Modeling of Passengers’ Boarding During the Urban Rail Transit Rush Hours

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Abstract: As an important part of public transportation, urban rail transit becomes the main travel mode for residents during the rush hours. In this paper we proposed the concept of passengers’ willingness to board and find that boarding selection was closely related to the number of queuing passengers and train load factor. By using passenger flow data of Beijing subway network, we constructed passengers’ boarding model based on different load factors. The results of boarding model proposed in this paper and fixed train capacity model were compared in the simulation analysis. The boarding model based on different load factors accorded with the actual condition better, which embodied that passengers’ willingness to board do influence the behavior of passengers.

1. Introduction

Urban rail transit plays an important role in alleviating the ground traffic pressure, which is a way to optimize the travel diversion of the residents. In order to identify the behavior of passengers when boarding, the construction of urban rail transit passenger boarding model is of great significance for the distribution of passenger flow and improvement of the operation plan and the station’s passenger flow organization.

Gao Ziyou, Song Yifan et al.[1] believed that the demand between any OD in the bus system is variable, and proposed the stochastic user equilibrium distribution model based on an elastic demand. Zhu Yuting et al.[2] established the urban rail traffic flow distribution model based on the train schedule, and the capacity of urban rail transit train is a strong constraint. Cao Shouhua et al.[3] established the mathematical model of the subsection form by studying the time distribution law of the passengers boarding the train. Liu Zhiyuan, Wang Shuaian et al.[4] systematically analyzed and modeled the of passengers’ willingness to board. In their study, the queuing order of passengers was regarded as the only factor influencing the willingness of passengers to board. However, passengers' boarding is also related to many other factors, such as passengers’ luggage, sense of time and whether there is a seat or not. Previous studies have been considered inadequately, so this paper can fill up some vacancy in this field.

2. Description

Urban rail transit passengers’ willingness to board refers to whether they are willing to take the next arriving train when waiting at the station platform. It is influenced by various factors. During the morning rush hours, urban rail transit passengers were mostly commuter passengers. Due to the existence of late penalty for work, these passengers' concept of time is expressed as eager to get to work place. The characteristics of rush hours is that the load factor of the train increased obviously, and the train is always crowded even extremely crowded. Under such conditions, passengers can only get on the train with increasing crowding tolerance. This paper focuses on the boarding selection of passengers at urban rail transit rush hours, and we use the number of people to get on the train at a certain station as the willingness to board of most passengers, so the load factor of the train and the queuing number at the station are the main influencing factors, also the most important variables to construct passengers’ boarding model.

Based on this, the Beijing subway network are taken as the object to carry on the survey of the passengers boarding data. When collecting data, we recorded the number of passengers queuing when the train arrived, the number of stranded passengers when train left, as well as the load factor of the train. According to the actual elastic range load factor of Beijing subway network, the load factor interval of 0-1.3 is divided into the following situations: below 0.7, 0.7-0.9, 0.9-1.1, 1.1-1.3. By fitting the original survey data, we obtained the relationship between the number of boarding passengers and the number of queuing passengers under different load factor conditions.

3. Model

According to the analysis of the survey data on passenger boarding, the linear relationship between the number of boarding passengers and the number of queuing passengers is obtained. Based on multi-load factor level function relationship, we can build the passengers' boarding model during urban rail transit rush hours. The following symbols are used in the model.

$x_{i,j}$, refers to the number of queuing passengers when train "i" arrived at station "j";

$y_{i,j}$, refers to the number of boarding passengers when train "i" arrived at station "j";

$w_{i,j}$, refers to the number of new arrived passengers when train "i" arrived at station "j";

$u_{i,j}$, refers to the number of getting off passengers when train "i" arrived at station "j";

$z_{i,j}$, refers to the number of stranded passengers when train "i" arrived at station "j";

$S_{i,j}$, refers to the number of passengers on the train when train "i" arrived at station "j";

C , refers to the capacity of urban rail transit train;

$a_{i,j}$, refers to the actual load factor of the train.

We assumed that the passengers on the train when arrived at station "$j+1$" is the same with train left station "j" in this model. $S_{i,0}=0$, which means the train was empty when arrived at station "1". The number of new arrived passengers $w_{i,j}$ and getting off passengers $u_{i,j}$ are known quantity in this model. According to the definition and logical relationship of these variables, there are the following equations.

$$a_{i,j} = S_{i,j} / C \tag{1}$$

$$x_{i,j} = z_{i-1,j} + w_{i,j} \tag{2}$$

$$z_{i,j} = x_{i,j} - y_{i,j} \tag{3}$$

$$S_{i,j} = S_{i,j-1} + y_{i,j} - u_{i,j} \tag{4}$$

According to the previous fitting results of survey data, the function relationship and image of the number of boarding passengers and queuing passengers are shown below:

$$y_{i,j} = \begin{cases} 0.98x_{i,j}, & a_{i,j} < 0.7 \\ 0.9392x_{i,j} - 7.3074, & a_{i,j} \in [0.7, 0.9) \\ 0.5811x_{i,j} + 14.683, & a_{i,j} \in [0.9, 1.1) \\ 0.4558x_{i,j} + 4.9221, & a_{i,j} \in [1.1, 1.3) \end{cases} \tag{5}$$

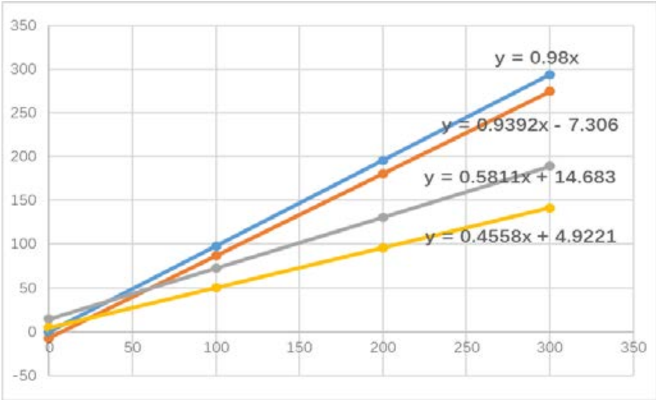

Fig 1. The relationship of boarding passengers and queuing passengers based on different load factor

The picture above reveals that when $x_{i,j} > 50$, the number of boarding corresponds to the load factor one to one, so we can use iterative method from load factor 1.3 to 0 to calculate the number of boarding passengers. When $x_{i,j} < 50$, The lines at different load factor levels intersect, iterative method is no longer applicable. But the number of queuing passengers below 50 can hardly happen at rush hour stations, and the number of boarding according to the different load factor level is less than 25, usually $C = 1440$, so the calculation influences load factor less than 0.017, which is in an acceptable error range.

At different load factor interval we can get different function relationships of boarding and queuing, so the following iterative method is used to determine the number of boarding passengers when train "i" arrived at station "j". Set intervals: $L_k = \begin{cases} [0,0.7), k=1 \\ [0.7,0.9), k=2 \\ [0.9,1.1), k=3 \\ [1.1,1.3), k=4 \end{cases}$

(1) Assume $k=4$, $a_{i,j} \in L_4$,use the function relationship of the number of boarding and queuing passengers.

(2) $y_{i,j} = 0.4558x_{i,j} + 4.9221$.

(3) Calculate $S_{i,j} = S_{i,j-1} + y_{i,j} - u_{i,j}$.

(4) Calculate $a_{i,j} = S_{i,j} / C$, if $a_{i,j} \in L_k$, the number of boarding passengers will be $y_{i,j}$. If $a_{i,j} \notin L_k$, then $k = k-1$, goes to step (1).

4. Simulation

After completing the model construction, it's appropriate to carry on the simulation of several stations' passengers boarding condition based on the multi-load factor level with Anylogic. The basic data of the simulation case is set as below:

M line is a subway line of Beijing subway network with a large passenger flow at rush hours, and the train load factor reaches 1.2 or more, causing the passenger stranded situation obviously. Station A is the beginning station of M line, and B, C, D and E are middle stations of M. The headway of M line at rush hours are 2min30s, and the train stayed at each station for 30s, inter-station operation time is unified as 90s. When train "i" arrived at platform, there is 500 new passengers in station "A", 700 new passengers in station "B", 300 new passengers in station "C" and "D", 150 new passengers in station "E". Capacity of the trains are 1440. Assume that when train "i" operates from station A to E, no passengers get off. We don't simulate the condition after station E. After base data set, we apply the passengers' boarding model based on multi-load factors to simulate the train's operating. The statistical information are as follows: queuing situation, number of boarding passengers, train load factor and number of stranded passengers at the platform. Results of the boarding model simulation are shown in the tables below, three consecutive trains are simulated. (QP: quening passengers. BP: boarding passengers. SP: stranded passengers. OP: passengers on the train. LF: load factor)

Table 1. Simulation results

Statistics	TRAIN 1					TRAIN 2					TRAIN 3				
	QP	BP	SP	OP	LF	QP	BP	SP	OP	LF	QP	BP	SP	OP	LF
Station A	500	490	10	490	0.34	510	500	10	500	0.35	510	500	10	500	0.35
Station B	700	650	50	1140	0.79	750	697	53	1197	0.83	753	700	53	1200	0.83
Station C	300	189	111	1329	0.92	411	254	157	1451	1.01	457	280	177	1480	1.03
Station D	300	189	111	1518	1.05	411	192	219	1643	1.14	519	242	277	1722	1.2
Station E	150	73	77	1591	1.11	227	108	119	1751	1.22	269	127	142	1849	1.28

In addition to the simulation of the boarding model, set another two model in which train capacity is fixed as 1440 (load factor 1.0) or 1872(load factor 1.3), all other conditions remaining the same.

5. Conclusions

Comparing the different models com es the conclusion that when train capacity is fixed as 1400 (load factor 1.0), at Station C the train has already been full loaded and nobody can get on the train at Station D and E. And when capacity is fixed as 1872 (load factor 1.3), the train has not been full loaded until Station E, that means all the passengers at Station C and D can get on the train when such large passengers coming continuously. The two conditions are due to the rule in which passengers won't get on the train once the number arrives the limitation, train capacity. Obviously that is far different from the actual train operating regularity and passengers boarding regularity, not conforming to the characteristic of rush hour Beijing subway network.

On the contrary, passengers boarding model based on multi-load factors are more close to the facts. Therefore, when considering the influence of train capacity on passengers' boarding selection and passenger flow distribution, it is not reasonable to set the train capacity as a fixed value. Instead, a comprehensive consideration should be given to the factors influencing passengers boarding, which can reveal the fluctuation of the limitation of train capacity. And we should analyse passengers' willingness to board for a more accurate number of boarding passengers and restrained passengers, so the train capacity can be a elastic value both in research and in reality.

Acknowledgments

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