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Research Paper

A Model to Predict the Bus Dwell Time in Stations

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Abstract

The focus of this research is to develop a bus dwell time model based on formulas presented in the Highway Capacity Manual (HCM) and Transit Capacity and Quality of Service Manual (TCQSM). The dwell time model proposed in this paper not only includes factors like the number of boarding and alighting passengers, but a number of secondary factors like crowding in the bus, crowding in the station, roadway congestion, bus type, the status of bus lines, the number of alighting passengers, the number of boarding passengers, level of service of the station before passengers alighting, level of service at the bus before passengers alighting, bus type, level of service at the bus after passengers alighting, the number of bus lines passing through the station, the average headway of bus lines, and level of service of roadway are considered and taken into account in our proposed model as well. Furthermore, the developed model is validated using data collected from bus lines in Tehran, Iran. The model validation demonstrates that it has relatively good accuracy (85%) to estimate the bus dwell time. Moreover, the sensitivity analysis on the developed model indicates that increasing the number of alighting passengers and crowding at the bus has a greater effect on the dwell time than any other factors. Decrease in level of service of roadway, increase in the number of boarding passengers, crowding at the station, and decrease in the average headway of bus lines are the other important factors respectively.

Keywords: Dwell Time; Bus Lines Headway; Level of service at Station; Level of service at Bus; Level of service of Roadway

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1. Introduction

The growth and densification of the urban population have resulted in an increase in using private car as primary means of transportation which, in turn, caused increase in social costs such as traffic congestion, fuel consumption, air pollution, and accidents. Increasing the share of public transport could be a part of the solution to these problems. Public transport system consists of various modes, one of which is the urban bus transit system. Bus Transit System is of greater importance due to its high flexibility, low maintenance, and availability compared to other public modes. Public transport system offers many benefits though, ridership is an important factor that is fully depended on users' acceptance. Hence what may increase the share of the bus system is its utility. Decreasing bus travel time is one of the parameters that may lead to increasing the utility of Urban Bus system. Bus travel time consists of several parts: 1) access and walking time, 2) waiting time, 3) dwell time at the stations, and 4) travel time on the line segments. Therefore, one of the factors reducing travel time which may lead to increase the utility of the bus system is the dwell time at stations. The bus stop is the first and closest point of contact between passengers and the city bus service. The dwell time at stations is one of the most important parameters in bus performance and reliability.

Dwell time is defined as "the amount of time a bus spends while stopped to serve passengers. When buses operate in mixed traffic and stop in travel lane, the reduction in the roadway capacity is directly related to the amount of time the buses stop. It is the time required to serve passengers at the busiest door plus the time require to open and close the doors"(Highway Capacity Manual, 2000). In other words, the dwell time includes the arrival time at the bus stop, the stop time for passengers alighting and boarding, and the departure time from the station and entry into the traffic flow. Increasing the dwell time at the station increases traffic congestion as well as creating long queues and wasting passengers' time. Thus, reducing the waiting time of passengers or the dwell times at the bus station saves time and reduces travel costs, which in turn increases the utility of the bus system and ultimately the share of public transport. Furthermore, the dwell time model is also necessary for the public transport assignment and should be applied in the transportation modeling software. Therefore, in this paper, due to the importance of this issue, the development of a model for the bus dwell time prediction and its effective parameters are discussed.

The remainder of this paper is organized as follows: Section 2 provides an overview of previous studies on this subject; in Section 3, the methodology and process of the model development, the effective variables, and the general form of the model are presented; The data collection and database formation, process of model development and its validation are presented in Section 4; and finally, Section 5 summarizes the main findings of the study.

Table 1 lists the abbreviations used in this paper and their corresponding meanings.

2. Literature Review

Numerous models and methods have been developed and adopted to estimate bus dwell time., including statistical methods (regression analysis, time-series) and machine learning techniques such as artificial neural network and support vector machines.

As part of a comprehensive transportation plan for Tehran, Aashtiani and Iravani developed two types of models (aggregated and disaggregated depending on the data used for model calibration) to estimate the time a transit vehicle spends to allow passengers to board and alight. Various parameters including the number of passengers in a transit vehicle prior to stop, divided by vehicle capacity, and number of doors designated for boarding and alighting were introduced in the proposed models. They have calibrated each model for each bus type as well (Aashtiani & Iravani, 2002). Rajbhandari et al developed two linear regression models and two nonlinear regression models for the dwell time with single and multiple independent variables such as number of boarding and alighting passengers and the number of standing passengers. Among these four models, Multivariate Nonlinear Model outperformed the other models. The results showed that the number of passengers served is the key variable that has a major influence on bus dwell time. Though, the inclusion of other variables such as number of doors and fare collection methods (Rajbhandari et al., 2003). Jaiswal et al. investigated the effects of passengers walking on a relatively longer BRT station platform. They found out that the average walking time of a passenger at a BRT platform is 10 times more than that of a bus stop, which led to higher bus dwell times for a BRT system (Jaiswal et al., 2010). Zhang and Teng proposed a dynamic dwell time prediction model based on Automatic Vehicle Location (AVL) and Automatic Passenger Counters (APC) dynamic data that provide real-time information on bus arrival times. They have introduced and included factors such as the number of passengers boarding and alighting and some secondary factors like crowding and fare collection method in their developed model (Zhang & Teng, 2013).

Table 1. A List of Aberration and their Meanings

Abbreviations	Meaning	Abbreviations	Meaning
t_d	Dwell time	BLOSB	Level of Service at the Bus before Passengers Alighting
P_a	The Total Number of Alighting Passengers per Bus through Busiest Door (p)	BLOSA	Level of Service at the Bus after Passengers Alighting
P_b	The Total Number of Boarding Passengers per Bus through Busiest Door (p)	SLOS	Level of Service at the Station before Passengers Alighting
NC	The Number of passing channels that equal to the allocated width for passing each passenger	FTYPE	Type of Fare Collection Method
t_a	The Time of Passenger Alighting (s/p)	SLOC	Status of Station Location
t_b	The Time of Passenger Boarding (s/p)	RLOS	Level of Service of Roadway
t_{oc}	The Time Required for Entry to and Exit from the Station and Doors Opening and Closing (s)	PARK	Status of On-street Park
h_n	The Headway of n^{th} bus line passing through the station	BROW	Type of Bus Line
STYPE	Station Type	SPOS	Status of Station Position at the Roadway
BTYPE	Bus Type	Land-use	status of the Adjacent Land-uses in the Distance of 100 meter
BOWN	Bus Ownership	BLPS	Number of Bus Lines passing through the Station
BAGE	Bus Life	BLH	Average Headway of Bus Lines
FLOC	Fare Payment Location	--	--

Arhin et al developed regression models for the Washington Metropolitan Area bus transit system in the District of Columbia. Their findings showed that the dwell time on bus routes in dense urban areas varies by time-of-day and therefore bus stop location and time of the day could be considered as contributing factors to the dwell time of the bus (A Arhin & Noel, 2015). Xin and Chen developed a dynamic model to predict bus dwell time at bus stops using real-world data. Their model based on the k-Nearest Neighbor (KNN) algorithm using history and current data collected by GPS devices fixed on buses. They have compared their proposed model with two other methods. The results indicated that their model had a better performance in predicting bus dwell time (Xin & Chen, 2016). Mahdavilayen et al adopted Monte Carlo method and simulated the dwell time in order to investigate the impacts of the combination of bus boarding conditions and wheelchair users on bus dwell time and headway/bus schedule adherence. In order to evaluate the impact of individuals with disabilities in a bus transit system under different traffic conditions, they have also employed microscopic traffic simulation. Their findings showed that bus dwell time can be significantly influenced by the percentage of wheelchairs who board at a specified bus stop. According to the results of this study, assisting the participant during ascending the ramp, an 11-cm curb boarding ramp as opposed to a ramp deployed at street level, mid-entry, and exit layout configuration and also using an automated securement system instead of the traditional 4-point securement system are some factors that may reduce the boarding time of wheelchair users (Mahdavilayen et al., 2020). Bie et al generated and developed two statistical models so as to investigate the impacts of bus crowding level on bus dwell time. They have manually collected data along two major bus routes in Harbin, China. According to Bie et al, the accuracy of bus dwell time estimation could be vastly improved by introducing carriage crowding level into the estimation model. They have suggested that the total amount of time used for opening and closing bus doors, as well as passenger preparation time, could influence the bus dwell time as well (Bie et al., 2020). Chen et al. developed and introduced a linear regression model to study the effect of disorder, in the form of the number of queues, on bus dwell time. The number of boarding passengers, the number of passenger queues, the maximum queue length, the number of passengers jumping in the queue, the number of alighting passengers at the front door, whether the vehicle docked in the bus berth, and the degree of in-vehicle congestion are seven influencing factors that were introduced as independent variables in their model. The results show that when boarding passengers are organized by two queues, the service time per passenger decreased by about 16.88% in comparison to when passengers are organized by a single queue (Chen et al., 2020).

3. Methodology and Research Process

3.1. Model Development Process

The process of model development is shown in Figure 1. As can be seen in this figure, the model development process involves the following steps:

1) Identifying and choosing the important independent variables,
2) Data collection and database formation,
3) Choosing the general form of the model,
4) Model calibration and processing by statistical tests,
5) Model validation with the observed data,
6) Model discussion

3.2. Effective Variables

As shown in the model development process, the first step in processing an appropriate model is to identify the effective variables in the dwell time at the bus stations. Based on various sources and field observations, variables such as “station type”, “average headway of bus lines”, “number of bus lines passing through the station”, “number of bus doors”, “width of bus doors”, “bus type”, “bus ownership”, “bus life”, “number of boarding passengers”, “number of alighting passengers”, “number of male and female passengers”, “level of service of the station before passengers alighting”, “level of service at the bus before passengers alighting", "level of service at the bus after passengers alighting", "number of disabled passengers", "type of fare collection method", "fare payment location", "status of station location", "level of service of roadway", "status of the on-street park", "type of bus line", "station position at the roadway", "station dimension", and "status of adjacent land use" can be introduced as the important factors in bus dwell time at the station.

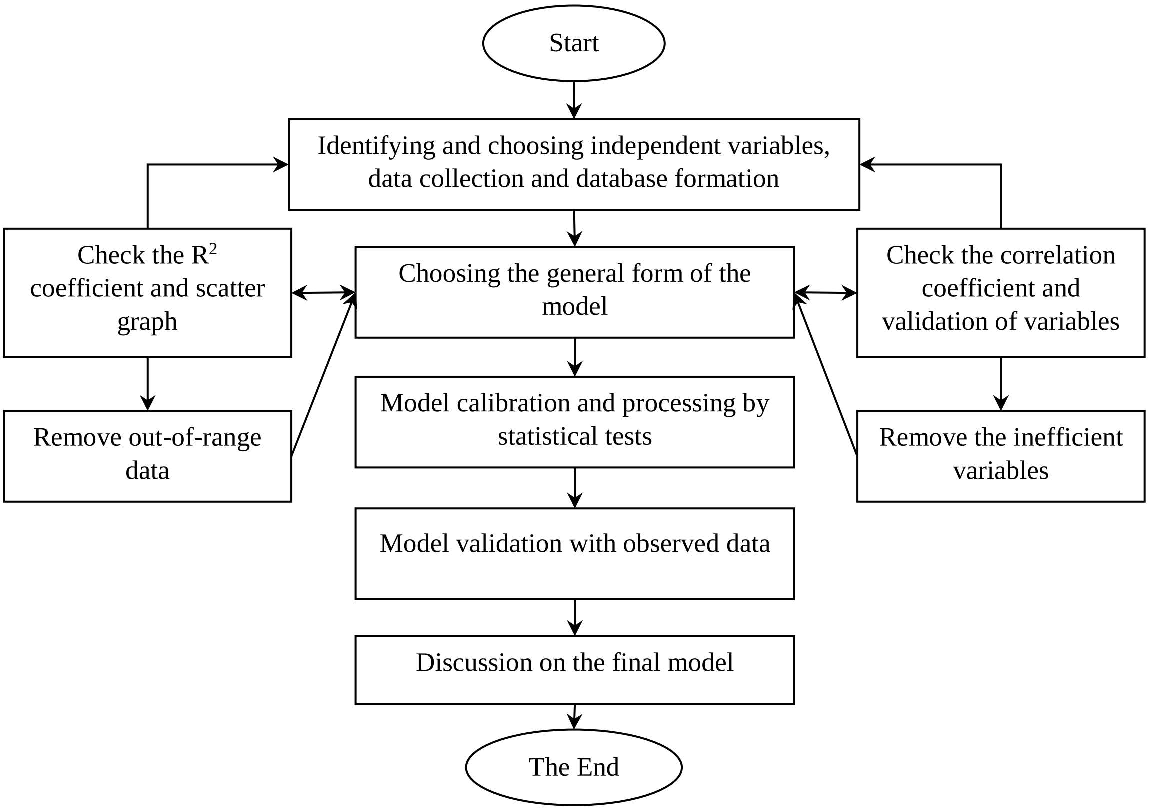

Figure 1. Model Development Process

Examination of the mentioned factors indicates that some of the above variables, which are often used to describe the station's environmental conditions, have a qualitative nature. Since one of the most important criteria in selecting the appropriate variable is their quantification capability, quantification of the identified qualitative variables is necessary. Therefore, variables that may not be quantify eliminated from the list of variables. Among the identified variables, variables such as "station type", "bus type", "bus ownership", "bus life", "type of fare collection method", "fare payment location", "station location", "level of service at the bus before passengers alighting", "level of service at the bus after passengers alighting", "level of service of the station before passengers alighting", "level of service of roadway", "status of the on-street park", "type of bus line", "station position at the roadway", and "status of the adjacent land-uses" have a qualitative nature that can be quantified by classification. Accordingly, quantification of these variables is presented below.

- Station type (STYPE): This variable is equal to zero (0) if the station has a platform and one (1) otherwise.
- Bus type (BTYPE): This variable is equal to one (1) if the bus is an articulated bus and zero (0) otherwise.
- Bus ownership (BOWN): This variable is equal to one (1) if the bus belongs to the private sector and zero (0) otherwise.
- Bus life (BAGE): This variable is equal to one (1) if the bus is worn out and zero (0) otherwise.

- Level of service at the bus before passengers alighting (BLOSB): This variable is equal to zero (0) If the bus space before passengers alighting is acceptable and one (1) otherwise.

Based on the assessments in various sources, the level of service (LOS) at the station and the bus is expressed by the area index per passenger, but the standard ranges of values for each level of service are very different. In other words, the quantitative and qualitative criteria for this index are different based on regulations and standards. In this study, we use the TCQSM standards that propose the following criteria for different levels of service based on the area index:

1) Suitable space: This space is equal to 0.5 square meters per person that provides relatively comfortable conditions.
2) Tolerable space: This space is equal to 0.35 square meters per person, which is the lower limit of space intended for the system.
3) Unbearable space: This space is equal to 0.20 square meters per person, which is the least space that can sometimes occur.

Accordingly, the BLOSB is equal to zero (0) if the space allocated to each passenger exceeds 0.35 square meters, the space allocated will be considered acceptable and one (1) otherwise.

- Level of service at the bus after passengers alighting (BLOSA): This variable is equal to zero (0) if the allocated space for passengers at the bus after alighting and before boarding passengers is acceptable (more than 0.35 square meters) and one (1) otherwise.
- Level of service at the station before passengers alighting (SLOS): This variable is equal to zero (0) if the allocated space for passengers at the station before passengers alighting is acceptable (more than 0.35 square meters) and one (1) otherwise.
- Type of fare collection method (FTYPE): This variable is equal to one (1) if the fare is paid in cash and zero (0) otherwise.
- Fare payment location (FLOC): This variable is equal to one (1) if the fare is paid during passengers boarding and alighting at the bus and zero (0) otherwise.
- Status of station location (SLOC): This variable is equal to one (1) if the station is located on-street and zero (0) otherwise.
- Level of service of roadway (RLOS): This variable is equal to zero (0) if the roadway adjacent to the station has an “A” to “C” service level and one (1) otherwise.
- Status of the on-street park (PARK): This variable is equal to one (1) if the possibility of on-street park near the station is permitted and zero (0) otherwise.
- Type of bus line (BROW): This variable is equal to zero (0) if the type of bus line is Right of Way (ROW) “A” or “B” (divided lane) and one (1) otherwise.
- Status of station position at the roadway (SPOS): This variable is equal to one (1) if there is an intersection in the distance of 50 meters after the station and zero (0) otherwise.
- Status of the adjacent land-uses (Land-use): This variable is equal to one (1) if there are dense land-uses with the ability to generate trips such as office, commercial and residential in the distance of 100 meters of the station and zero (0) otherwise.

Moreover, since the impossibility of predicting passenger’s type based on gender (male and female) and ability (older people, children, etc.), these variables are neglected in the model development process.

3.3. The General Form of Proposed Model

One of the most important issues in model development is the general form of the model. In this study, we consider the formulas presented in the Highway Capacity Manual (HCM) and Transit Capacity and Quality of Service Manual (TCQSM) as Equation (1) (Highway Capacity Manual, 2000)(Associates et al., 2003).

$$t_d = P_a t_a + P_b t_b + t_{oc} \quad (1)$$

As Equation (1) shows, the influential variables are categorized into three groups, as follows:

1) The variables related to the number of alighting and boarding passengers from the busiest door, that are distributed uniformly across all doors due to the lack of knowledge of the spatial distribution of the arrival and departure of passengers. It should be noted that due to the width of the existing bus doors which is not allow more than one passenger to board or alight in each passing channel at once, the effect of door widths is therefore ignored.
2) Predictor variables of boarding and or alighting time, mentioned in the Highway Capacity Manual (HCM 2000), are independent of the status of the transit demand and may be studied according to the type of bus, the position of the doors, and the type of fare collection (Highway Capacity Manual, 2000).
As mentioned, the time required to board and alight in addition to those provided in the HCM depends on the performance characteristics of the lines and stations and the condition of the passengers in them. Table 2 presents the factors affecting passenger boarding and or alighting time.

Table 2. The Variables Affecting Passengers Boarding and Alighting Time

passenger boarding time	passenger alighting time
Station type	Station type
Number of bus lines passing through the station	Bus type
Bus ownership	Level of service of the station before passengers alighting
Level of service at the bus after passengers alighting	Level of service at the bus before passengers alighting
Status of the adjacent land uses	Type of fare collection method
--	Fare payment location

Finally, the relationship between time of passengers alighting and boarding can be considered as a function of different variables in accordance with general Equations (2) and (3).

$$t_a = f_1(STYPE, BTYPE, BLOSB, FTYPE, FLOC) \quad (2)$$

$$t_b = f_2(STYPE, BLPS, BOWN, BLOSA, Land-use) \quad (3)$$

The variables related to the minimum time required for a bus to enter the station and or complete its departure from the station, which are independent of the alighting and boarding demand and operating status of the station and line. Since this time is the sum of time required to bus enter to and exit from the station and the time required to operate the door opening and closing mechanism, it depends entirely on the environmental characteristics of the station as well as the status and facilities of the fleet.
Finally, the variables such as "average headway of bus lines", "bus life", "status of station location", "level of service of roadway", "status of the on-street park", "type of bus line" and "status of station position at the roadway" can be identified as the most important variables affecting the time required to start the bus entrance process to the station and complete the departure process from the station are considered as a function of various variables according to Equation (4).

$$t_{oc} = f_3(BLH, BAGE, SLOC, RLOS, PARK, BROW, SPOS) \quad (4)$$

It should be noted that Equation (5) is used to determine the average headway of bus lines at a station.

$$\mathrm{BLH} = \frac{1}{\frac{1}{h_1} + \frac{1}{h_2} + \ldots + \frac{1}{h_n}} \quad (5)$$

Thus, by placing Equations (2) to (4) in Equation (1), the total equation of the bus dwell time at the station can be presented in Equation (6).

$$t_d = \frac{P_a}{NC} f_1(\mathrm{STYPE}, BTYPE, \mathrm{SLOS}, BLOSB, \mathrm{FTYPE}, \mathrm{FLOC}) + \frac{P_b}{NC} f_2(\mathrm{STYPE}, BLPS, \mathrm{BOWN}, BLOSA, \text{Land-use}) + f_3(BLH, \mathrm{BAGE}, \mathrm{SLOC}, RLOS, \mathrm{PARK}, \mathrm{BROW}, SPOS) \quad (6)$$

3.4. Calculating the Sample Size

Due to the impracticality of accurately estimating the exact number of stops at bus stations all over the city on a given day, we decided to apply the standard formula for sample size calculation typically used for infinite populations, without considering the finite population correction. Using this approach, we calculated the sample size for a 95% confidence level and a 7%margin of error by Equation (7). The resulting sample size was 197, which was subsequently rounded up to 200.

$$S = \frac{Z^2 \times P \times (1 - P)}{d^2} \qquad (7)$$

Where S is the required sample size; Z is the Z-score corresponding to the confidence level (for a 95% confidence level, Z = 1.96); P is the assumed proportion (0.5 for maximum variability); and d is the margin of error (here, equal to 7%).

4. Model Development

4.1. Data Collection

The first step in the model development process involved data collection through field surveys. These surveys were conducted at 20 bus stations, comprising 12 street-level bus lines and 8 Bus Rapid Transit (BRT) stations, during both peak and off-peak times. Figure 2 illustrates the locations of the surveyed stations in Tehran.

Data collection was performed by two individuals: one used a chronometer to record the dwell time, as well as the times of passenger boarding and alighting, while the other gathered various additional parameters, such as the number of passengers waiting at the station, the number of passengers boarding and alighting, the number of doors in use, the crowding level, the type of bus, the type of station, the fare collection method, among other factors. Subsequently, the compiled data were entered into an MS Excel spreadsheet. Based on the calculated sample size, a numerical database consisting of 200 records was created.

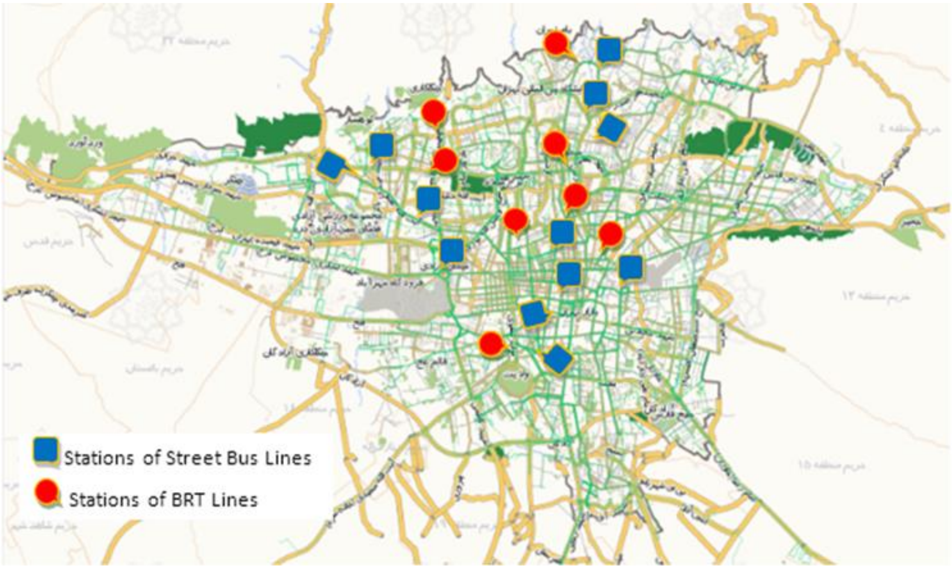

Figure 2. The Location of the surveyed Stations based on the Bus Line Type in Tehran

4.2. Choosing the Proper Variables

Choosing proper variables for model development is related to their effectiveness and independence, which is done through the variable correlation matrix. Thus, the variables that have a higher correlation with the dependent variable have a higher priority for entering the model. Moreover, the simultaneous use of variables with high correlation to each other should be avoided.

Table 3 shows the correlation matrix of the effective variables. As can be seen from this table, the variables such as “bus type (BTYPE)”, “number of bus lines passing through the station (BLPS)”, “level of service of the station before passengers alighting (SLOS)”, “level of service at the bus before passengers alighting (BLOSB)”, “level of service at the bus after passengers alighting (BLOSA)”, “average headway of bus lines (BLH)”, “bus life (BAGE)” and “level of service of roadway (RLOS)” are highly dependent on dwell time (t_d) variable. Therefore, these variables can be considered as the primary list of independent variables for entering the bus dwell time model at the station.

Table 3. The Correlation Matrix of Variables

Variables	t_d	STYPE	BTYPE	BOWN	BLPS	SLOS	BLOSB	BLOSA	FLOC	Land-use	BLH	BAGE	SLOC	RLOS	PARK	BROW	SPOS
t_d	1	0.38	0.57	0.33	0.64	0.77	0.73	0.67	0.19	0.42	0.81	0.71	0.34	0.62	0.41	0.38	0.31
STYPE		1	0.34	0.24	0.19	0.34	0.20	0.28	-0.33	0.22	0.21	0.12	0.37	0.24	0.08	0.52	0.18
BTYPE			1	0.17	0.29	0.39	-0.21	-0.16	0.10	0.16	0.11	0.10	0.22	0.16	0.11	-0.30	0.13
BOWN				1	0.21	0.20	0.26	0.24	0.19	0.17	0.09	-0.36	0.10	0.16	0.16	0.11	0.22
BLPS					1	-0.16	0.23	0.41	0.19	0.10	-0.27	0.07	0.13	0.16	0.03	0.10	0.32
SLOS						1	0.12	0.21	0.33	0.13	0.31	0.24	0.31	0.16	0.11	0.09	0.15
BLOSB							1	0.31	0.11	0.15	0.13	0.25	0.11	0.16	0.19	0.20	0.20
BLOSA								1	-0.14	0.06	0.08	0.11	0.14	0.16	0.15	0.26	0.18
FLOC									1	0.13	0.23	0.18	0.27	0.16	0.22	0.28	0.09
Land-use										1	0.06	0.08	0.26	0.16	0.19	0.16	0.12
BLH											1	0.05	0.06	0.16	0.11	0.13	0.17
BAGE												1	0.10	0.16	0.18	0.12	0.23
SLOC													1	0.38	0.33	0.15	0.35
RLOS														1	0.09	0.11	0.15
PARK															1	0.17	0.10
BROW																1	0.21
SPOS																	1

4.3. Model Calibration

Before model development, the database was randomly divided into two data sets, the first set for model calibration (including 140 records) and the second set for model validation (including 60 records). Then, based on the conceptual relationship presented in the HCM and correlation matrix, the proposed model is developed and processed in accordance with the general Equation (8).

$$t_d = \frac{P_a}{NC} f_1(\text{BTYPE,SLOS}, BLOSB) + \frac{P_b}{NC} f_2(BLOSA,\text{BLPS}) + f_3(BLH,\text{BAGE,RLOS}) \quad (8)$$

Moreover, we assumed that there is a linear relationship between functions f_1, f_2, f_3. Therefore, Equation (8) is converted into Equation (9) which is used for model calibration.

$$t_d = c_0 + c_1 BLH + c_2 \text{SLOS} \frac{P_a}{NC} + c_3 \text{BLOSB} \frac{P_a}{NC} + c_4 \text{BAGE} + c_5 \text{BLOSA} \frac{P_b}{NC} + c_6 BLPS \frac{P_b}{NC} + c_7 RLOS + c_8 \text{BTYPE} \frac{P_a}{NC} \quad (9)$$

Then, based on a trial-and-error analysis, the most efficient model is developed by entering the most appropriate variables into the model and evaluating the model through statistical tests using SPSS.in the first step, the variable with the highest correlation with the dwell time variable used to calibrate the model. Then, the model was evaluated through statistical tests. As a result, the input variable may be accepted or rejected. in the next step and based on the correlation matrix, the new variable was added to the model, and the new model was evaluated through statistical tests. This process continued until all the remaining variables were added and evaluated.

Table 4 presents the results of all stages of the model developing process according to the described method.

Equation (10) shows the finalized equation for the proposed model to predict bus dwell time at the station.

$$t_d = 7.71 + 25.02\text{BL} + 0.98\text{SLOS} \frac{P_a}{NC} + 0.93 BLOSB \frac{P_a}{NC} + 1.03 BLOSA \frac{P_b}{NC} + 0.36 BLPS \frac{P_b}{NC} + 22.18 RLOS + 1.14 BTYPE \frac{P_a}{NC} \quad (10)$$

Table 4. All Stages of the Model Developing Process

		Model No.							
		1	2	3	4	5	6	7	8
Variables	BLH	√	√	√	√	√	√	√	√
	$\text{SLOS}\frac{P_a}{NC}$		√	√	√	√	√	√	√
	$\text{BLOSB}\frac{P_a}{NC}$			√	√	√	√	√	√
	BAGE				√				
	$\text{BLOSA}\frac{P_b}{NC}$					√	√	√	√
	$\text{BLPS}\frac{P_b}{NC}$						√	√	√
	RLOS							√	√
	$\text{BTYPE}\frac{P_a}{NC}$								√
R^{2a}		0.591	0.632	0.651	0.659	0.693	0.716	0.742	0.769
Sig. F		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C_0		10.94	10.11	8.32	8.72	8.10	8.10	8.00	7.71

	Model No.							
	1	2	3	4	5	6	7	8
Sig. T	0.026	0.035	0.026	0.034	0.035	0.039	0.036	0.030
C_1	32.25	34.63	30.78	28.39	27.49	26.32	25.36	25.02
Sig. T	0.048	0.043	0.022	0.028	0.018	0.018	0.016	0.028
C_2		1.21	1.13	1.13	1.11	1.11	1.01	0.98
Sig. T		0.036	0.042	0.033	0.033	0.036	0.022	0.036
C_3			1.02	1.12	1.01	1.01	0.97	0.93
Sig. T			0.023	0.026	0.045	0.029	0.036	0.016
C_4				1.09				
Sig. T				0.036				
C_5					1.16	1.16	1.07	1.03
Sig. T					0.038	0.025	0.039	0.032
C_6						0.41	0.39	0.36
Sig. T						0.039	0.038	0.045
C_7							23.56	22.18
Sig. T							0.040	0.038
C_8								1.14
Sig. T								0.036

4.4. Model Validation

As mentioned before, in order to validate the model one dataset with 60 records has been created. To validate the proposed model, the estimations of the model compared with the observations. As shown in Figure 3, the dispersion of observed data and model estimation around the x=y line indicates that the proposed model has relatively good accuracy (85%) in estimating the bus dwell time at the station.

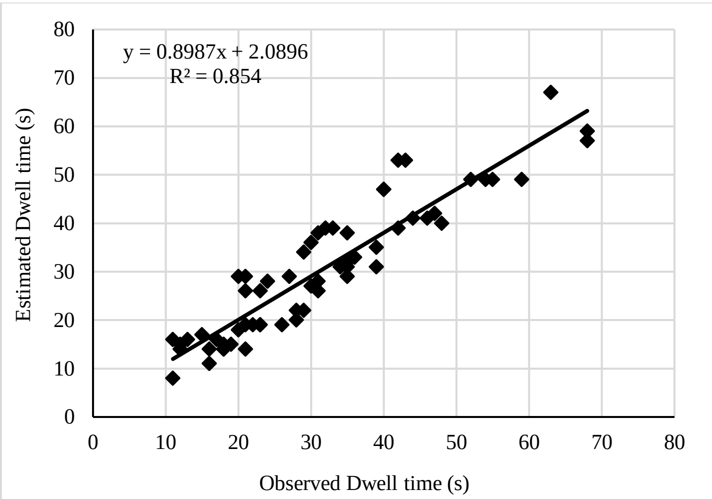

Figure 3. Validity of the Model, Based on Observations and Model Estimation

4.5. Proposed Model

Finally, based on the functions suggested in HCM and TCQSM, the bus dwell time model can be presented by Equation (11).

$$t_d = 7.71 + \frac{P_a}{NC}[0.98\text{SLOS} + 0.93BLOSB + 1.14\text{BTYPE}] + \frac{P_b}{NC}[1.03BLOSA + 0.36BLPS] + 25.02BLH + 22.18RLOS \quad (11)$$

Examination of the final model to predict the bus dwell time shows that:

1) The following variables are effective for estimating the passengers alighting time:

- The average number of alighting passengers through each passing channel (p),
- Level of service of the station before passengers alighting,
- Level of service at the bus before passengers alighting, and
- Bus type.

2) The following variables are effective for estimating the passengers boarding time:

- The average number of boarding passengers through each passing channel (p),
- Level of service at the bus after passengers alighting, and
- The number of bus lines passing through the station.

3) The following variables are effective for estimating the time required for a bus to enter and or exit the station and to open and close the doors:

- Number of bus lines passing through the station, and
- Average headway of bus lines.

Furthermore, for further discussion on the final model, we have considered 6 different scenarios as follow:

1) In case 1 (Base) it is supposed that:

- There is no alighting passenger on the bus.
- There is no boarding passenger at the station.
- There is no crowding at the bus, i.e., the level of service at the bus is acceptable.
- There is no crowding at the station, i.e., the level of service at the station is acceptable.
- There is no congestion at the roadway, i.e., the level of service of roadway is acceptable.
- There is no conflict between buses to enter the station, i.e., the average headway of bus lines is high.

In other words, in the base case scenario, the situation is suitable and is equivalent to the minimum dwell time at the station.

2) In case 2 we supposed that:

- There is no alighting passenger at the bus.
- There is no boarding passenger at the station.
- There is no crowding at the bus, i.e., the level of service at the bus is acceptable.
- There is no crowding at the station, i.e., the level of service at the station is acceptable.
- There is no congestion at the roadway, i.e., the level of service of roadway is acceptable.
- There is a conflict between buses to enter the station, i.e., the average headway of bus lines is low.

In other words, in this case, compared to the base case scenario, the average headway of bus lines is low and there is a conflict between buses to enter the station.

3) In case 3 it is supposed that:

- There is no alighting passenger at the bus.
- There are many boarding passengers at the station.
- There is no crowding at the bus, i.e., the level of service at the bus is acceptable.
- There is crowding at the station, i.e., the level of service at the station is not acceptable.
- There is no congestion at the roadway, i.e., the level of service of roadway is acceptable.
- There is no conflict between buses to enter the station, i.e., the average headway of bus lines is high.

In other words, in comparison to the base case scenario, the number of boarding passengers is high, and the station is crowded as well.

4) In case 4 it is supposed that:

- There are many alighting passengers at the bus.
- There is no boarding passenger at the station.
- There is crowding at the bus, i.e., the level of service at the bus is not acceptable.
- There is no crowding at the station i.e., the level of service at the station is acceptable.
- There is no congestion at the roadway, i.e., the level of service of roadway is acceptable.
- There is no conflict between buses to enter the station, i.e., the average headway of bus lines is high.

In other words, in comparison to the base case scenario, number of alighting passengers is high and the bus is crowded as well.

5) In case 5 it is supposed that:

- There is no alighting passenger at the bus.
- There is no boarding passenger at the station.
- There is no crowding at the bus i.e., the level of service at the bus is acceptable.
- There is no crowding at the station, i.e., the level of service at the station is acceptable.
- There is congestion at the roadway, i.e., the level of service of roadway is not acceptable.
- There is no conflict between buses to enter the station, i.e., the average headway of bus lines is high.

In other words, compared to the base case scenario, the level of service of roadway is undesirable.

6) In case 6 it is supposed that:

- There are many alighting passengers on the bus.
- There are many boarding passengers at the station.
- There is crowding at the bus, i.e., the level of service at the bus is not acceptable.
- There is crowding at the station, i.e., the level of service at the station is not acceptable.
- There is congestion at the roadway, i.e., the level of service of roadway is not acceptable.
- There is a conflict between buses to enter the station, i.e., the average headway of bus lines is low.

In other words, compared to the base case scenario, all situations are undesirable.

Then, based on the developed model, we estimated the dwell time for all 6 scenarios. The results are presented in Table 5.

Comparison of six scenarios shows that:

1) The minimum dwell time is 10 seconds.

2) By decreasing the average headway of bus lines, the dwell time will increase from 10 seconds to 14 seconds.

3) By increasing the boarding passengers and crowding at the station, the dwell time will increase from 10 seconds to 16 seconds.

4) By increasing the alighting passengers and crowding at the bus, the dwell time will increase from 10 seconds to 46 seconds.

5) By increasing in roadway congestion, the dwell time will increase from 10 seconds to 32 seconds. In other words, 22 seconds will be added to the minimum dwell time.

6) The maximum dwell time is 114 seconds (applying cases 2, 3, 4, 5). In other words, 104 seconds will be added to the minimum dwell time.

Table 5. Comparison of Different Situations

Time	Case 1 (Base)	Case 2	Case 3	Case 4	Case 5	Case 6
Alighting Time (s)	0	0	0	36	0	53
Boarding Time (s)	0	0	6	0	0	24
Time required for entry to and exit from station and doors opening and closing (s)	2	6	2	2	24	28
Dwell Time (s)	10	14	16	46	32	114

The sensitivity analysis of the final model shows that increasing the number of alighting passengers and crowding at the bus (scenario no.4) has a greater effect on the dwell time. decreasing the level of service of roadway (scenario no.5), increasing the number of boarding passengers and crowding at the station (scenario no.3), and decreasing the average headway of bus lines (scenario no.2) are respectively critical.

5. Discussion

5.1. Practical Applications of the Proposed Model

Our proposed model can significantly enhance the accuracy of travel time estimates in public transit systems. By incorporating more precise dwell time predictions, the model helps adjust total travel time calculations, reflecting real-world conditions more accurately. This is particularly useful for improving transit assignment processes, as it enables a more realistic representation of how buses interact with traffic, passenger flow, and other variables at stops. Once the transit assignment and real travel times are calibrated, transportation authorities can begin implementing the practical solutions provided by the model. These include adjustments to critical parameters such as the number and type of buses in service, as well as the design and layout of bus stations. By fine-tuning these factors based on the calibrated travel times, local governments can improve bus operations, reduce delays, and enhance the overall passenger experience. Adjustments to the number of buses, bus type specifications, and station design—such as platform size, fare payment method and boarding processes—can be aligned with demand fluctuations and operational needs. This flexibility ensures that the public transport system remains responsive to evolving urban dynamics, thus promoting more efficient operations and improved service delivery.

5.2. Balancing Complexity and Practicality in the Proposed Model

While simpler models may be more practical in certain contexts, they often fall short in terms of predictive accuracy. Our model, though more complex than some previously proposed models in the existing literature, has been specifically designed to improve accuracy in travel time calculations by incorporating more detailed factors and parameters, such as variations in dwell time and real-time passenger flow. This added complexity allows the model to capture a more realistic representation of transit conditions, which enhances its overall predictive performance. At the same time, we have taken careful steps to mitigate the risk of overfitting, employing techniques like cross-validation and regularization during model calibration. These safeguards ensure that the model remains generalizable to different transit systems and does not become overly tailored to specific datasets, thereby maintaining its practical applicability. We are confident that our proposed model meets both ends—offering the necessary complexity to improve predictive accuracy while remaining practical for real-world application.

6. Conclusions

The dwell time at stations is one of the most important parameters in bus performance and reliability. Thus, reducing the dwell time at the station saves time and reduces travel costs, which in turn increases the utility of the bus system and ultimately the share of public transport. Therefore, in this paper, a model is developed to predict the bus dwell time based on formulas presented in the Highway Capacity Manual (HCM) and Transit Capacity and Quality of Service Manual (TCQSM). The dwell time model developed in this paper not only includes the number of passengers boarding and alighting but also considers other factors like crowding in the bus, crowding in the station, roadway congestion, bus type, the status of bus lines, and so on. number of alighting passengers, number of boarding passengers, level of service of the station before passengers alighting, level of service at the bus before passengers alighting, bus type, level of service at the bus after passengers alighting, the number of bus lines passing through the station, the average headway of bus lines, and level of service of roadway are all taken into account in the model. Furthermore, the proposed model is validated with the data of bus lines in Tehran, Iran. The model validation shows that the proposed model has relatively good accuracy (85%) in estimating the bus dwell time at the station.

Moreover, investigation of the final proposed model shows that:

1) The variables such as the average number of alighting passengers through each passing channel, level of service of the station before passengers alighting, level of service at the bus before passengers alighting, and bus type

have a meaningful effect on estimating the passengers alighting time.

2) The variables such as the average number of boarding passengers through each passing channel, level of service at the bus after passengers alighting, and the number of bus lines passing through the station have a meaningful effect on estimation of the passengers boarding time.

3) The variables such as number of bus lines passing through the station and average headway of bus lines have meaningful effect on estimation of the time required for entry to and exit from the station and door opening and closing.

Furthermore, the sensitivity analysis on the final model shows that increasing the number of alighting passengers and crowding at the bus has a greater effect on the dwell time. decreasing the level of service of roadway, increasing the number of boarding passengers, crowding at the station, and decreasing the average headway of bus lines are respectively important.

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