Fundamental diagram of urban rail transit: An empirical investigation by Boston's subway data

ボストン地下鉄運行データを用いた都市鉄道交通流基本図の実証的研究

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Introduction

- In many metropolises, passengers commuting by rail transit suffer from severe congestion and frequent delays during the rush hours. Temporally surging demand and improper behavior of passengers are considered as the main causes of congestion and delays (MLIT, 2017). Therefore, it is crucially important to understand congestion and delay mechanisms due to passenger influence.
- Seo et al. (2017) proposed a fundamental diagram (FD) of urban rail transit to describe the interaction between passenger demand and train operation. This research investigates their proposed FD and its variants by using empirical data from the Boston subway system.

Boston Redline Operation Data & Empirical Train-FD

- The Massachusetts Bay Transportation Authority (MBTA) recently published a substantial amount of subway operation data through its APIs. The raw data includes per minute turnstile entry counts at each station, as well as real-time train trajectories in Google's GTFS format.
- The average flow & density of railway system can be calculated by Edie's definition of traffic flow as:

$$q(A) = \frac{\sum_{n\in N} d_n}{|A|} \qquad k(A) = \frac{\sum_{n\in N} \tau_n}{|A|}$$

A: measurement time-space area, $|A| = L \times \Delta t$, $L = 14.4\ km$, $\Delta = 10\ min$
d_n & τ_n: total travel distance & travel time of vehicle n in A

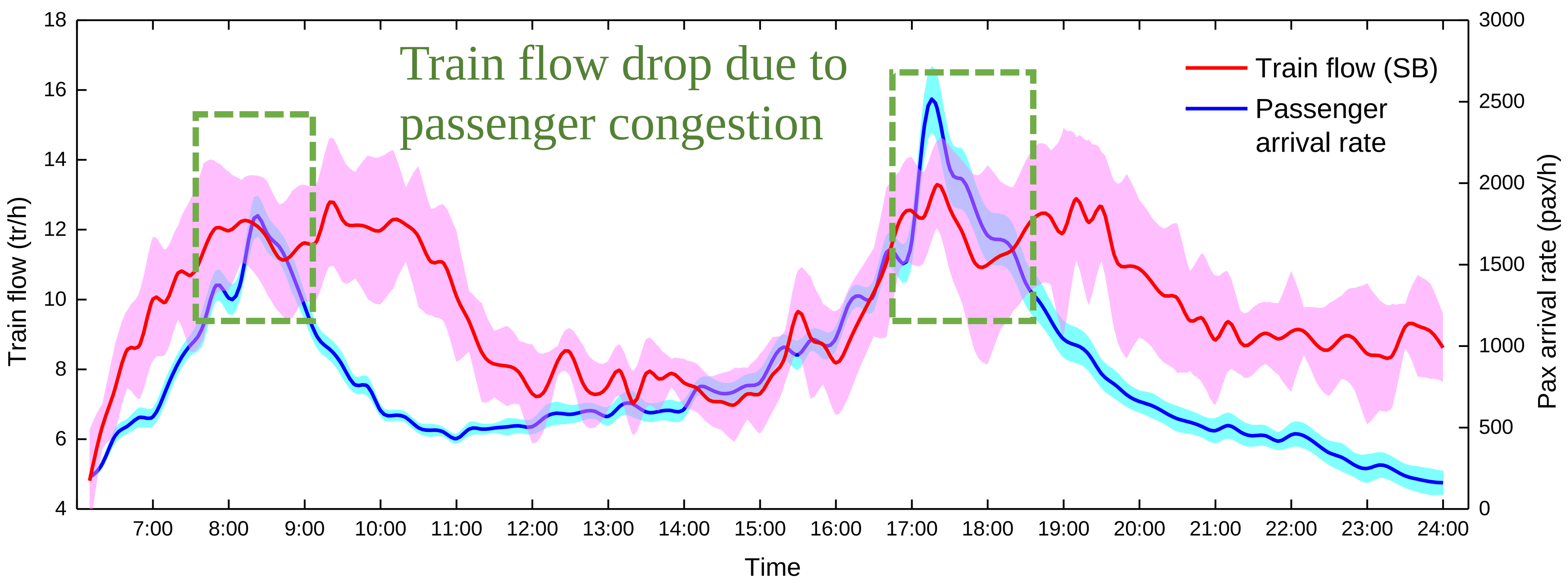


Figure 1: Train and passenger flow transition during one day

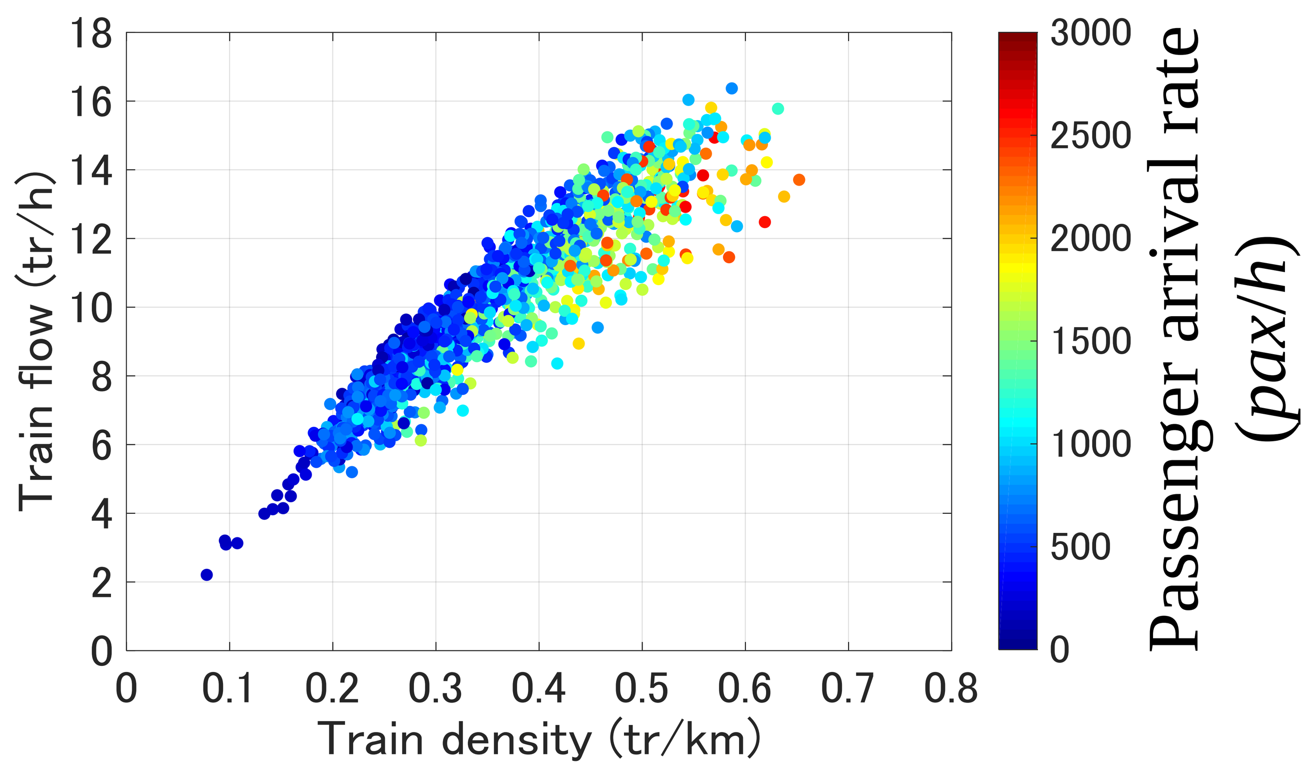
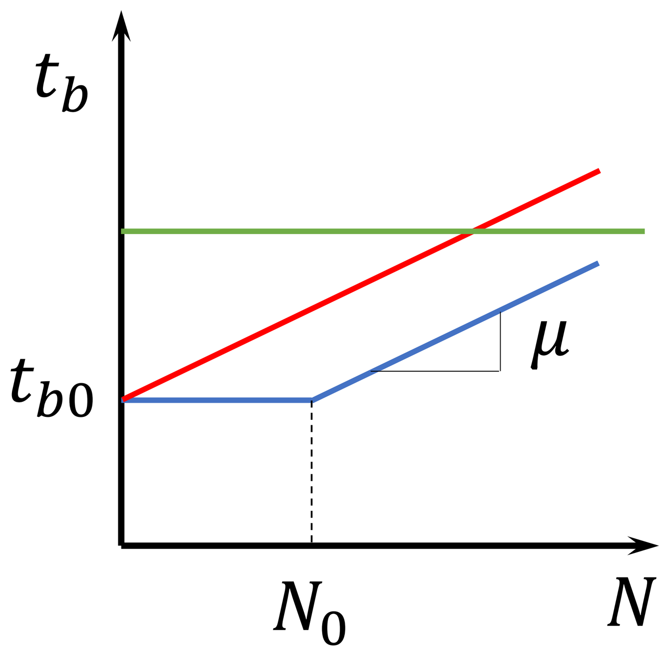


Figure 2: Weekday FD of Boston Redline (SB)

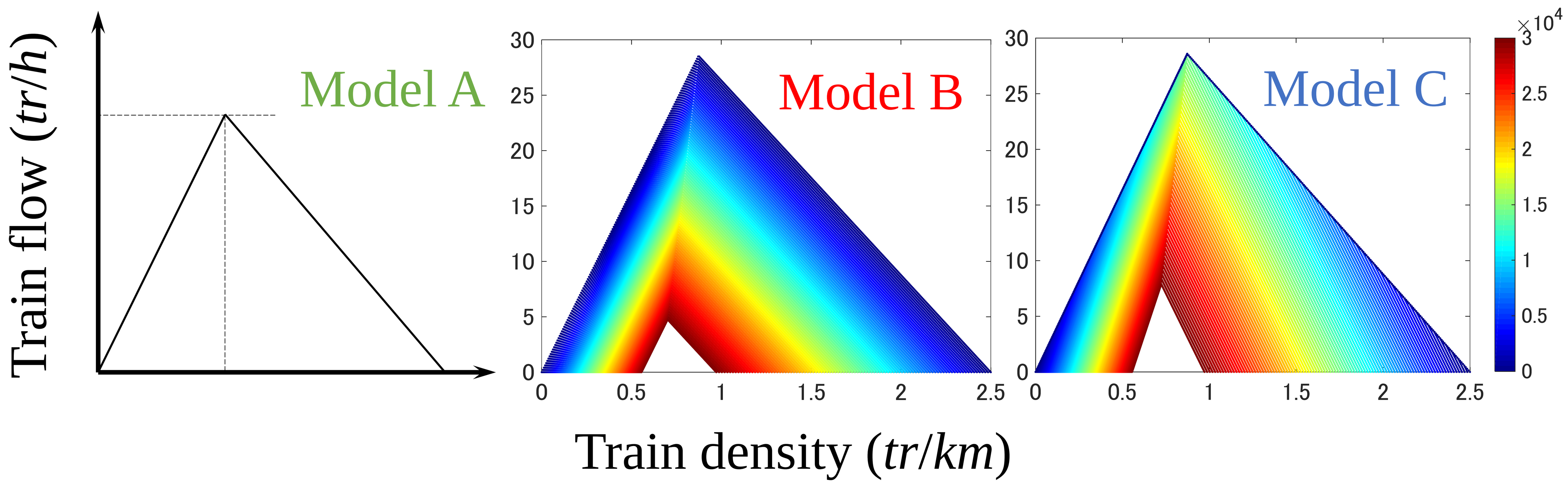
Train-FD Models

- Three train dwelling time t_b assumptions



Model A: constant (t_{bcon}, v_f)
Model B: monotonic ↗ (t_{b0}, v_f, μ)
Model C: piece-wise ↗ (t_{b0}, v_f, μ, N_0)

- Three train-FD models $q = Q(k, a_p)$



Comparison by RMSE & AIC

- Comparison by root square mean error (RMSE)

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(q_i^m - q_i^e\right)^2} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(q_i^m - Q\left(k_i^m, a_{p,i}^m\right)\right)^2}$$

	Model A	Model B	Model C
$RMSE$ (tr/h)	1.04	0.94	0.94

- Comparison by Akaike information criterion (AIC)

$$AIC = n\ln(2\pi) + n\ln\left(\sum_{i=1}^{n}(q_i^m - \hat{q}_i^e)^2/n\right) + n + 2p$$

	Model A ($p = 2$)	Model B ($p = 3$)	Model C ($p = 4$)
AIC	4286.64	3991.42	3993.39