins have to be decided properly through the observation of actual train operations.

Also, bottlenecks on the train diagrams make the propagation of the secondary delays. In this context, a bottleneck means the prevention of the smooth running of planned train diagrams. To make train diagrams less fragile, it is necessary to figure out the bottlenecks and avoid them. In this paper, we propose an approach to detect the bottlenecks of a given timetable by properly visualizing the historical train traffic records.

2. Literature review

To avoid delays and delay propagation is by far the most important topic in railways and lots of papers which deal with this topic have been published. Goverde and Büker proposed models to compute delay propagation respectively[3][4]. Yamamura introduced an approach to express timetables as a directed graph and find a cause of delays by tracing a critical path[5]. Joborn introduced concepts and metrics about the causes of unpuctual trains, which they call delay contribution and critical disturbance[6]. As was already written, the major cause of delays in congested railway lines is an extension of dwell times. Kuipers wrote a good review about the passengers' influence on dwell times[7]. Cornet presents a data-driven approach for assessing the influence of the numbers of alighting, boarding and on board passengers on the dwell time[8]. But little was found about the topic of proper visualization of historical train traffic records to find the bottleneck of timetables.

3. Methodology

Delays propagate to two directions (Fig. 1); train-wise direction (blue arcs) and station-timewise direction (red arcs). The delay propagation mechanism is very complicated because the routes sometimes mingle together. In this paper, we propose to separate these two directions and analyze one direction after another.

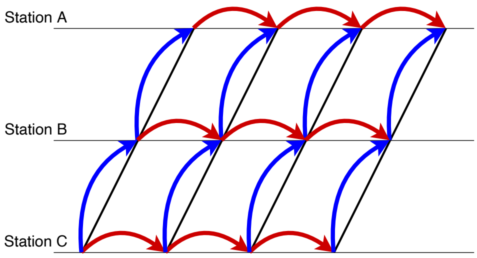

Fig. 1: Delay Propagation.

Step 1 Overview

Firstly, we would like to roughly know where delays emerge, propagate and expand. We introduce two diagrams; Node-based Chromatic Diagram and Node-based Delay Diagram. In the chromatic diagram which we already developed[9][10], train lines are colored reflecting the delay. In these diagrams, we draw two types of nodes; ones which correspond to arrival events and the others which correspond to departure events and nodes are colored reflecting the delay. A delay diagram is similar to a chromatic diagram but the difference is the horizontal axis is the delay. Hence, we can easily grasp where delays are increasing; namely whether between stations (extension of running times) or at stations (extension of dwell times).

Step2 Delay propagation and extension of train-wise direction

We analyze how a delay of a train is composed of; at which stations its dwell time extended, at which stations its running time extended. We devised Train-wise Delay Factor Graph (Fig. 2), in which x-axis depicts trains and y-axis depicts delays and we draw bars which correspond to extensions of dwell times or extensions of running times at each station.

Step3_1 Station-Timewise delay propagation

We analyze how delays chronologically vary at a station - if headways increase/decrease or dwell times increase/decrease and clarify its reason. We devised Station-Timewise Delay Factor Graph, in which x-axis depicts the arrival time of trains and y-axis depicts the delays (Fig. 3).

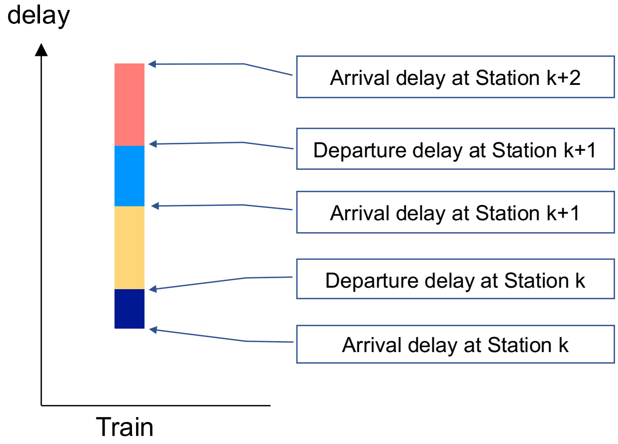

Fig. 2: Train-wise Delay Factor Graph.

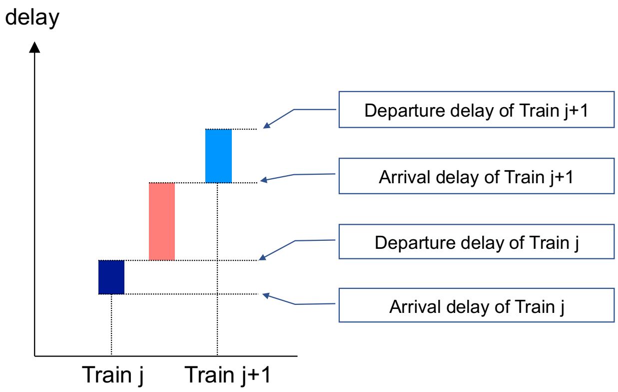

Fig. 3: Station-Timewise Delay Factor Graph.

Step3_2 Analysis of Headways

We want to find trains which ran with unreasonably large headways. We have developed Departure Difference Scatter Diagram, in which x-axis depicts the departure difference and y-axis depicts the headway. The departure time difference is defined as the interval between the departure time of the preceding train at a station and the departure time of a train at the previous station (Fig. 4). A Departure Difference Scatter Diagram shows the relationship between departure time difference and the headway (Fig.5). We can find trains whose headway is unreasonably large by finding the points which are NOT on the line.

4. Results

We have applied our approach to a part of an actual railway line (20km, 13stations, 27 trains/hour) choosing a typical one day. The maximum delay on this day was 9 minutes.

From Fig. 6 and Fig. 7, we can know that delays occurred around 8 am at Station I and they expand to station M. Also, at Station M, the delay decreased after 9:30 am. From these figures, we can figure out that the main reason for the delay is the expansion of the running time from Station H to Station I.

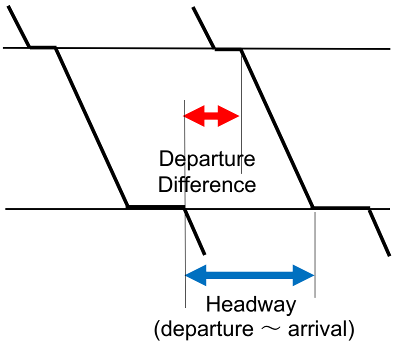

Fig. 4: Departure difference.

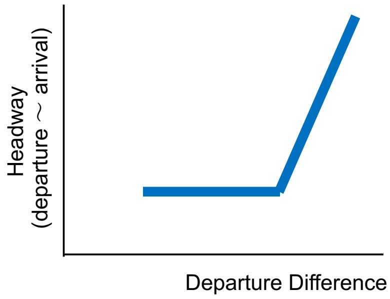

Fig. 5: Departure Difference Scatter Diagram.

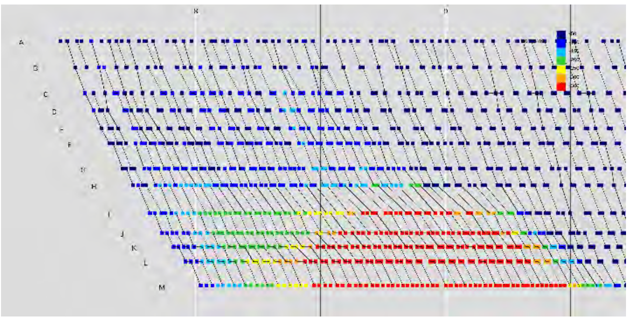

Fig.6: Node-based Chromatic Diagram.

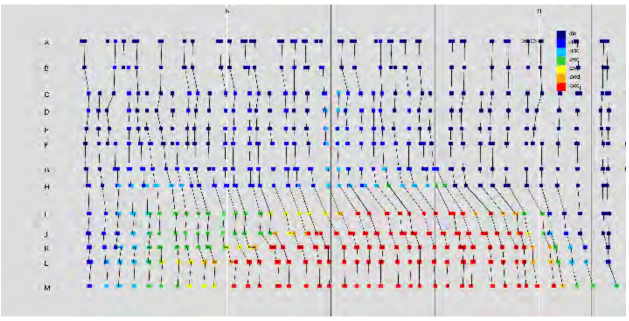

Fig. 7: Node-based Delay Diagram.

From the Train-wise Delay Factor Graph (Fig.8), we can quantitatively analyze the problem figured out in Step1. We confirmed the main factor of delays is the expansion of running times from Station H to station I.

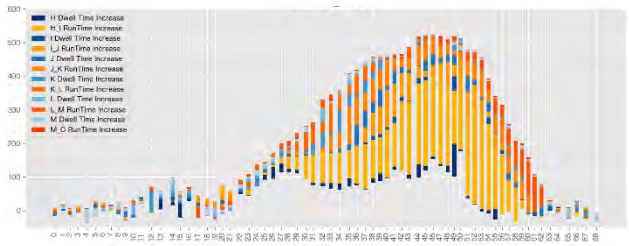

Fig.8: Train-wise Delay Factor Graph.

The Station-Timewise Delay Factor Graph (Fig. 9) is for chronological analysis of the problem figured out in Step2. The expansion of the dwell times caused the delays and the delays tend to increase because the buffer times in the headway times are small. This made the running times between Station H and Station I large.

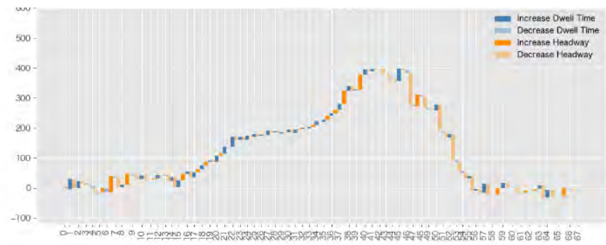

Fig.9: Station-Timewise Delay Factor Graph.

Fig 10 is a Departure Difference Scatter Diagram based on the data of Station I for 2 months whereas Fig 11 is one made from the data of the designated one day. By comparing Figure 10 with those of other stations (not shown in this paper), we can know that the technically minimum headway time of Station I is a little larger than other stations; hence delays are not absorbed by the buffer times. In addition, from Fig.11, there existed several trains on this day which ran with unreasonably large headway times (trains in the red circle), and these trains prevented the delays at this station from decreasing earlier.

Thus, we can conclude the bottleneck is at Station I. More concretely, dwell times slightly increase for some trains; these small delays accumulate and delays become larger, because the excess of dwell times are not absorbed by the buffer times. In addition, there exist some trains which ran with unreasonably large headway times. Without these trains, delays would have decreased earlier.

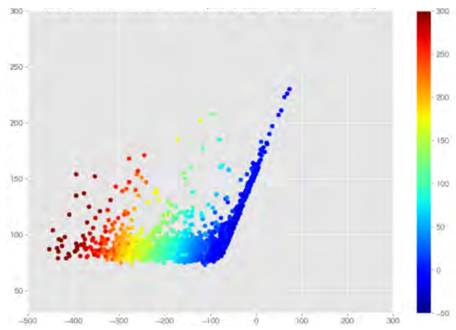

Fig.10: Departure Difference Scatter Diagram (two months).

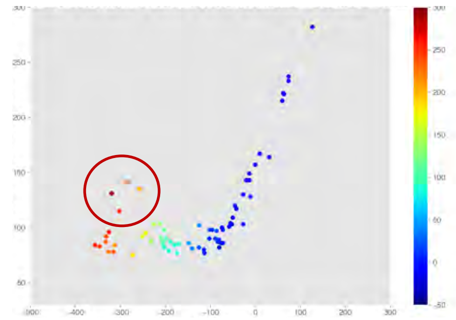

Fig.11: Departure Difference Scatter Diagram (one day).

5. Conclusion

We have introduced an approach which enables to effectively identify bottlenecks of a timetable. This approach is based on an idea to visualize the historical traffic records in various formats which are suitable for the purpose of each step of analysis. In order to cope with the volume of the data and the complexity of delay propagation patterns, we proposed to decompose the problem into the overview, the train-wise direction analysis and the station-timewise direction analysis. We have introduced Node based Chromatic Diagram and Node based Delay Diagram to get an overview of delay propagation and extension. Then, we introduced Train-wise Delay Factor Graph, which we use for the analysis of train-wise direction. With this graph, we can analyze how delays of one train increased. Then we introduced Station-Timewise Delay Factor Graph to analyze the delay propagation/extension to the succeeding trains. We also introduced Departure Difference Scatter Diagram to analyze the relationship between headway times and delays.

We have applied this approach to actual railway line, which was notorious for its congestion and delays. We showed that we successfully identified the bottleneck. As a matter of fact, we found that the direct cause is an extension of running time at a station. Then, we showed the extension of running times occurs because dwell times at this station tend to extend. Although the excess is not so large, because the excesses are not recovered by the buffer time in the headway time, the excesses accumulate and consequently, a big delay occurs. We also proved that the reason why the excesses of dwell times are not recovered is that the value of the technically minimal headway time of this station is a little larger than those of other stations. In addition, we found that there exist several trains which arrived with an unreasonably big headway time and these trains prevented the delays from decreasing earlier.

A lot of attention has been paid to train delays. But until now, not many researchers have been interested in finding the delay propagation/extension mechanism by visualization of data. Our major contribution is we have established an approach to visualize historical train traffic records which is helpful in each step of analysis and proved this approach enables efficient identification of bottlenecks of timetables using actual train traffic data.

References

[1] A. Yamamura et al, How we have succeeded in regaining Punctuality in Tokyo Metropolitan Railway Network? , WCRR2013, Sydney, Australia, 2013.

[2] Y. Mouri et al, Investigation of relationship between volume of passengers and train delays, STECH2021, Chiba, Japan, 2021.

[3] Rob M. P. Goverde, A delay propagation algorithm for large-scale railway traffic networks, Transportation Research Part C, Vol. 18, Issue 3, June 2010.

[4] T. Büker et al, Stochastic modelling of delay propagation in large networks, Journal of Rail Transport Planning & Management, Vol. 2, Issues 1-2, November-December 2012.

[5] A. Yamamura, Identification of Causes of Delays in Urban Railways, COMPRAIL 2012, New Forest, UK.

[6] M Joborn et al, Understanding causes of unpunctual trains: Delay contribution and critical disturbances, Proc. RailBeijing2021, Beijing, China, 2021.

[7] R. A. Kuipers et al, The passenger's influence on dwell times at station platforms: a literature review, TRANSPORT REVIEWS, 2021, VOL. 41, NO. 6

[8] S. Cornet et al, Methods for quantitative assessment of passenger flow influence on train dwell time in dense traffic areas, Transportation Research Part C, Vol. 106, Sep. 2019.

[9] K. Ushida et al, Increasing Robustness of Dense Timetables by Visualization of Train Traffic Record Data and Monte Carlo Simulation, WCRR2011, Lille, France, 2011.

[10] M. Komori et al, Visualization of train traffic records to realize more robust timetable, 1st Asian Conference on Railway Infrastructure and Transportation, Jeju, Korea, 2016.