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PASSENGER ORIGIN-DESTINATION TRAVEL TIME ESTIMATION MODEL FOR BRT

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Abstract. *In recent twenty years, Bus Rapid Transit (BRT) becomes a more and more popular public transport with high quality, high efficiency and low pollution. However, BRT is not always the first choice for passenger traveling at any time especially on rush hours, rainy days or other situations. Passenger walking time, bus dwelling time, passenger waiting time and bus running time are the four basic main segments of passenger travel time from the origin to the destination. By combining the used and revised algorithms to estimate the travel time for the four segments, a passenger travel time estimation model for BRT in Xiamen is proposed in detail. The proposed model will supply passengers with a great measurement for passenger service.*
Keywords: BRT, Travel time, Estimation, Poisson process, Model-driven

1. **Introduction.** Bus Rapid Transit (BRT) is a high-quality bus-based transit system that delivers fast, comfortable, and cost-effective services at metro-level capacities. Since the first BRT has been commenced in Kunming in 1999, BRT plays a more and more important role in Chinese public transport in recent twenty years. However, BRT is not always the best choice in any situation compared to metro, normal bus and taxi. During rush hours, an increasing number of passengers will rush into the station. Moreover, in-vehicle passengers always get off at several relatively concentrated bus stops. Such reasons lead to a serious problem that the bus will be so crowded and the capacity will be greatly decreased. As a result, few passengers could get on the crowded buses, and most of them have to increase a lot of additional waiting time. The duration of their trips will be much longer.

The aforementioned problems have been solved by many different bus dispatching optimization strategies such as controlling the number of buses, non-stopping for all bus stops, adding the reserved buses, and empty driving in [1]. Obviously, bus dispatching is not the unique solution due to many other influencing factors such as the number of boarding and alighting passengers, weather and emergencies. It is very necessary to develop a passenger travel time estimation model to provide passengers with recommendation to choose the suitable public traffic tools during different time periods.

According to travel procedure, passenger travel time could be separated into four successive segments: passenger walking time, passenger waiting time, bus dwelling time and bus running time. Historically, researches on the four segments are active. Because Xiamen's BRT uses the elevated roadways as its running roadways [2], it forces passengers to spend several minutes to enter and exit the elevated stations. As a result, it could not be ignored to consider the passenger walking time. A linear regression model of waiting time estimation quantified the differences between the perceived and the actual passenger waiting time in [3]. Taylor expansion was used to propose accurate formulas for estimating the average passenger waiting time (AWT) in [4]. Two estimation methods of passenger waiting time were presented in [5]. Bus dwelling time has been widely studied for a considerable time. Two BRT bus dwelling time models were proposed in [6]. The linear one and the nonlinear one were compared. S. Jaiswal et al. calculated the bus dwelling time by considering the effects of passenger walk time from waiting position to their bus entry door [7]. Bus running time is the time that a bus moves between two defined bus stops along a specific route. It was estimated through using the archived AVL and APC data in [8]. [9,10] proposed an integrated framework to predict the bus average travel time based on artificial neutral network by combining data from AVL services and historical data.

In summary, many researchers have been studying on passenger travel time for its importance on public transport service performance. The previous researchers have considered only one or two segments as the whole passenger travel time and discussed them separately. The contribution of this paper is to use a model-driven method to propose a passenger origin-destination travel time estimation model for BRT with a case study in Xiamen. By analyzing the relationship among the four travel time segments and the related influencing factors, the algorithms for estimating the four travel time segments are developed, respectively. The performance of passenger service has been also analyzed, which will supply passengers with a great instruction.

The remainder of this paper is organized as follows. Section 2 illustrates the passenger travel procedure. The passenger travel time estimation model and the algorithms for each segment are proposed in Section 3. An experiment is given in Section 4. Section 5 is conclusion.

2. Passenger Travel Procedure.

2. Passenger Travel Procedure. There are totally ten major steps of passenger travel procedure as shown in Figure 1. Firstly, a passenger will go to the nearest elevated bus station and wait for a bus. Once a bus gets close to the passenger's waiting bus stop, it will enter the bus stop areas soon. Due to only two berths in each station, if there are other buses parking and serving in front, the current bus has to wait at the outside of the bus stop areas. Otherwise, it will directly enter the station and serve for passengers. After the passenger gets on the bus, the bus leaves the bus stop area directly or keeps waiting at the bus stop depending on whether there is another bus parking in front of it. The passenger will be on the bus until he reaches his destination. After getting off the bus, the passenger will go downstairs and leave the elevated bus station. During the

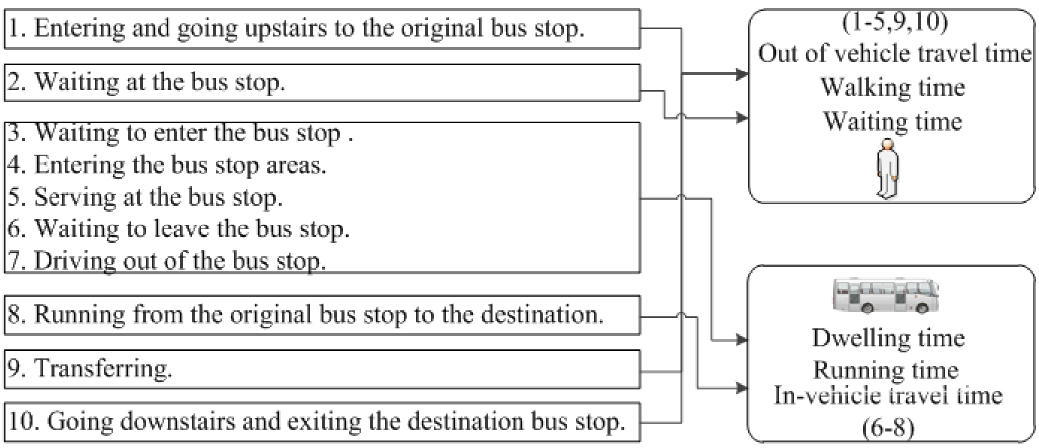

Figure 1. The passenger travel procedure of BRT

procedure, it will probably involve the walking time for transferring. In sum, we define a passenger travel time as two phases: out of vehicle travel time mainly refers to passenger walking time and passenger waiting time, and in-vehicle travel time refers to bus dwelling time and bus running time.

3. **Passenger Travel Time Estimation Model for BRT.**

3.1. **Passenger walking time estimation.** People usually take an escalator up to the bus stop platform, and leave the bus stop on foot. It means that T_{w_j} and T_{w_n} are usually constants which can be easily estimated based on the historical data. Dongfang Shanzhuang station is the only interchange station in the network of BRT in Xiamen, so passengers need to transfer at most once. The transfer time is defined as the time during the passengers getting off at Dongfang Shanzhuang station and getting on another bus at the same station in either the same or opposite direction. Totally T_{w_j}, T_{w_n} and $T_{Transfer}$ are defined as the passenger walking time shown in Formula (1).

$$T_w = T_{w_j} + T_{w_n} + T_{Transfer} \quad (j = 1, 2, \ldots, n) \tag{1}$$

where T_w is the time for passengers entering and leaving the bus stop (including transfer time); T_{w_j} is the walking time for passengers going upstairs to the original bus stop platform j; T_{w_n} is the walking time for passengers going downstairs from the final bus stop platform n; $T_{Transfer}$ is the walking time for passengers transferring.

3.2. **Bus dwelling time estimation.** Bus dwelling time is the duration of the bus waiting time and serving time at a bus stop. The BRT buses in Xiamen are driven in the special roadway with two-lane, which indicates that no bus could be overtaken by other further back buses in the queue. Furthermore, BRT buses in Xiamen have 2 or 3 doors. Passengers could board or alight at any door as they like. In other words, the waiting passengers in front of a door could not get on the bus until the in-vehicle passengers have gotten off from the same door. The formulas of bus serving time and dwelling time are shown as follows.

$$T_{bs_j} = C + \max\left[door_i(T_{PA_j} + T_{PB_j})\right] \quad (i = 1, 2, 3 \text{ and } j = 1, 2, \ldots, n) \tag{2}$$

$$T_{bd_j} = T_{bs_j} + T_{me_j} + T_{ml_j} + T_{we_j} + T_{wl_j} \quad (j = 1, 2, \ldots, n) \tag{3}$$

where T_{bs_j} is the bus service time at the bus stop j including the time of all passengers boarding and alighting, doors opening and closing; C is the dead time for opening and closing doors; T_{PA_j} is the total alighting time for all the passengers at the bus stop j; T_{PB_j} is the total boarding time for all the passengers at the bus stop j; T_{bd_j} is the bus dwelling time at the bus stop j; T_{me_j} is the time wherein that buses enter in the bus stop j; T_{ml_j} is the time wherein that buses drive out of the bus stop j; T_{we_j} is the time wherein that buses wait to enter the bus stop j; T_{wl_j} is the time wherein that buses wait to leave the bus stop j.

The number of in-vehicle passengers is a key factor to affect the time for both passengers boarding and alighting. Formula (4) is used to calculate it. If the bus is over crowded, passengers could not get on or get off very smoothly. Formulas (5) and (6) show the passenger alighting time and boarding time at each station by considering the in-vehicle crowdedness. If the value of $X_{j-1} - PM$ is negative, it indicates that the bus is not crowded. It is easier for passengers to alight or board. So the values of T_{PA_j} and T_{PB_j} will be less than the average values of $N_{PA_j} \times Ah_j$ and $N_{PB_j} \times Bq_j$, respectively. If the value of $X_{j-1} - PM$ is positive, it indicates that the in-vehicle crowding degree will be more and more serious with the increasing value of $X_{j-1} - PM$. The values of T_{PA_j} and T_{PB_j} will be more than the average values of $N_{PA_j} \times Ah_j$ and $N_{PB_j} \times Bq_j$, respectively. By considering the special situations of no passenger alighting at the first station and no passenger boarding at the final station, the subscripts of T_{PA} and T_{PB}, and range of value j in both Formulas (4)-(6) are different.

$$X_j = \begin{cases} 0 & j = 0, n \\ N_{PB_j} & j = 1 \\ X_{j-1} + (N_{PB_j} - N_{PA_j}) & 1 < j < n \end{cases} \tag{4}$$

$$T_{PA_j} = \left(1 + \frac{X_{j-1} - PM}{PM}\right) \times N_{PA_j} \times Ah_j \quad 1 \leqslant j \leqslant n \tag{5}$$

$$T_{PB_{j-1}} = \left(1 + \frac{X_{j-1} - PM}{PM}\right) \times N_{PB_j} \times Bq_j \quad 1 \leqslant j \leqslant n+1 \tag{6}$$

where X_j is the current number of in-vehicle passengers after all passengers alighting and boarding at the bus stop j; N_{PA_j} is the number of alighting passengers at bus stop j; N_{PB_j} is the number of boarding passengers at bus stop j; Ah_j is the average time of each passenger h alighting at bus stop j; Bq_j is the average time of each passenger q boarding at bus stop j; T_{PA_j} is the total passenger alighting time at bus stop j; T_{PB_j} is the total passenger boarding time at bus stop j; PM is the largest carrying capacity of a BRT bus.

3.3. **Passenger waiting time estimation.** Passengers are more sensitive to the waiting time than the in-vehicle time. The past researchers always make an assumption that every passenger will take on the first arriving bus in [4]. In fact, both of the number of in-vehicle passengers alighting and out-vehicle passengers boarding are the factors to affect the total passenger waiting time. If X_{j-1} is more, and N_{PA_j} is less, the actual number of boarding passengers will be decreasing. This will make passengers have to wait for several more minutes than a normal interval at their waiting bus stops.

In general, the passenger waiting time is a Poisson process in [11]. The expectation of total passenger waiting time during the period $[0, t)$ is shown in Formula (7). Undoubtedly, during rush hours, not all passengers could get on the first coming bus. The time of the first passenger arriving at the bus stop j does not begin from 0. Therefore, the t in Formula (7) could be defined as Formula (8) by considering the rush hours and non-rush hours. The expectation of each passenger average waiting time is shown in Formula (9), which is approximately equal to T_{pw_j}. The parameter t in Formula (9) is defined in Formula (8).

$$E(T_{tw_j}) = E\left[\sum_{i=1}^{N_{PB_j}} (t - w_i)\right] = \frac{\lambda t^2}{2} \quad 1 \le i \le N_{PB_j} \tag{7}$$

$$t = \begin{cases} t_1 - w_1 & t \in \text{rushhours [7:00-9:00am, 5:00-8:00pm]} \\ t_1 - t_{bus} & t \notin \text{rushhours} \end{cases} \tag{8}$$

$$T_{pw_j} = E(T_{pw_j}) = \frac{E\left[\sum_{i=1}^{N_{PB_j}} (t - w_i)\right]}{N_{PB_j}} = \frac{\lambda t^2}{2N_{PB_j}} \quad i = [1, N_{PB_j}] \tag{9}$$

where T_{tw_j} is total passenger waiting time at bus stop j; T_{pw_j} is the average passenger waiting time at bus stop j; t_1 is the current bus arriving time at bus stop j; w_i is the time for the i^{th} passenger arriving at bus stop j; λ is the passenger arriving rate at bus stop j; t_{bus} is the time of the former bus leaving from bus stop j; N_{PB_j} is described in Formula (4).

3.4. **Bus running time estimation.** The system uses the dedicated elevated roadways as well as dedicated lanes on bridges which allow buses to reach speed of no more than 60 km/h by considering the safety. In general, the average speed of a running BRT bus is about 55 km/h. As a result, the bus running time is formulized as follows.

$$T_{br_j} = D_{j,j+1}/V \quad (j = 1, 2, \ldots, n) \tag{10}$$

where T_{br_j} is the bus running time from bus stop j to bus stop $j+1$; $D_{j,j+1}$ is the distance between the bus stop j and bus stop $j+1$ according to bus stops' GPS data; V is the average speed of BRT buses calculated by historical data.

3.5. **Total travel time estimation.** According to the above discussion, the total passenger origin-destination estimated travel time is shown in Formula (11).

$$T_{BRT} = T_w + \sum_j^n T_{bd_j} + T_{pwj} + \sum_j^n T_{br_j} \tag{11}$$

where T_{BRT} is the total passenger travel time from the original station j to the destination station n; T_w, T_{bd_j}, T_{pw_j}, T_{br_j} are described in Formulas (1), (3), (9) and (10).

4. **Primary Experiments.** The measurement of passenger service is given in Figure 2. There are two parameters to evaluate the passenger service performance. One is the travel time and the other is the ratio of out of vehicle time and travel time. Passengers are more sensitive to the out of vehicle time especially passenger waiting time, so the ratio is a suitable value to evaluate the service performance besides the travel time.

The numbers of passengers in Wenzao and Qianpu stations are among the top five in 42 BRT stations in Xiamen. The distance between the two stations is about 8 km and covers 7 bus stops. There are 1519 records from the original station (Wenzao) to the destination station (Qianpu) on Jan. 11$^{\text{th}}$, 2016. We calculated the average values to find the real passenger travel time from the real-time automatic ticket checking dataset. The out of vehicle time is 168 seconds and in-vehicle time is 834 seconds. The estimated travel time for each segment is obtained according to the formulas proposed in our model. The time and

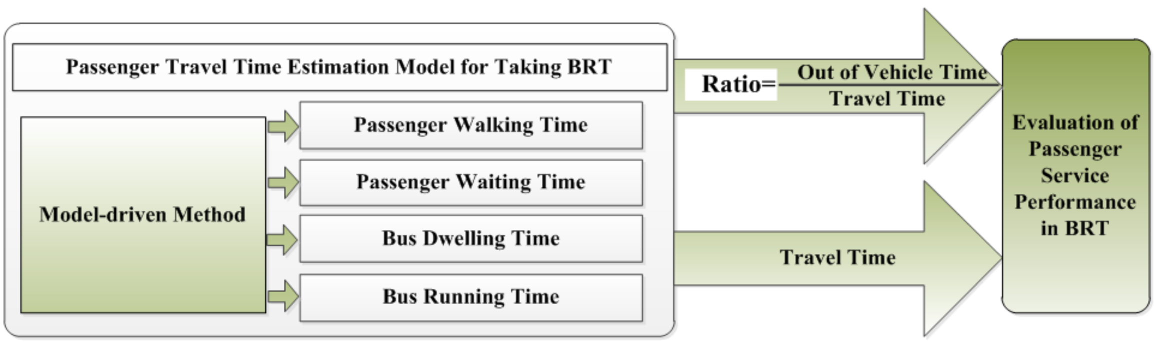

FIGURE 2. The measurement of passenger service

TABLE 1. The results of passenger travel time from Wenzao to Qianpu on Jan. 11$^{\text{th}}$, 2016

Title of Time	Out of Vehicle Time (s)		In-vehicle Time (s)		System Estimated Travel Time (s)	Average Real Travel Time (s) from Database
Item of Time	Passenger Walking Time (s)	Passenger Waiting Time (s)	Bus Running Time (s)	Bus Dwelling Time (s)		
Time (s)	118	50	524	310		
Total time (s)	168		834		1002	1023

measurement are computed to evaluate the performance of the proposed model in Table 1. The results indicated that the accuracy of estimation model is approximately equal to 98% of the average of the real travel time. In addition, the ratio (%) of out of vehicle time and travel time is 16.8% (168/1002). The ratio value is lower, which is better, because the passengers will not spend much time on walking from check-in to the front of BRT's door.

5. **Conclusion.** In the paper, the passenger origin-destination travel time estimation model is proposed in a model-driven way. To our limited knowledge, the proposed algorithms could not be the best, but it will be helpful for researchers to better understand the passenger travel time profile and develop more appropriate algorithms for their future studies with the characteristics of the actual public transport in their own cities. At last, the measurement of passenger service is proposed. We hypothesize that passengers only use a single public traffic tool for traveling. However, for some routes, they have to choose more than one public traffic tool to get to their destinations. The research on travel time estimation model with multiple traffic tools for a given trip will be a good direction. Furthermore, the estimated travel time is calculated only according to the data collection on Jan. 11$^{\text{th}}$, 2016. In order to improve the performances of the proposed model, it is a good choice to combine the proposed model with ANN or other methodologies by using more historical datasets to construct a more robust estimated model.

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