EMPIRICAL INVESTIGATION OF FUNDAMENTAL DIAGRAM FOR URBAN RAIL TRANSIT USING TOKYO'S COMMUTER RAIL DATA

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Background and Objective

In some megacities like Tokyo, urban rail transit has served as one of the countermeasures for alleviating congestions mainly due to huge number of commuting passengers. Some railway operators provide their rail transportation service at their maximum supply capacities and thereby trains are operated with high service frequency. Under such situations, however, small delay in one train may lead to network-level disruptions of urban transit services because such delay propagates to other trains. It further may bring severe delays due to the complex interactions between passenger-congestion at platforms and train-congestion on tracks. For example, it is reported that sixteen out of fifty-one railway lines in Tokyo causes delay in two-thirds of weekdays and those sixteen railway lines are operated with high service frequency for two or four minutes per one train (Council for Transport Policy, 2016). Furthermore, it reported that short delay accounts for eighty-six percentage of all delay cases, and daily passenger-congestion accounts for a half of its causes.

To understand such urban train delay phenomena and to explore countermeasures for improving service reliability, it would be necessary to explore analytical train cruising models with the effects of passenger boarding/alighting for urban rail transit system. So far, simulation-based approaches have been mainly employed for the analysis (e.g. Kariyazaki et al. 2015) but they have some limitations in terms of theorizing train delay phenomena. Recently, Seo et al. (2017) proposed a concept of train-passenger fundamental diagram (FD) for urban rail transit. The proposed FD is simple but theoretically rigorous. To examine the validity of the proposed FD, it is necessary to perform empirical investigation by using real and comprehensive dataset of transit-passenger interactions in an urban rail transit. This study, therefore, aims at checking the exiting transit-passenger FD in urban transit systems by using Tokyo's commuter rail data.

Train-Passenger Fundamental Diagram

Consider a railway system on a single line track with some equally-spaced stations. Further assume that all trains stop at every station; the passenger boarding time at each station is modeled using a standard queuing model; the cruising behavior of a train is modeled using the simplified car-following model by Newell (2002); trains have infinite capacity for passengers and so on. Seo et al. (2017) then developed a microscopic model of rail transit system and further derived the train-passenger FD as a steady-state relationship among train-flow, train-density, and passenger-flow. For a given number of passenger-flow with some key parameters, the functional relation between train-flow and train-density is triangular as in the case of FDs in standard vehicular traffic and it may have an unique maximum capacity and an corresponding critical train-density.

Outline of the Dataset

We selected Tokyu Den-en-Toshi Line as our validation study. This railway line runs from the center area of Kanagawa prefecture to Shibuya, and it operates directly to Tokyo-Metro Hanzomon Line and further to Tobu Isesaki Line. The target line operates in every 2 or 3 minutes per one train during the morning peak period with high congestion rate of passengers. We chose the section of Futako-Tamagawa and Shibuya (9.4 km) along which six stations are arrayed.

The dataset contains: (a) Train operation data including departure and arrival times of all trains in seconds; (b) Passenger counts data for each station based on the field survey in a particular day; (c) Passenger counts data from automatic ticket gate; and (d) Speed limit information for each block based on automatic train control protocol. We analyze the data of 10 weekdays in October 2017, from 6:30AM to 10:30AM.

Key Empirical Findings

By applying Edie (1963)'s generalized definition of traffic states to the time-space diagram of train vehicles in the target section, we computed tuples of train-flow, train-density and passenger-flow for each predetermined space-time region where steady-state of traffic is assumed. For each adjacent station-to-station section as well as for the whole section of the case study area, we found inverse U-shape like scatter plots of train-flow and train-density observations mainly in the domain of congested train flows. We also found that the maximum train-flow capacity tends to reduce as passenger flow increases. Furthermore, the plot for the whole section has been low-scattered compared with plots for each individual section and this empirical fact is consistent with the findings for vehicular traffic in urban cities (Geroliminis and Daganzo, 2008).

We further performed the data fitting to the triangular FD by Seo et al. (2017) by performing non-linear least square methods to minimize the gap between the data and the model estimates of train-flow. Though the goodness-of-fit of the FD for each individual section are mostly poor, we found that the model fitting to the whole section is moderate having a determination coefficient of 0.81.

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