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# Three-Stage Least Squared Models of a Station-Level Subway Ridership: Incorporating an Analysis on Integrated Transit Network Topology Measures

**Authors :** Jungyeol Hong, Dongjoo Park

**Abstract :** The urban transit system is a critical part of a solution to the economic, energy, and environmental challenges. Furthermore, it ultimately contributes the improvement of people's quality of lives. For taking these kinds of advantages, the city of Seoul has tried to construct an integrated transit system including both subway and buses. The effort led to the fact that approximately 6.9 million citizens use the integrated transit system every day for their trips. Diagnosing the current transit network is a significant task to provide more convenient and pleasant transit environment. Therefore, the critical objective of this study is to establish a methodological framework for the analysis of an integrated bus-subway network and to examine the relationship between subway ridership and parameters such as network topology measures, bus demand, and a variety of commercial business facilities. Regarding a statistical approach to estimate subway ridership at a station level, many previous studies relied on Ordinary Least Square regression, but there was lack of studies considering the endogeneity issues which might show in the subway ridership prediction model. This study focused on both discovering the impacts of integrated transit network topology measures and endogenous effect of bus demand on subway ridership. It could ultimately contribute to developing more accurate subway ridership estimation accounting for its statistical bias. The spatial scope of the study covers Seoul city in South Korea, and it includes 243 subway stations and 10,120 bus stops with the temporal scope set during twenty-four hours with one-hour interval time panels each. The subway and bus ridership information in detail was collected from the Seoul Smart Card data in 2015 and 2016. First, integrated subway-bus network topology measures which have characteristics regarding connectivity, centrality, transitivity, and reciprocity were estimated based on the complex network theory. The results of integrated transit network topology analysis were compared to subway-only network topology. Also, the non-recursive approach which is Three-Stage Least Square was applied to develop the daily subway ridership model as capturing the endogeneity between bus and subway demands. Independent variables included roadway geometry, commercial business characteristics, social-economic characteristics, safety index, transit facility attributes, and dummies for seasons and time zone. Consequently, it was found that network topology measures were significant size effect. Especially, centrality measures showed that the elasticity was a change of 4.88% for closeness centrality, 24.48% for betweenness centrality while the elasticity of bus ridership was 8.85%. Moreover, it was proved that bus demand and subway ridership were endogenous in a non-recursive manner as showing that predicted bus ridership and predicted subway ridership is statistically significant in OLS regression models. Therefore, it shows that three-stage least square model appears to be a plausible model for efficient subway ridership estimation. It is expected that the proposed approach provides a reliable guideline that can be used as part of the spectrum of tools for evaluating a city-wide integrated transit network.

**Keywords :** integrated transit system, network topology measures, three-stage least squared, endogeneity, subway ridership
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