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Simulation analysis of train operation to recover knock-on delay under high-frequency intervals

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ABSTRACT

The railway network in Tokyo Metropolitan Area has been continuously improved to reduce train congestion and impedance of transfers through providing high frequency train operations. However, small irregularities in services are resulting in significant delays in the railway service, as the rail system is currently operating very close to its capacity.

Therefore, this research formulated a train operation simulation model, which reproduces the behavior of train operation, taking into account the interaction between the trains. The simulation model includes the passenger-boarding model at each station. The dwell time correlates with the increase in the irregularities in train headway. Using this simulation model, this study attempted to reproduce the situation of train operation under the knock-on delay. Finally, this paper suggested a practical method to recover the knock-on delays. The result shows that keeping a moderate separation between trains with necessary adjustment at the departure time, under the delay situation, was found to be an effective measure. The measures can shorten the travel time and recover the train delay earlier.

1. Introduction

In Tokyo Metropolitan Area (hereinafter TMA), the railway network serves a large number of passengers everyday over a wide area with high reliability, speed and safety. Today, the TMA's railway network is known as one of the world's leading transport systems in handling a huge traffic volume with reliable operation. Service quality of the network has been improving constantly through the development of a high density railway network, using train consisting of many cars, operating at high-frequency intervals, sharing tracks between railway companies, introducing platform screen doors and so on. Operating at high-frequency intervals and sharing tracks between railway companies have been, particularly, key policies of Japan's railway to reduce crowdedness on the trains. The introduction of these policies has considerably contributed in making the TMA's railway network effective and in increasing the convenience for the passengers. However, these policies have also brought about undesirable effects, including (1) frequent occurrence of train delays in rush hours, (2) extension of the train delays to a wider network area and (3) making necessary time to untangle the delayed train system much longer. The congestion and train delay, which occur in an almost daily basis, particularly in the morning rush hours, have caused intolerable pain to the passengers. Moreover, the total social cost due to the train delays is estimated to exceed 200 billion yen per year (Kariyazaki and Iwakura, 2009).

The railway system of TMA is operating at a capacity close to its limit. This makes the system vulnerable to even a small irregularities, which are causing significant delays in the service. Delay time increases by the interaction of train operation and dwell time under high-frequency. Therefore, in order to carry a large number of passengers efficiently in the limited capacity, not only an individual service improvement but also comprehensive and unified measures, which deal with the whole railway system, are important. Simulation model which analyzes a station passenger flow and train operation comprehensively can help to better understand the phenomena and identify more effective measure to improve railway service.

Therefore, this research formulated a train operation simulation model, which reproduces the behavior of train operation, taking into account the interaction between the trains. The simulation model includes the passenger-boarding model at each station. The dwell time correlates with the increase in the irregularities in train

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headway. Using this simulation model, this study attempted to reproduce the situation of train operation under the knock-on delay. Finally, this paper suggested a practical method to recover the knock-on delay earlier, which involves keeping a moderate separation between trains with necessary adjustment at the departure time.

Relevant literature is reviewed in the following chapter, and analysis of present state using actual data is presented in Section 3. Section 4 explains the simulation model, and Section 5 and Section 6 discuss the simulation results respectively, before the conclusion in Section 7.

2. Literature review and scope

Recent studies of train delay have proposed that a method based on a delay propagation algorithm that use max-plus algebra for analyzing time table stability and determining infrastructure capacity (de Kort et al., 2003; Goverde, 2007, 2010 and so on). In the field of the bus, Daganzo has showed a phenomenon of bunching bus by using recurrence formula (Daganzo, 2009). Some paper has discussed treatment of the train delay by changing of the network structure for modeling user equilibrium assignment (Taguchi et al., 2005; Kunimatsu et al., 2007). Most studies of train delay have focused on how the delay affects railway transportation and demand.

On other hand, some simulation models of traffic flow have been developed. One of these models is Cellular automaton model, and numerous researches have been done, especially in the vehicles field (Nagel and Schreckenberg, 1992; Nagel et al., 2003; Chowdhury et al., 2000; Helbing, 2001; Daganzo, 2006). The model based on Cellular automaton has been also adopted in train operation modeling (Spyropoulou, 2007; Fu et al., 2008; Xun et al., 2009). Iwakura et al. have proposed a multi-agent simulation model for estimating knock-on delay (Miyazaki et al., 2007; Uematsu and Iwakura, 2009). Chiusolo et al. have analyzed the present state and simulated the results of automation through case study (Chiusolo et al., 2012). There are some approaches undertaken by metro systems around the world to reduce delays on high frequency services. For example, it is in London, in New York and in Taipei. Moscow Metro adopted some methods in operating the system to achieve high-frequency intervals services, along with smooth flows of passengers and trains (Kariyazaki and Hibino, 2011). However, because there is little data available concerning the behavior of train under the delay, these previous studies do not enough account for the delay time increased by an interaction between the trains and by an interaction between train operation and dwell time. Therefore, to the best of the authors' knowledge, no research has yet been carried out to specifically examine a practically feasible operating method on how to recover the knock-on delay earlier.

With this background, the study focuses on the behavior of train which is under the operation delay. To achieve this, this research formulated a train operation simulation model, which reproduces the behavior of train operation. The simulation model is taking into account the interaction between the trains, and includes the passenger-boarding model at each station. Finally, using this simulation model, this study attempted to reproduce the situation of train operation under the knock-on delay. And this paper suggested a practical method to recover the knock-on delay earlier.

3. Present data analysis

3.1. Data profile

Data on dynamic operation is necessary to grasp the actual mechanism of worsening punctuality. So this study obtained the actual data from Centralized Traffic Control (CTC) where data on

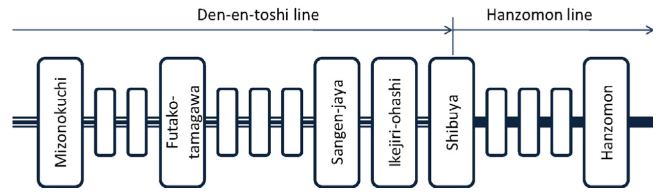

Fig. 1. Rail Routes of Den-en-toshi line and Hanzomon line.

the departure and arrival time of every train at each station is recorded. This research covers Den-en-toshi line by TOKYU CORPORATION and Hanzomon Line by Tokyo Metro Co., Ltd. Den-en-toshi line is a radial commuter train, that is one of the most crowded lines in TMA. Den-en-toshi and Hanzomon lines are interconnected with each other. These trains operate at a minimum headway of 125 s during rush hours. Analysis in this study used the actual data of 4 h (7:00–11:00) on January 19, 2009. The maximum arrival delay in Shibuya station of the research day was about 9 min. Shibuya station is the major one, where these trains interconnect each other. Although Den-en-toshi line runs express trains, each train stops at every station from Hutako-tamagawa to Shibuya (involving 7 stations) during rush hours (7:50–9:00) to level the train congestion.

3.2. Composition of delay time

Fig. 2 shows relations of dwell time at a station to the irregularities in headway. The horizontal axis shows the time between the departure of the train and the arrival of the following train. An increase in dwell time occurs by various factors. To reduce the influence of a unique factor, the time is ranked every 10 s, and the mean of dwell time for every rank is drawn as vertical axis. The data was acquired from 7 stations, which have high congestion, Futako-tamagawa station to Shibuya station (Fig. 1).

As Fig. 2 shows, the dwell time is directly correlated with the irregularities in train headway. Thus, when the arrival of the train is late, the passengers at the station increase and the dwell time of the following train increases. This delay propagates to the following train, and the running time between stations increases.

Train schedule is usually planned by assuming travel time at rush hour to be 1.2 times as that of daytime, based on extrapolating an increasing dwell time from past experience. However, delays have been longer than the assumption, and the increase in delay is irregular. Fig. 3 shows an increased travel time of each train against the schedule between specific sections that consist of 14 stations from Mizonokuchi to Hanzomon. It usually takes about 30 min to travel along the entire line. However, increased travel time, which exceeded the normal travel time by 720 s, was observed at about 9:20. The longest travel time was about 1.4 times as long as that of being assumed.

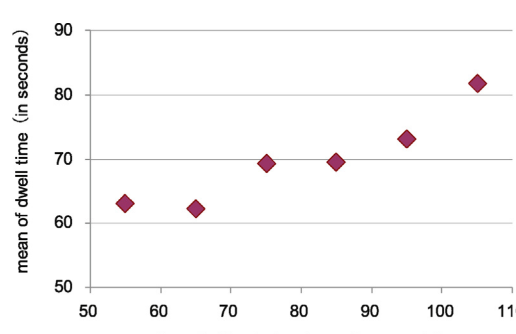

Fig. 2. Relationship between irregularities in headway and dwell time.