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A simulation model for evaluating facilities' adaptability in the fare collection area of subway stations

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A R T I C L E I N F O

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A B S T R A C T

According to relative position between ticket office and automatic fare gates, the facility layout of a fare collection area can be classified into three types. The application of these facility layout types are analyzed in the 15 subway hubs and 85 general stations, Beijing. According to the analysis results of facility layout and passenger flow line, fare collection area can be classified into 9 functional subareas. The adjacency degree is defined as the location relationship between adjacent subareas. Secondly, the simulation model is developed with an individual passenger as the object, to update an individual passenger's status. And the moving behavior model of an individual passenger is developed based on the macro pedestrian flow model according to traffic characteristics of many passengers in the field data. In status updating, the average speed of the passengers in different simulation time varied with the density in the subarea. In the case study the facility configurations of the fare collection system in the rail transit hub, DongZhiMen are evaluated with the proposed model for the adaptability of the facility configuration in the fare collection systems. Results show that the provided simulation model is effective and valuable for facility layout optimization and adaptability analysis.

1. Introduction

In China, the practical processes of urban rail transit hub design have following 3 steps (BMCUP, 2013). Rail transit project feasibility study is completed based the national standard of "Code for Design of Metro" –GB50157-2013 (BMCUP, 2013) and traffic survey data (Helbing and Molnár, 1995). According to the forward peak hourly passenger volume forecast, the overall size of the hub station is computed and determined (Helbing et al., 2001). Then the relevant import and export facilities, facilities and transfer facilities, the overall design and detailed design of the station are obtained. To sum up, it is to adopt the static calculation method of the static total quantity (peak passenger flow rate) control, and the relative independent calculation of all kinds of facilities. This approach brings the problem, the empirical judgment or analogy to optimize the configuration of the components is completely analyzed, just for the specific design purposes. Coordination between the size and the layout of the various facilities, the effectiveness of the whole system, cannot be analyzed and considered. Because of the high cost potential of constructing urban rail transit hubs, it is especially important, at the engineering design stage, to assess the suitability of a hub system for handling passenger flows. Many analytical and simulation models are available for

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evaluating rail transit hub systems. Simulation models have become popular in such applications due to many advantages of simulation.

Microscopic simulation is modeling of pedestrian movement where every agent in the model is treated as an individual. A large number of microscopic simulation models have been developed, examples of which are the social force model (Helbing and Molnár, 1995; Helbing et al., 2001), Nomad (Daamen, 2004; Hoogendoorn and Daamen, 2004; Hoogendoorn and Nuno Rodrigues, 2004), VISSIM (PTV Traffic Mobility Logistics, 2008), Legion (Still, 2000), Pedflow (Willis et al., 2002; Willis et al., 2004), and Streets (Schelhorn et al., 1999). In the "*social force*" model, Helbing used the notion of attraction and repulsion to model microscopic behaviour and developed complex equations to model a range of pedestrian behaviours. The model is based on the assumption that every pedestrian has an intention to reach a certain destination at a certain target time and the direction is a unit vector from a particular location to the destination point. SimPed and Nomad are two simulation tools developed by Hoogendoorn and Daamen based on pedestrian flow characteristics. Hermant (2012) conducted extensive video-based pedestrian observations aimed at exploring the macroscopic fundamental relationships, considering the various personal, situational and environmental factors that characterise the context in which pedestrians move. Ganansia et al. (2014) presented a promising approach to estimate traffic flow in the station transforming potentially the video protection system into a network of low-cost sensors for flow assessment. Van den Heuvel and Hoogenraad (2014) developed a Station Transfer Monitor based on automatic fare collection data to monitor the performance of the pedestrian function of train stations in The Netherlands, showing that smart card data can help to detect transfer bottlenecks, the potential impact of train schedule changes on transfer times, the importance of station services to alleviate waiting time. Hänseler (2016) developed a mathematical framework and a computationally efficient model for describing the propagation of pedestrians in walking facilities based on the continuum theory for pedestrian flow and the cell transmission model. Hanseler also put forward the idea of using a pedestrian flow density to estimate travel times and describe pedestrian propagation in rail access facilities, using a macroscopic loading model for time-varying pedestrian flows in public walking areas.

Kaakai et al. (2007) present a simulation model based on hybrid Petri nets able to help transit authorities to carry out performance evaluation procedures in order to prevent, to reduce and if possible to avoid these accidents which deteriorate the image of public transport in general and make it less attractive. He and Su, 2008 developed a metro platform simulation system based on a virtual environment for training metro drivers. The system was composed of a sensible platform virtual environment and a virtual passenger-flow system. However, the system was designed primarily for training metro drivers and it could not fit to evaluating facility designs. Ni et al. (2008) developed a subway passenger's simulation system based on virtual reality, but it did not consider the characters of different passengers. Li (2007) developed a simulation model named MTR-PedSIM using the multi-agent simulation technique; however, it was not suitable for assessing facility adaptability. Liu and Zhang (2004) established a computer simulation model to analyze queuing issues at metro entry gates; but the model was not enough to consider different passenger types in fare collection systems.

Different studies have shown that travelers are more sensitive to transfer time than in-vehicle time (Kaakai et al., 2007; William et al., 1999). Therefore, it becomes critical to minimize passenger transfer times by providing optimal design of transfer hubs, platform allocation, and fare collection system. Traffic operations at transfer hubs are however complex. This is partly caused by the interactions among different processes (e.g. walking, public transit operation), as well as different services offered by contemporary transfer hubs (access and egress public transit services, buying tickets, waiting, eating, shopping, etc.). Another complicating factor is the heterogeneity in passenger composition with respect to trip purpose, age, gender, etc.

The focus of this research is to analyze the facilities configuration in the fare collection area of transfer hubs. This paper is organized as follows. After the introduction, analysis of facilities configuration and passenger flow line is presented. The next section describes the parameter settings for the microscopic simulation model of the fare collection system. Then macro pedestrian flow model and status updating algorithm are put forward for the simulation model. A case study and results are presented. Finally, some conclusions and recommendations are reached based on the research.

2. Analysis of facility configuration and passenger flow line

2.1. Facility configuration and passenger flow line

A fare collection system includes a number of necessary devices, including ticket office (TO), automatic ticket vending machines (TVM), automatic analyzers, recharging machines, automatic fare gates (FG), tickets adjustment (TA), service counters (SC), and security check machines (SCM). According to the relative position between ticket office and automatic fare gates, the device layout of a fare collection area can be classified into three types: paratactic, parallel, and vertical.

(1) Paratactic fare gate and ticket office: This device layout can be divided into single exit direction and double exit directions, as shown in Fig. 1. For example, in Fig. 1(a), after passing the auto fare gates, the exiting passengers will leave the fare collection area in the exit direction directly. In this case, the conflict is minimal between the entering passengers and the exiting passengers. Contrast to Fig. 1(a), in Fig. 1(b), after getting across the fare gates, the exiting passengers are divided into two parts and then leave the fare collection area separately in the two exit directions. At the