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What determines rail transit passenger volume? Implications for transit oriented development planning

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ABSTRACT

Transit oriented development (TOD) has been an important topic for urban transportation planning research and practice. This paper is aimed at empirically examining the effect of rail transit station-based TOD on daily station passenger volume. Using integrated circuit (IC) card data on metro passenger volumes and cellular signaling data on the spatial distribution of human activities in Shanghai, the research identifies variations in ridership among rail transit stations. Then, regression analysis is performed using passenger volume in each station as the dependent variable. Explanatory variables include station area employment and population, residents' commuting distances, metro network accessibility, status as interchange station, and coupling with commercial activity centers. The main findings are: (1) Passenger volume is positively associated with employment density and residents' commuting distance around station; (2) stations with earlier opening dates and serving as transfer nodes tend to have positive association with passenger volumes; (3) metro stations better integrated with nearby commercial development tend to have larger passenger volumes. Several implications are drawn for TOD planning: (1) TOD planning should be integrated with rail transit network planning; (2) location of metro stations should be coupled with commercial development; (3) high employment densities should be especially encouraged as a key TOD feature; and (4) interchange stations should be more strategically positioned in the planning for rail transit network.

1. Introduction

Traffic congestion and environmental pollution brought by cars have drawn attention from academics and policy makers worldwide. To alleviate these problems, Chinese megacities have been constructing rail transit to strengthen urban public transportation and pursuing transit oriented development (TOD) around rail transit stations to ensure ridership. However, as rail transit lines extended far away from city center, the centrally located stations often become over crowded, whereas stations in periphery area do not have adequate passenger volumes. Consequently, the operation of the rail transit system is becoming less efficient. How to balance the passenger volumes and increase the efficiency of rail transit are key challenges for planners.

TOD is conceptually a highly promising approach to reducing car dependence and promoting public transportation. Its key characteristics are mixed land use and high density in areas adjacent to public transportation (Cervero et al., 2002; Cervero, 2006). Urban planning principles under TOD emphasize the use of compact urban form to support efficient public transportation service and provide a good walking environment. However, to be effective in generating transit ridership, the general TOD principles may have to adapt to various settings, which can be quite different due to the specific geographic location and position in the transit network,

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neighborhood characteristics, and residents' socio-economic profiles.

This paper presents an empirical analysis of the effects of TOD elements on passenger volumes at rail transit stations, using data for Shanghai. Shanghai's rail transit construction began in 1990 and the first metro line was put into operation in 1995. Since then Shanghai rail transit has been developing rapidly. By 2005, there were 4 lines with a total length of 158 km. By December 2015, the city's metro system had grown into an extensive and complex network with 14 lines totaling 617 km. According to the transportation development plan of Shanghai, the city's rail transit network will be 970 km by 2020. Similar expansion of metro network has been planned for many megacities in China. This means that many new stations will be developed in the future, and most of them will be located in peripheral areas, creating many opportunities for TOD.

Generally Chinese cities still have a strong city center area, with high levels of employment concentration. For example, Shanghai covers an area of 6340 km^2, including city center area (114.2 km^2, within the inner -ring), central city (663.7 km^2, inside the outer-ring) and suburbs outside. Employment is highly concentrated in center city area, reflecting intensive service activities in this cosmopolis. Urban land use in suburban areas is primarily residential and industrial. TOD as a concept is well recognized in planning practice in China, but few studies have developed guiding principles for improving TOD planning contextually based on rigorous examination of the outcomes. In particular, the traditional TOD concept focuses mostly on station areas along a specific rail transit line. This work is aimed at filling some of the knowledge gaps by addressing two research questions. First, what are the key factors that determine the station passenger volume in a large rail transit network? Second, what TOD planning measures should be implemented to increase passenger volumes in rail transit stations, especially those located in peripheral areas?

Shanghai will add 300 km of metro lines to its rail transit system, and most of the extension will be in peripheral areas. Given that many metro stations in such areas do not have enough passenger volumes, how to achieve operation efficiency in the future with the extended system is a critical question worthy serious discussion.

Prior research on the influential factors of rail transit passenger volume is summarized below in the literature review. Regression models are then specified and estimated. A distinctive methodological strength of this research is that it employs integrated circuit (IC) card data and cellular signaling data. With IC card data, we can obtain station passenger volume (sum of station entry and station exit passengers) of every metro station on the whole rail transit network, whereas with cellular signaling data, we are able to not only identify the distribution of employment, but also estimate residents' commuting distances. The quantitative analysis will provide a solid basis for answering the research questions.

2. Literature review

The literature identifies many factors that influence rail transit passenger volume. These factors can be grouped into two types: "internal factors", which refer to the factors related to rail operations, including frequency, speed, and punctuality rate; and "external factors", which refer to the factors associated with built environment features surrounding stations. In Shanghai, all metro lines run at similar speeds and offer similar levels of service. It is therefore not surprising that most researchers have found the external factors more important than the internal factors in determining passenger volume (Tilahun et al., 2014; Yim et al., 2005; Walton and Sunseri, 2010; Sung et al., 2014). Consequently, this literature review will not discuss internal factors. Key external factors include land use, transportation factors, and social economic factors (Chakraborty and Mishrab, 2013; El-Geneidy et al., 2010; Jun et al., 2013; Kim and Nam, 2013; Lindsey et al., 2010; Loo et al., 2010; LTA, 2011; Moniruzzaman and Páez, 2012; Ratner and Goetz, 2013). Because this paper is about urban land use and transportation planning, the literature review here focuses on the first two sets of external factors.

2.1. Land use

Land use is a key factor influencing passenger volume. At the scale of TOD planning, land use is most often characterized by development density and built environment.

2.1.1. Density

Density is considered the most relevant factor to passenger volume. The key indicators include total residents, total employment, residential density, and employment density (Taylor and Fink, 2003; Gutiérrez and García-Palomares, 2008). Chen and Mcknight (2007) assesses the effect of development density on travel mode choice, using residential density and employment density. The study shows that density has an impact on travel mode choice, and that the effect of destination density is greater than density around origin. Zhang (2004) studies the influence of land use on travel mode in Boston and Hong Kong. His results show that the residential densities at both destination and origin have significant positive correlation with the choices of public transport or non-motorized means as commuting mode. Destination employment density is found to significantly increase the probability of non-motorized travel, but origin employment density is not found to have obvious correlation with the travel choiceLoo et al. (2010) use the rail transit IC card data around 406 stations in New York City and 79 stations Hong Kong to estimate regression models of average weekday patronage entry at metro stations. Their results indicate that population density explains the choice of rail transit in New York City quite well, and that in the case of Hong Kong, residential density is also positively related to rail transit choice but the ratio of employment to residents is negatively correlated with rail transit choice within service catchment area.

Cervero (2006) researches factors influencing travel demand based on 11 cases in the United States and 2 cases in Canada, with a total of 261 light rail stations. His results show that the higher the population and employment density within 0.5 miles of a station, the larger the daily passenger volume. Ewing and Cervero (2010) find employment density having a great influence on commuting