CALIBRATION OF HIGHWAY/TRANSIT SPEED RELATIONSHIPS FOR IMPROVED TRANSIT NETWORK MODELING IN FSUTMS

Final Report
Contract No. BD015-07

Prepared for
Research Office
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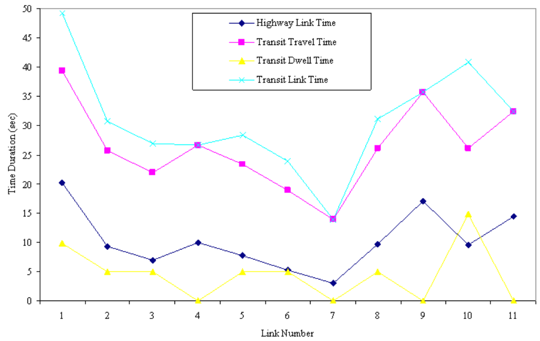

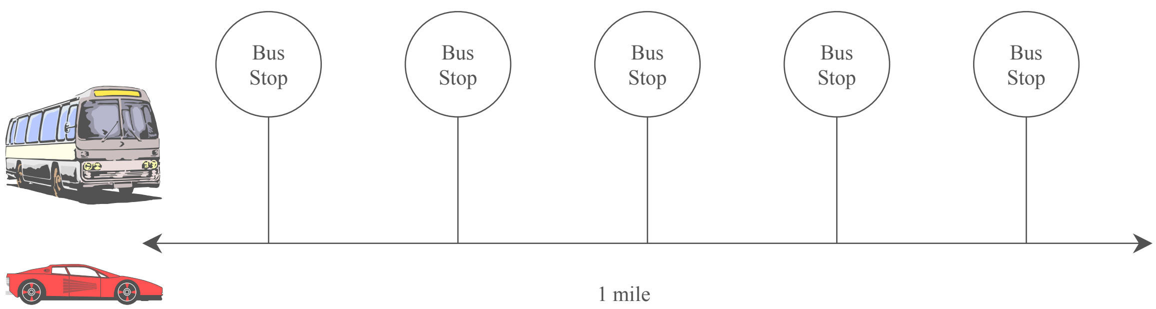

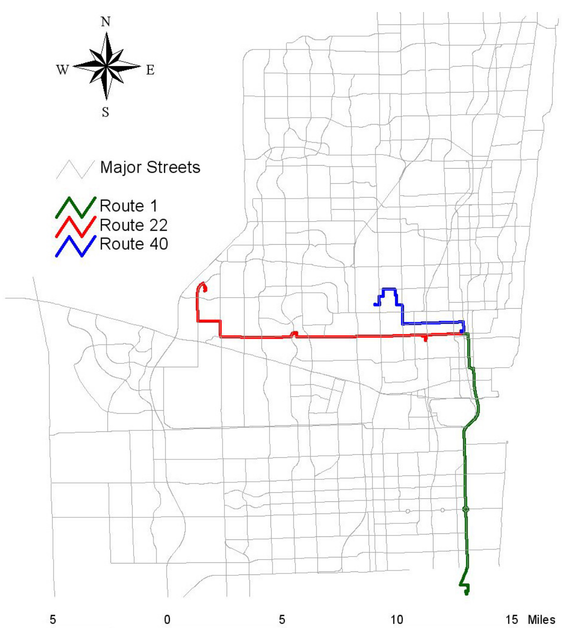

Lehman Center for Transportation Research
Department of Civil & Environmental Engineering
Florida International University

March 2005

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Florida Department of Transportation
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16. Abstract

Current FSUTMS model uses a set of highway-transit speed curves based on facility type and area type to model the relationship between highway speed and transit speed. The drawbacks of this method include that there is considerable vagueness in the definition of area types and that transit boarding and alighting activities not considered in estimating transit travel time. Dwell time at a bus stop is one of the major components of bus travel time and is highly correlated with the number of boarding and alighting passengers. With more resources from federal, state, and local governments devoted to the improvement of public transit services, transit ridership is expected to increase. Consequently, dwell time at a bus stop needs to be modeled in terms of ridership to allow bus travel time to be accurately estimated. In a typical bus operation, passengers may only board a bus through the front door but may choose to get off the vehicle through either the front or rear door. In order to accurately estimate the dwell time, this study developed a binary door choice model that predicts the proportion of alighting passengers that would choose the front or rear door to get off the bus based on the data collected from the Broward County Transit (BCT) in Florida. Based on the door choice model, a transit link travel time estimation model was developed. The model predicts transit link travel time based on number of onboard, alighting, and boarding passengers, time-of-day, if a stop is a time point (optional), and highway travel time. To implement the model in FSUTMS, an iterative process that calculates transit link time based on boarding and alighting data from the previous iteration is necessary.

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ACRONYMS

AVL	Automatic Vehicle Location Systems
APC	Automatic Passenger Counter
APTA	American Public Transit Association
ATIS	Automatic Transit Information Systems
BPR	Bureau of Public Roads
CBD	Central Business District
CDF	Cumulative Distribution Function
CUTS	Characteristics of Urban Transportation Systems
FSUTMS	Florida Standard Urban Transportation Structure
GPS	Global Positioning System
HCM	Highway Capacity Manual
HPMS	Highway Performance Monitoring System
ITS	Intelligent Transportation Systems
LIMDEP	LIMited DEPendent variable models
OBD	Outlying Business District
OCTA	Orange County Transit Authority, California
Q/LOS	Quality/Level of Service
RCI	Roadway Characteristics Inventory
SAS	Statistics Analysis Software
TCQSM	Transit Capacity and Quality of Service Manual
TNET	Transit Network Model
TriMet	Tri-County Metropolitan Transportation District of Oregon

EXECUTIVE SUMMARY

Introduction

Current FSUTMS model uses a set of highway-transit speed curves based on facility type and area type to model the relationship between highway speed and transit speed. This method has a number of limitations such as the considerable vagueness in the definition of area types and that ridership is not considered. As a result, such an approach is unable to reflect appropriately delays at bus stops due to passenger loading and alighting. Alternative method is therefore needed.

Estimating different components of transit travel time accurately to reflect the true traffic condition is important since delay significantly affects the operating statistics of a transit network. The components of transit travel time may include:

- Dwell time at stops;
- Travel time between stops;
- Traffic signal delay time;
- General traffic delay time; and
- Recovery time at the end of each trip.

In the literature, dwell time is generally defined as "the time in seconds that a transit vehicle is stopped for the purpose of serving passengers" [HCM85]. Dwell time at a bus stop is highly correlated with the number of boarding and alighting passengers. A higher demand at a bus stop means longer dwell time. In a typical bus operation, passengers may board a bus only through the front door but may have the choice to get off the vehicle at either front or rear door. This study developed a methodology to more accurately estimate dwell time by predicting the proportion of alighting passengers that would choose the front door to get off the bus using a door choice model based on a travel time survey. A transit link travel time model was then built by considering the dwell time, acceleration and deceleration of a vehicle approaching or leaving a bus stop, and highway travel time.

Literature Review

A review of the literature indicates that it remains a challenge to estimate travel time and speed for a bus operated in mixed traffic for planning purpose. Traditionally, models with deterministic parameters are implemented to estimate transit travel time at the route level. With the advanced technologies developed in the recent decades, computer simulation and Automatic Transit Information Systems (ATIS) may provide real time information to assist in collecting data of better quality and in evaluating and monitoring the operation of a transit system. However, before adequate resources become available to the transit agencies, more detailed and portable models need to be developed at a less aggregate level, such as bus stop, to better estimate transit vehicle delays.

Study Area and Data Collection

Bus dwell time is influenced mainly by three factors: the number of passengers alighting through the front door, alighting through the rear door, and boarding through the front door. For example, dwell time would be longer if all passengers only alight and board through the front door of a bus vehicle. On the other hand, if a proportion of alighting passengers is able to get off a bus at the rear door, the dwell time will be reduced as the result of better utilization of both exits on a bus. In this study, a transit dwell time survey was conducted to collect data on the durations and number of passengers boarding and alighting through the front and rear doors on a bus vehicle. The Broward County Transit (BCT) system was selected for the study. Based on the input from the BCT staff, Routes 1, 22, and 40 were selected for collecting bus dwell time data.

Two survey units, each of two people, conducted the dwelling time survey. The ride check approach described in the Transit Capacity and Quality of Service Manual (TCQSM) was adopted for collecting the bus travel time data. Each survey unit rode transit vehicles over the entire route for several runs at different times of day. To record locations of a bus at a given time, a GPS receiver was used. The following data were collected:

- type of delay encountered, i.e., delay at a bus stop or signalized intersection;
- time when a bus completely stops at a bus stop or signalized intersection;
- time when the front door is open at a bus stop;
- number of alighting passengers and the time when alighting completes at the front door;
- number of boarding passengers and the time when boarding completes at the front door;
- time when the front door closes;
- time when a bus clears out of the bus stop or signalized intersection to traverse on a regular moving lane on the street.
- number of alighting passengers and the time when alighting completes at the rear door;
- GPS readings at bus stop or intersection; and
- notes of atypical delays, e.g., incidents, encountered at a particular location.

A pre-test survey was first launched to collect bus travel time data for Routes 1 and 22. Based on experience and feedback from the pre-test survey, the responsibilities of each surveyor were adjusted. More surveys were then performed on Routes 1, 22, and 40.

Survey Results

After the survey was completed, the transit travel time data were entered into a database. Each record contains the following information about the delay encountered during a sampled bus trip on a given route:

- Record ID
- Route ID (1, 22, or 40)
- Direction (E, W, N, or S)
- Bus vehicle ID
- Sample date

- Delay type (S for stop delay; I for intersection delay)
- Latitude and longitude of the location where the delay occurred
- Bus arrival time
- Front door open time
- Number of passengers alighting through front door
- Ending time for alighting through front door
- Number of passengers boarding front door
- Ending time for boarding at front door
- Number of passengers alighting through rear door
- Ending time for alighting at rear door
- Front door close time
- Bus departure time

Based on the coordinate information from the GPS receivers, the survey data were matched with the bus stop locations from a GIS bus stop layer. Originally, a total of 1,045 records were collected during the survey. Among these records, 256 records were related to intersection delays and were excluded from the remaining bus dwell time analysis. An additional 57 records contained special remarks indicating irregular conditions during the data collection process. Overall, 732 records contained information on delays at bus stops. A total of 692 records remained after excluding those collected at the bus terminals. This exclusion was necessary because at a terminal where a bus trip starts, passenger boarding/alighting was not observed. At such terminals, passenger boarding/alighting patterns may also be different from those at a typical bus stop because of the prolonged period between a bus' arrival from a previous trip and departure for the next trip.

Bus Dwell Time Estimation

The data from the transit travel time survey were used to estimate the dwell time at a bus stop. The average duration for a passenger to board a bus though the front door at a given stop was first computed. This mathematic mean was used as the time needed for a passenger to board through the front door. The elapsed times for passengers to alight from a bus through the front and rear doors were similarly calculated. SAS (Statistics Analysis Software) Version 9.0 was used to fit the observed durations into the gamma, lognormal, and Weibull distributions. The results show that lognormal curves fit the elapsed times better than the other distributions. When combining the alighting durations observed from both exit doors, none of the distributions provided an acceptable fit. As a result, the time required for a passenger to alight from a bus should be modeled explicitly for each door. The same conclusion also applies to the data from combining both alighting and boarding activities.

A binary choice model for an alighting passenger to choose either the front or rear door was developed. Seven variables were compiled and applied in the calibration of the door choice model. They are:

- *ON*: total number of boarding passengers at a given stop;
- *TOTALOFF*: total number of alighting passengers at a given stop;
- *ONBOARD*: total passengers onboard before bus doors were open at a given stop;

- *TIMEPOINT*: dummy variable for a given bus stop, 1 for time point and 0 otherwise;
- *AM*: dummy variable, 1 for records observed during AM peak (6:30-9:30 AM) and 0 otherwise;
- *PM*: dummy variable, 1 for records observed during PM peak (3:00-7:30 PM) and 0 otherwise; and
- *Off*: dummy variable, 1 for records observed during off peak and 0 otherwise.

A time point refers to a location on a bus route that is assigned a fixed scheduled time that is part of a larger line schedule. It is used by transit properties to measure schedule adherence.

A total of 127 models specified with every possible combination of the seven explanatory variables were calibrated and examined. The model that yielded the highest log likelihood value includes the following variables: *TOTALOFF*, *ONBOARD*, *TIMEPOINT*, *AM*, and *PM*. The model shows that the number of passengers utilizing the front door to get off a bus is positively related to the total number of alighting passengers. In other words, a person tends to get off a vehicle through the front door when there are more alighting passengers at a given bus stop. The time-of-day effect, i.e., AM or PM peaks, also appears in favor of getting off through the front door. However, the rear door was favored when there were more passengers onboard. When the bus stop was a time point, which generally indicated a larger number of alighting and boarding passengers, passengers were more likely to get off a bus at the rear door.

Although Monte Carlo simulation may be adopted to implement the door choice model, assuming that the number of alighting passengers is known, it was not implemented in this study for practical applications due to the considerable computing time and technical background required of a user to understand the methodology. Instead, a computer application, DwellTime, was developed to estimate the dwell time related to boarding and alighting activities at a bus stop. DwellTime quantifies dwell time in terms of time of day, ridership, and average boarding/alighting duration per passenger. Ridership may be obtained from a typical transportation demand model program. A computer program, TLT, was also developed to calculate transit link time considering both dwell time and deceleration/acceleration delay. The methodology is easy to understand and may be incorporated in the current practice without significant effort.

Conclusions

The current practice in FSUTMS transit modeling does not reflect the fact that dwell time is dependent on transit use. The model accuracy in terms of transit travel time is therefore affected. This study was aimed at improving the estimation of transit travel time by examining various components in transit travel time that is not already considered as part of highway travel time. These components include transit vehicle acceleration and deceleration rates and dwell time. The study calibrated a door choice model for alighting passengers at a given bus stop, assuming that passengers board only through front door. The door choice model quantifies dwell time based on ridership, time of day, and average boarding/alighting duration per passenger. A computer program was also developed for calculating transit link time as the sum of highway travel time, dwell time, and deceleration and acceleration delays. The method is easy to understand and may be implemented in the current practice without significant effort. To implement the model in FSUTMS, an iterative process that calculates transit link time based on boarding and alighting data from the previous iteration is necessary because ridership data are required as input to the door choice model.

The dwell time model in this study was developed assuming typical operating conditions of a bus vehicle. Other delays caused by, e.g., loading bicycles and operating wheelchair lifts were not considered due to the limited observations collected in the survey. Because of the difficulty in precisely measuring elapsed time, the duration for a passenger to board or alight from a bus was taken as the average time that a passenger took to get on or off a bus at a given stop. In the future, with the help of APTS technologies, more detailed data may be collected to arrive at a more accurate distribution of passenger boarding and alighting time and to account for variations in the data.

The conclusions of this study are based on the analysis of the transit travel time data collected in Broward County, Florida. One limitation of the study is that demographics and climate are not considered in modeling the dwell time. When demographics changes significantly, e.g., when a large portion of the passengers are senior citizens, dwell time may also change. Therefore, data may need to be collected for areas with different user characteristics to determine the effects of local conditions and to obtain good estimates of dwell time thus transit travel time.

1. INTRODUCTION

Mixed traffic bus operation accounts for over 99 percent of total bus route distance in North America [KIT99]. When buses operate in general traffic lanes, they are vulnerable to delays caused by automobile traffic that shares the right-of-way. In the current Florida Standard Urban Transportation Structure (FSUTMS), the TNET model is used to build a transit network based on user-supplied transit and highway network data [TNET97]. Highway network characteristics are overlaid upon the transit network during the execution of TNET, which reduces the effort required for creating transit network. TNET derives transit speeds mostly from a linear function of highway speeds. The area type and facility type coded on the highway network, together with mode, are used to define the operating characteristics of a transit link. A total of fifteen speed functions may be employed for different combinations of modes, area types, and facility types. Changes to any of the functions are allowed to properly reflect each urban area's own transit system performance. Speed differences at different time of day may also be considered in the modeling process. For example, when modeling the peak-period transit network, congested speeds from the capacity-restrained highway assignment are used as input to TNET. When modeling an off-peak (i.e., midday) network, free-flow auto speeds are used as input. The travel times, calculated by dividing the link lengths with the transit speeds obtained from the speed functions, then become the main disutility, i.e., in-vehicle time, for the associated transit modes in the modal split process.

The highway-transit speed curve method has a number of limitations such as the considerable vagueness in the definition of area types and that ridership is not considered. As a result, such an approach is unable to reflect appropriately delays at bus stops due to passenger loading and alighting. Alternative method is therefore needed.

Accurately estimating different components of transit travel time to reflect the actual traffic condition is important since delay is a major factor that determines the operating statistics of a transit network. The components of transit travel time may include [MAL99]:

- Dwell time at stops;
- Travel time between stops;
- Traffic signal delay time;
- General traffic delay time; and
- Recovery time at the end of each trip.

In the literature, dwell time is generally defined as "the time in seconds that a transit vehicle is stopped for the purpose of serving passengers. It includes the total passenger service time plus the time needed to open and close doors" [HCM85]. In addition to dwell time, other variables such as clearance time may be considered in bus speed estimation. However, extensive data such as bus travel time, roadway geometry, traffic control, traffic composition, and traffic flow, which are difficult to obtain, are needed to develop a bus delay model [ABD98]. As a result, more research efforts have been devoted to estimating bus dwell time in the past.

Dwell time at a bus stop is highly correlated with the number of boarding and alighting passengers. A higher demand at a bus stop means longer dwell time for passengers to get on and off the bus. Currently, bus transit is a relatively lowly utilized transportation mode in major urban areas in the U.S. As a result, dwell time may not be a significant component in transit travel time estimation. For example, Tantiyanugulchai and Bertini determined that the mean observed dwell time based on data collected in November 2001 from the Powell Boulevard corridor in Portland, Oregon was merely 16.3 seconds per stop with an average of two boarding passengers and one alighting passenger per station, excluding bus terminals [TAN03]. However, with more resources from federal, state, and local governments devoted to the improvement of public transit services, ridership is expected to rise. As a result, dwell time at a bus stop need to be modeled in terms of ridership to allow bus travel time to be accurately estimated. In a typical bus operation, passengers may only board a bus through the front door but have the choice to get off the vehicle at either the front or rear door. This study developed a methodology to predict the proportion of alighting passengers that would choose the front door to get off the bus using a door choice model based on a travel time survey. Dwell time and acceleration/deceleration delay at a bus stop were subsequently considered in the calculation of transit link time.

In the remainder of this report, Chapter 2 discusses the current practices of estimating transit speeds and literature on new technologies and methodologies that may be useful for the development of new methods for estimating transit speeds in a FSUTMS transit network. Chapter 3 describes the data collection effort conducted in Broward County, Florida for the durations of boarding/alighting activities. The survey results are present in Chapter 4. The calibration, implementation, and application of the door choice model for alighting passengers are described in Chapter 5. Chapter 6 provides the conclusions of the study.

2. BACKGROUND AND LITERATURE REVIEW

The components of transit travel time generally include both out-of-vehicle and in-vehicle times [GUE83]. Out-of-vehicle time includes time spent getting to and from a transit stop and time spent waiting for a transit vehicle. If a transfer is needed, additional walking and waiting time need to be included in the travel time estimation. Out-of-vehicle time is sometimes referred to as "excess time" since it is considered not spent directly on reaching the passengers' destinations. In-vehicle time is the time for a transit vehicle to traverse through a highway network. The procedure in the current TNET module to determine transit speeds for estimating in-vehicle travel time is originally based on the UTPS INET process [TNET97]. INET infers the cruising speed of a transit vehicle from the average automobile speed on the shared link [DIA80]. The INET's transit-speed model assumes that a link time is the sum of the vehicle's cruising time along the link plus a stop delay time (SDT). In INET, cruising time is the time that the vehicle takes to traverse the link with no stop at either of the end nodes. The stop delay time accounts for slowing down, stopping, and starting up of a transit vehicle, i.e., the sum of dwell time and acceleration and deceleration times.

Stop density also affects bus speeds. Levinson investigated the relationship between the total acceleration plus deceleration time per stop and the number of stops per mile and developed the following formula [LEV83]:

$$T = 23.4 - 1.53 \times X \tag{1}$$

where
- T = total acceleration and deceleration time per stop (seconds); and
- X = number of stops per mile.

In TNET, a procedure different from Levinson's is adopted to estimate SDT. The calculation uses a simple piecewise linear relationship to translate highway-link speed to transit-link speed. The effects of stop density, dwell time, and acceleration and deceleration rates of transit vehicles are considered in the procedure [SCA84]. The following section describes the parameters previously considered in the calculation of in-vehicle transit travel time in TNET and the default values that are used in the current highway/transit speed calculation in FSUTMS.

2.1 Parameters Considered in Defining Speed Curves in FSUTMS

This section describes the parameters that are considered in the original approach in developing the speed curves in TNET. They include stop density, dwell time, and acceleration and deceleration rates. Transit speed estimation, recent updates on model parameters, and the TNET procedure for determining transit speed are also discussed.

2.1.1 Stops Density

Table 1 shows the number of stops per mile by area type that is used as the default value in speed estimation for both local and express transit services, the latter operate only during peak hours [SCA84]. The area types in Table 1 are defined as follows [SCA80]:

1x. Central Business District (CBD)
2x. Fringe
3x. Residential
4x. Outlying Business District (OBD)
5x. Rural

Table 1. Stops per Mile for Different Area Type and Transit Service Combinations

Service		Area Type				
		1x	2x	3x	4x	5x
Local	At Min. Speed	5	4	4	3	3
	At Max. Speed	4	3	3	2	2
Express	At Min. Speed	4	2	2	2	2
	At Max. Speed	3	1	1	1	1

As indicated in Table 1, the number of stops per mile for local bus transit ranges from two to five. For express transit, it is from one to four. The total delay time due to stopping/starting maneuver and passenger boarding and alighting is calculated by multiplying the number of stops with the delay time per stop.

2.1.2 Dwell Time

Table 2 gives the default the INET average dwell time per stop by area type for local and express transit services [SCA84].

Table 2. Average Dwell Time per Stop in Seconds

Service	Area Type				
	1x	2x	3x	4x	5x
Local	48	48	30	30	30
Express	48	48	30	30	18

2.1.3 Acceleration and Deceleration Rates

Table 3 presents the acceleration/deceleration rates applied in the development of original speed delay curves in INET. These operating parameters for transit buses are cited from the 1979 version of *Characteristics of Urban Transportation Systems* (CUTS) report [SCA84].

Table 3. Acceleration/Deceleration Rates

	Speed (mph)	Rate (m.p.h.p.s.)
Acceleration	0 – 10	2.5
	10 – 30	1.5
	30 – 50	0.5
Deceleration	All Speeds	2.5

Table 4 shows the performance characteristics from the 1979 CUTS report [CUTS79]. It appears that the acceleration rates for gasoline engine vehicles are used in the original calculation. According to the *2001 Public Transportation Fact Book* published by American

Public Transit Association (APTA), 88% of all bus vehicles in the nation were using diesel as the power source [PTFB03]. Since a majority of the urban areas use diesel engine vehicles, the acceleration parameters need to be updated.

Table 4. Bus Performance Characteristics

Vehicle Type	Engine	Acceleration (m.p.h.p.s.)			Normal Deceleration (m.p.h.p.s.)
		0-10 mph	10-30 mph	30-50 mph	
Diesel Bus	GM V6-71	2.50	1.43	0.51	2-3
	GM V8-71	3.33	2.22	0.95	2-3
Gasoline Bus	Gasoline	2.50	1.50	0.60	2-3
Gas Turbine Bus	Turbine	2.00	2.00	1.00	2-3
Trolley Bus	Electric	3.00	2.00	1.00	2-3
Transbus	Any Type	2.22	2.30	0.92	2-3

2.1.4 Transit Speed Estimate

The existing approach for transit speed estimation may be illustrated with the hypothetic example depicted in Figure 1, which shows a one-mile roadway segment that serves both automobile and transit vehicles. The time needed for an automobile to traverse through the segment at a constant speed of 25 mph is 144 seconds. A bus vehicle requires additional travel time to maneuver to a complete stop for boarding and alighting passengers and to resume the normal operating speed at each stop.

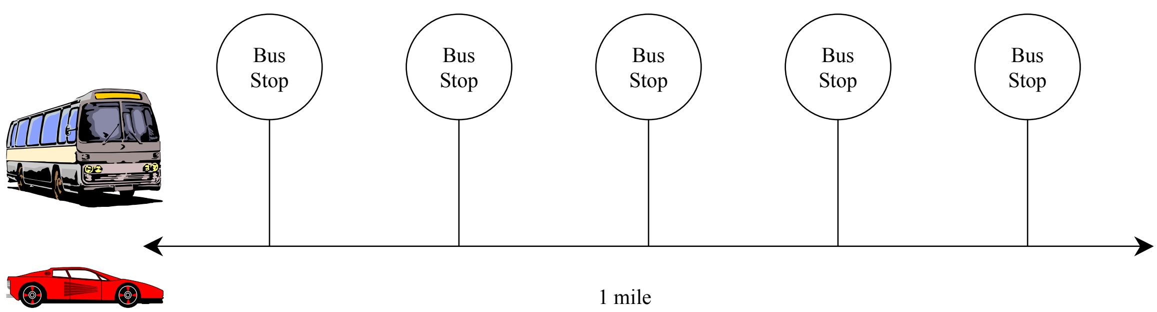

Figure 1. Example of Highway/Transit Speed Calculation (adopted from [SCA84])

Based on the values provided in Table 3, the deceleration time from a speed of 25 mph to a full stop at each bus stop is

$$\frac{(0-25\ mph)}{-2.5\ mphps} = 10 \text{ seconds} \tag{2}$$

Also from Table 3, the acceleration time from 0 to 25 mph is

$$\frac{(10-0\ mph)}{2.5\ mphps} + \frac{(25-10\ mph)}{1.5\ mphps} = 14 \text{ seconds} \tag{3}$$

Hence, the distance for the acceleration and deceleration maneuvers at each stop is

$$\frac{1}{2}2.5\times10^2 + \left(\frac{1}{2}2.5\times4^2\right) + \left(10\times14+\frac{1}{2}1.5\times10^2\right) = 0.086 \text{ mile} \tag{4}$$

The total bus travel time (t_B) may thus be estimated as follows, assuming average dwell time per stop to be 48 seconds:

$$t_B = \frac{(1-0.086\times5\ stops)}{25\ mph}\times3600+5\times(10+14+48) = 440 \text{ seconds} \tag{5}$$

When auto speed is 25 mph, the corresponding bus speed is 8 mph on the one-mile segment. This procedure is applied to determine the transit speeds corresponding to the minimum and maximum highway speeds. A linear relationship is established by connecting the two transit speed points corresponding to the minimum and maximum speeds. The transit/highway speed relationship is incorporated into TNET to estimate transit speeds. The values for some parameters considered in the original estimation of speed curves are not up-to-date. The following section describes the updates to the variables used in transit speed estimation.

2.1.5 Parameter Updates

Several studies conducted after the 1984 study provided the necessary updates. For example, Table 5 shows the typical acceleration and deceleration rates for bus vehicles in the revised version of the CUTS report [CUTS92]. Acceleration and deceleration rates for diesel engine buses are adopted, which reduce stop delay time and allow higher operating speeds to be achieved. Table 6 gives the stop density by area type (coded as two digits) for both local and express transit services in the 1999 transportation model for Miami-Dade County, which is much higher than what has been in the original speed curve calculation. As a result, more delay is expected since more frequent stops take place when a bus transit traverses a street segment.

Table 5. Updated Acceleration/Deceleration Rates

	Speed (mph)	Rate (mphps)
Acceleration	0 – 10	3.33
	10 – 30	2.22
	30 – 50	0.95
Deceleration	All Speeds	2-3

Table 6. Stop Density from the 1999 Dade County Model

	Area Type				
	1x	2x	3x	4x	5x
Distance (mile)	23.91	1.43	396.68	253.87	0.90
Total Stop	138	8	2736	1449	4
Stop Density	5.77	5.59	6.90	5.71	4.44

2.1.6 Procedure to Determine Transit Speed in TNET

In FSUTMS, each speed relationship or speed curve is given a number. A look-up table based on area type, facility type, and transit mode is used to determine which curve number is to be used for transit speed estimation. Tables 7 and 8 show the default speed curve numbers by area and facility types for local and express bus transportation, respectively [SCA84]. As indicated in the tables, the same set of speed curves is used to estimate both local and express transit speeds for links of area type 1x. The same applies to links of facility types 1x and 5x for every area type. Originally in FSUTMS, facility types 1x and 5x are used to specify freeways/expressways and centroid connectors, respectively, and area type 1x is used to specify links located in CBD area. Centroid connectors are specified solely for loading trips generated from traffic analysis zones and no transit buses are operated on these links. As a result, links of area type 5x are excluded from the remaining analysis.

Table 7. Default Function Number for Transit Mode 4 by Area and Facility Types

Area Type	Facility Type					
	1x	2x	3x	4x	5x	6x
1x	3	6	6	13	1	6
2x	4	6	6	6	1	6
3x	4	8	8	8	1	8
4x	4	10	10	10	1	10
5x	5	12	12	12	1	12

Table 8. Default Function Number for Transit Mode 5 by Area and Facility Types

Area Type	Facility Type					
	1x	2x	3x	4x	5x	6x
1x	3	6	6	13	1	6
2x	4	7	7	8	1	7
3x	4	9	9	9	1	9
4x	4	9	9	9	1	9
5x	5	11	11	11	1	11

The facility type definition in the current FSUTMS is as follows:

1x. Freeways and Expressways
2x. Divided Arterials
3x. Undivided Arterials
4x. Collectors
5x. Centroid Connectors
6x. One-way Facilities
7x. Ramps
8x. HOV Facilities
9x. Toll Facilities

Up to fifteen speed relationships may be defined in TNET. As shown in Tables 7 and 8, curves 14 and 15 are absent therefore are not used in estimating transit speed. Furthermore, as shown in Table 9, a constant transit speed of 2.5 mph is given by curve 1 as the default walk speed, independent of the highway speeds. Transit speeds based on curve 2 are the same as highway speeds. In other words, links that use curve 2 have no bus stops. Consequently, only curves 3 to 13 are utilized in the current procedure to estimate bus speeds under regular mixed traffic condition. The highlighted cells in Table 7 to 9 present the default values in FSUTMS speed curves.

Table 9. Highway to Transit Speed Conversion Functions

Function Number	Highway Speed (mph)		Transit Speed (mph)	
	Low	High	Low	High
1	30	70	2.5	2.5
2	30	70	30	70
3	26	43	26	35
4	26	50	26	45
5	42	55	42	50
6	18	32	8	12
7	22	35	13	22
8	18	37	10	15
9	18	36	14	24
10	18	36	11	18
11	24	48	16	29
12	24	48	13	19
13	10	26	6	11
14	7	40	7	20
15*	-	-	-	-

* Not used

The current default approach in FSUTMS has some apparent limitations. For example, fifteen speed curves may be inadequate to properly model transit speeds for urban areas that have many unique attributes. Area type definition is also vague. Moreover, the assumption of linear relationship between transit and highway speeds may not hold. Additionally, the delay encountered at signalized intersections is not considered in the original procedure for estimating transit speeds. The following section describes the approaches reported in the literature for quantifying and incorporating signal delay at a signalized intersection in transit speed estimation.

2.2 Impacts of Congestion on Bus Transit

Literature shows that traffic signal delays only account for a small proportion of total running time. For example, Maloney and Boyle define the components of transit travel time as follows [MAL99]:

- Dwell time at stops;
- Travel time between stops;

- Traffic signal delay time;
- General traffic delay time; and
- Recovery time at the end of each trip.

In Maloney and Boyle's study, experienced traffic checkers collected travel time data from the Beeline transit network in the city of Glendale in Los Angeles County, California. It was found that the primary component of the total time for a bus in service was the actual travel time along the route (59%), followed by recovery time (13%), deadhead time (9%), time maneuvering out and into traffic (7%), dwell time (7%), and time caused by signal delay (5%) [MAL99]. Recovery time is the time built into a schedule to provide break time for operators and accommodate unexpected traffic delays to permit a transit route to stay on schedule. Recovery time also allows transit system to operate "clockface" headways, e.g., at 10, 20, and 30 minutes after the hour. Deadhead time, also known as non-revenue time (i.e., the transit vehicle is not available for travel by the general public), is the time that a revenue transit vehicle travels either between the garage and route or when changing routes.

Although delay at a signalized intersection is not significant according to literature, large urban areas such as the Miami metropolitan area are known to suffer from severe traffic congestion. Consequently, intersection delay should be considered in transit speed estimation. McKnight *et al*. developed the following regression model to estimate bus travel time as a function of general traffic speeds and passenger boardings [MCK97]:

$$BusTime/D = 2.6 + 0.57\, AutoTime/D + 0.076 Pass/D + 0.39 Stops/D + 0.54 N/S \tag{6}$$

where

BusTime/D = average time for buses to travel between check points during a one hour period divided by the distance between the check points (minutes/mile);

AutoTime/D = average time for automobiles to travel between the same check points during the same one hour period divided by the distance between check points (minutes/mile);

Pass/D = number of passengers boarding buses on the route segment between check points in the one hour period divided by the distance between check points (passengers/mile);

Stops/D = number of stops on the route segment divided by the distance of the segment (bus stops/mile); and

N/S = dummy variable: 1 for north and south directions and 0 for cross-town streets.

As shown in the literature, transit travel time has been generally estimated at a route level in the past. Compared with other studies that explore the effects of bus operating characteristics and stop density on transit speed, significant more research efforts have been devoted to improving transit dwell time modeling. The research findings related to dwell time estimation are described in this section. The research conducted in the past decade has shifted to estimate the elapsed time for the delay components such as dwell time observed during a transit operation. In section 2.3 to 2.8, a summary for selected studies relevant to bus well time estimation is provided.

2.3 TCQSM Methods

In the Transit Capacity and Quality of Service Manual (TCQSM), dwell time is defined as the time required for serving passengers at the busiest door, plus the time required to open and close the doors [KIT99]. Dwell time is known to be proportional to the boarding and/or alighting volumes times the service time per passenger. Five main factors influence dwell time:

- Passenger demand and loading;
- Bus stop spacing;
- Fare payment procedures;
- Vehicle types; and
- Onboard circulation.

Dwell time may also be affected by the time to board and disembark passengers in wheelchairs and for bicyclists to load and unload bicycles onto a bus-mounted bicycle rack. TCQSM provides three methods for determining bus dwell time:

- Field measurements;
- Default values; and
- Calculation.

Field measurement is considered the most accurate. The resulted mean dwell time and its standard deviation from a series of observations may then be used in the modeling process. Ride check is known as the best approach for collecting dwell time data. This data collection technique requires at least one observer to ride the transit vehicle over the entire route for several runs at different times of day to record the time when the bus vehicle comes to a complete stop, doors are fully opened, doors are fully closed, and the vehicle starts to run. Time spent waiting at time points or at signalized intersections is not included in the dwell time. Time lost due to fare disputes, lost property, or other events are also not considered as part of dwell time. The steps in field data collection for estimating dwell time are [KIT99, DUE04]:

- Record the stop number or name of each stop.
- Record the time that the vehicle comes to a complete stop.
- Record the time that the doors are fully opened.
- Count and record the numbers of alighting and boarding passengers through the front and rear doors.
- Count the number of passengers onboard.
- Record the time that the doors are fully closed.
- Record the time when the vehicle starts to move.
- Note any special circumstances such as lift operation or delay that is not associated with passenger services.

Major data collection for bus dwell time is often infeasible because of the cost, especially for transit agencies serving small urban areas. The following values, varied mainly by the locations of transit stops and the transit demand at these locations, have been suggested as the default bus dwell times: 60 seconds for each stop located in CBD, transit center, major transfer point, or major park-and-ride facility, 30 seconds for a major stop, and 15 seconds for a typical stop [KIT99]. These default values allow bus dwell times to be estimated with minimum data requirement. However, cautions should be used when applying these values since they are from a reference published more than two decades ago.

The steps involved in the third approach of dwell time estimation in TCQSM are as follows:

1. Obtain hourly passenger volume estimates.
2. Adjust hourly passenger volumes to peak passenger volumes.
3. Determine base passenger boarding and alighting time.
4. Adjust passenger boarding and alighting times for special conditions.
5. Calculate dwell time.

The base passenger boarding and alighting time determined in Step 3 may be approximated by the values given in Table 10, assuming that bus vehicles operate under typical conditions, i.e., single-door loading and pay-on-bus [KIT99]. In Step 4, base passenger service times are further adjusted to take passenger boarding and alighting conditions into consideration. Table 11 shows the factors that are used to multiply the base values for different cases.

Table 10. Typical Bus Passenger Boarding and Alighting Service Times

	Payment	Service Time (sec)
Boarding*	Pre-payment	2.0
	Single ticket/token	2.6
	Exact fare	3.0
Alighting	-	1.7 – 2.0

* Add 0.5 seconds to the barding times if standees are present on the bus.

Table 11. Adjusted Factors for Special Boarding and Alighting Conditions

Phenomenon	Factor
Heavy two-way flow through a single door	1.20
Double-stream door	0.60
Low-floor bus	0.85

Dwell time is then calculated using the following equation:

$$t_d = P_a \times t_a + P_b \times t_b + t_{oc} \quad (8)$$

where

t_d = dwell time in seconds;
P_a = number of alighting passengers though the busiest door during the peak 15 minutes;
t_a = passenger alighting time in seconds per person;
P_b = number of boarding passengers through the busiest door during the peak 15 minutes;
t_b = passenger boarding time in seconds per person; and
t_{oc} = door opening and closing time in seconds.

A value of two to five seconds is generally assumed for door opening and closing under normal operation conditions. Loading and unloading wheelchairs and bicycles should be included in the dwell time estimation when these users regularly use a bus stop. Typical wheelchair lift cycle times are 30 to 60 seconds, including the time required to secure the wheelchair inside a low-floor bus. The process for passengers to deploy the bicycle rack and load their bicycles into one of the available loading positions on a bus takes approximately 20 to 30 seconds.

2.4 Tehran Transportation Model

In the Tehran Transportation Model, dwell times at stops are considered as a function of the number of passengers boarding and alighting and other variables. A total of 3,454 observations at various stops were made from 24 bus routes in Tehran, Iran and the following seven models were calibrated to estimate dwell time at each stop [AAS02]:

Model 1: $DWT = \alpha_1 \times I + \alpha_2 \times (2/ND)^{0.5} \times O$ (9)

Model 2: $DWT = \alpha_0 \times \beta_1 + \alpha_1 \times I + \alpha_2 \times (2/ND)^{0.5} \times O$ (10)

Model 3: $DWT = \alpha_0 \times \beta_1 + \alpha_1 \times I + \alpha_2 \times (2/ND)^{0.5} \times O + \alpha_3 \times \beta_2$ (11)

Model 4: $DWT = \alpha_0 \times \beta_1 + \alpha_1 \times I^{\beta_1} + \alpha_2 \times (2/ND)^{0.5} \times O^{\beta_2}$ (12)

Model 5: $DWT = \alpha_0 \times \beta_1 + (\alpha_1 \times I + \alpha_2 \times (2/ND)^{0.5} \times O) \times (1 + \alpha_4 \times LF^{\beta_4})$ (13)

Model 6: $DWT = \alpha_0 \times \beta_1 + (\alpha_1 \times I + \alpha_2 \times (2/ND)^{0.5} \times O + \alpha_3 \times \beta_2) \times (1 + \alpha_4 \times LF^{\beta_4})$ (14)

Model 7: $DWT = \alpha_0 \times \beta_1 + (\alpha_1 \times I^{\beta_1} + \alpha_2 \times (2/ND)^{0.5} \times O^{\beta_2}) \times (1 + \alpha_4 \times LF^{\beta_4})$ (15)

where

DWT = dwell time at a station in seconds;
I = number of boarding passengers at the station;
O = number of alighting passengers at the station;
LF = loading factor (number of passengers in a transit vehicle prior to stopping divided by vehicle capacity);
α_i = parameters of the model, $i = 1, 2, 3$;
β_1 = 1 if $I + O > 0$, and 0 otherwise; and
β_2 = 1 if $I + O > 0$, and 0 otherwise.

Parameter β_1 was used to estimate the fixed time spent for at least one passenger alighting or boarding at a stop. Parameter β_2 was used to measure the additional time spent given that alighting and boarding occur simultaneously at a stop. The results showed that Model 7 had a better fit. However, Model 6 was selected for model validation due to its linear structure associated with boarding and alighting variables.

The following three models were also calibrated to estimate accumulated dwell time at an aggregate level for all stops on a given route:

Model 8: $DWT = \alpha_0 \times NS + \alpha_1 \times I \times (2/ND)^{0.5}$ (16)

Model 9: $DWT = \alpha_0 \times NS + \alpha_2 \times LF$ (17)

Model 10: $DWT = \alpha_0 \times NS + \alpha_1 \times I \times (2/ND)^{0.5} \times (1 + LF)$ (18)

where NS is the number of stops on the route and the rest of the variables are previously defined. Model 8 was selected for model validation due to its higher R^2 value. The performance of Models 6 and 8 was then evaluated by implementing the dwell time models in the traffic assignment process of the Tehran Transportation Model. The results showed that both Models 6 and 8, especially the former, replicated the field observations better.

2.5 Guenthner and Sinha's Approach

Guenthner and Sinha applied statistical methods to estimate transit dwell time [GUE83]. They first concluded that the number of passengers boarding and alighting at stops followed a negative binomial distribution. Dwell time per passenger was then developed as a function of passenger boardings and alightings along a bus route. To estimate total bus delay, the following equation was first used to estimate average demand at a stop m, assuming that the passenger demand was uniformly distributed along the route:

$$m = \frac{2Q_1 \times HDWY}{Y \times L} \quad (19)$$

where
- Q_1 = total demand for a given route;
- $HDWY$ = bus headway in hours;
- Y = stops per mile; and
- L = route length in miles.

The probabilities for a stop with zero passengers boarding and z passengers alighting were given as follows:

$$P(0) = p^k \quad (20)$$
$$P(z) = \frac{z + k - 1}{z} \times q \times P(z-1) \quad (21)$$

In the above equations, k, p, and q are parameters of a negative binomial distribution defined as follows:

$$p = m/s^2 \quad (22)$$
$$q = 1 - p \quad (23)$$
$$k = pm/q = m^2/(s^2 - m) \quad (24)$$

where
- m = sample mean; and
- s^2 = sample variance.

Different from Poisson distribution, which requires only one parameter, negative binomial distribution requires both a mean and a variance. Guenthner and Sinha developed the following linear regression model to predict the variance for a stop with a known average number of boarding and alighting (m):

$$s^2 = -1.305 + 4.870 \times m + 1.085 \times m^2 \tag{25}$$

The following models were then developed to relate the natural logarithm of the dwell time per passenger to the number of boarding and alighting at each stop:

$$\varepsilon(z) = 5.0 - 1.2 \times \ln(z) \quad z \leq 23 \tag{26}$$
$$\varepsilon(z) = 1.2 \times z \quad z \geq 24 \tag{27}$$

where
- ε = dwell time per passenger; and
- z = number of boarding and alighting at a stop.

The number of stops per mile, SPM (> 0), was given as follows:

$$SPM = Y \times [1 - P(0)] \tag{28}$$

The delay per mile, D_1, for the stopping/starting maneuver was then derived as follows:

$$D_1 = \delta \times SPM \tag{29}$$

where δ is the time penalty for each passenger stop ranging from 10 to 20 seconds. The dwell time per mile for stops with 23 or fewer boarding and alighting passengers was then calculated using the following equation:

$$D_2^{'} = Y \times \sum_{z=1}^{23} \varepsilon(z) \times P(z) \tag{30}$$

The dwell time for stops with 24 or more boardings and alighting was given as follows:

$$D_2^{''} = 1.2 \times Y \times \left[m - \sum_{z=1}^{23} \left(P(z) \times z \right) \right] \tag{31}$$

The total dwell time per mile was then given as:

$$D_2 = D_2^{'} + D_2^{''} \tag{32}$$

Finally, the total delay in hours per mile for a bus stopping for passengers was obtained from the following equation:

$$Delay = (D_1 + D_2)/3600 \tag{33}$$

2.6 Levinson's Approach

Levinson developed the following formula to estimate dwell time using the field data collected from Boston, Chicago, New Haven, and San Francisco [LEV83]:

$$T = 2.75 \times n + 5 \tag{34}$$

where

T = total stopped time per bus in seconds; and

n = number of interchanging (i.e., boarding and alighting) passengers per bus.

2.7 Bertini and Ei-Geneidy's Approach

Bertini and Ei-Geneidy used archived bus dispatch system data from the Tri-County Metropolitan Transportation District of Oregon (TriMet) to model transit trip time [BER04]. The route chosen for the study was Route 14 inbound that had 105 scheduled bus service per weekday and 64 stops on the route. The data were collected and analyzed for a total of 14 trips for the selected route between 6 to 10 AM on Tuesday, February 1, 2001. The mean dwell time and the standard deviation SD from a total of 459 stop samples were 12.4 seconds and 9.2 seconds, respectively. The data revealed longer dwell time during peak periods. The lift was used only once for the 14 sampled trips and the dwell time was 102 seconds to serve one passenger. Among the 459 stops, 255 stops (56%) involved passengers boarding only with an average boarding time of 6.0 seconds, 111 stops (24%) included passengers alighting only with an average alighting time of 2.4 seconds, and 68 stops (15%) included both passengers alighting and boarding with an average time of 3.8 seconds. No boarding and alighting activities were observed at the remaining 24 stops (5%). The following linear regression model was developed to estimate the average time required for a bus of TriMet Route 14 to complete a trip:

$$T = 26.0 \times N_d + 0.85 \times N_a + 3.6 \times N_b + 1506.6 \tag{35}$$

where

T = trip time in second;

N_d = number of dwells (or stops);

N_a = total number of passengers alighting from the bus; and

N_b = total number of passengers boarding the bus.

The formula, however, did not take into consideration that passengers alighting from the bus used both doors.

2.8 Dueker's Approach

Dueker *et al*. used archived automatic vehicle location (AVL) and automatic passenger counter (APC) data recorded at bus stop level from TriMet, Portland, Oregon to estimate bus dwell time [DUE04]. The new Advanced Public Transportation System (APTS) technology deployed in TriMet automated the collection of dwell time data. However, the starting times that bus stopped and started were not recorded, nor were the starting and stopping times of passenger flows. The data from all TriMet's regular bus routes from a two-week period in September 2001 were analyzed. In the study, dwell time was defined as the duration in seconds when the front door was open at a bus stop where passenger activities occurred. The following three data sets were compiled: a full sample consisting of all observations; a lift operation-only sub-sample; and a no-lift operation only sub-sample. The corresponding dwell time statistics for the three data sets are given in Table 12.

Table 12. Bus Dwell Time Statistics (Source: [DUE04])

Sample	Mean Dwell Time (s)	Standard Deviation	Number of Samples
Lift Operation Only	80.70	37.44	2,347
No-Lift Operation	11.84	11.92	353,552
Full Sample	12.29	13.47	355,899

The following linear regression models were calibrated to estimate the dwell time using the data from the sub-samples of lift operation only (T_{Lift}), without lift operation ($T_{No\ Lift}$), and full sample (T_{Full}). The adjusted R^2 for the T_{Lift} and $T_{No\ Lift}$ models were 0.2848 and 0.3475, respectively.

$$\begin{aligned} T_{Lift} = \; & 10.206 \times ONS - 0.359 \times ONS^2 + 0.513 \times OFFS - 0.022 \times OFFS^2 \\ & - 0.037 \times ONTIME - 4.741 \times LOW - 0.234 \times FRICTION - 4.141 \times TOD2 \\ & + 6.271 \times TOD3 - 4.588 \times TOD4 - 14.447 \times TOD5 + 1.036 \times FEED \\ & - 1.675 \times XTOWN + 68.861 \end{aligned} \tag{36}$$

$$\begin{aligned} T_{No\ Lift} = \; & 3.481 \times ONS - 0.040 \times ONS^2 + 1.701 \times OFFS - 0.031 \times OFFS^2 \\ & - 0.144 \times ONTIME - 0.113 \times LOW + 0.069 \times FRICTION + 1.364 \times TOD2 \\ & + 0.924 \times TOD3 + 1.248 \times TOD4 + 0.069 \times TOD5 + 0.145 \times FEED \\ & - 0.388 \times XTOWN + 5.136 \end{aligned} \tag{37}$$

$$\begin{aligned} T_{Full} = \; & 3.551 \times ONS - 0.042 \times ONS^2 + 1.703 \times OFFS - 0.033 \times OFFS^2 \\ & - 0.145 \times ONTIME - 0.143 \times LOW + 62.07 \times Lift + 0.067 \times FRICTION \\ & + 1.352 \times TOD2 + 0.902 \times TOD3 + 1.231 \times TOD4 - 0.013 \times TOD5 \\ & + 0.148 \times FEED - 0.390 \times XTOWN + 5.117 \end{aligned} \tag{38}$$

where

FEED = dummy variable indicating if the route is a feeder route or radial route;
FRICTION = passenger friction associated with vehicle holding actions or operator shift changes;
Lift = dummy variable indicating if lift operation is included;
LOW = dummy variable indicating if the bus is a low floor bus;
OFFS = number of alighting passengers;
ONS = number of boarding passengers;
ONTIME = dummy variable indicating if the bus is ahead or behind schedule;
TOD2 = dummy variable indicating if operated during mid-day;

TOD3	=	dummy variable indicating if operated in the afternoon peak;
TOD4	=	dummy variable indicating if operated in the evening peak;
TOD5	=	dummy variable indicating if operated in the late evening and early morning period; and
XTOWN	=	dummy variable indicating if the route is a cross-town route or radial route.

The following section discusses research efforts on applying ITS and traffic simulation technologies in collecting travel time and the relevant data for transit speed estimation.

2.9 Transit Probe

Transit probe is designed to measure congestion on roadway segments using ITS related technologies. Data collected from an AVL system installed on a bus vehicle are utilized in estimating roadway congestion levels. The transit probe project conducted at Orange County Transit Authority (OCTA), California calculated bus speed using the following equation [HAL00]:

$$\text{estimated bus speed} = \frac{N_1 \times SL}{ST - SDT - N_2} \tag{39}$$

where

SL	=	length of segment;
ST	=	measured time to traverse the segment;
SDT	=	station dwell time (including acceleration and deceleration loss time); and
N_1, N_2	=	empirical coefficients to compensate for performance differences between cars and buses.

SL was estimated by first determining when a bus was near the points defining the start and end of the roadway segment and then calculating their difference. Because the Global Positioning System (GPS) onboard a bus did not continuously collect the bus location data, ST was approximated. *SDT* was calculated as the sum of the time during which the bus door was open and the time lost when uniformly accelerating to and decelerating from free-flow speed. Parameters N_1 and N_2 were set at 1 and 0, respectively, thus had no effect on the estimated speed. Four congestion classifications were established based on estimated bus speeds on roadway segments as a percentage of a nominal free-flow speed, approximated from the posted speed limit:

- None: 90 - 100% of normal;
- Light: 75 - 90% of normal;
- Moderate: 60 - 75% of normal; and
- Heavy: less than 60% of normal speed.

2.10 Computer Simulation

Several computer simulation packages have been developed to perform traffic network simulation. The TRAF-NETSIM program, now known as CORSIM, was used in several studies to simulate bus operation and estimate bus delay. The program is a microscopic simulation model designed to simulate the dynamics of traffic operation on an urban network [KHA96]. The program has been comprehensively applied as an evaluation tool for a wide range of transportation phenomena.

As an example, in Abdelfattah and Khan's study, a total of six regression models, $Delay_i$ ($i = 1, 2, \ldots, 6$), were calibrated for different scenarios. The dependent variable was the total delay in minutes for all buses on a link estimated from the TRAF-NETSIM software [ABD98]. Models $Delay_1$ and $Delay_2$ were general delay equations, while the other models provided a higher degree of calibration accuracy. The first two models were to be used for estimating bus delays within the CBD area. Model $Delay_3$ was to be used for streets and arterials with high proportion of heavy vehicles. Model $Delay_4$ incorporated the variable of total number of stops made by a bus for passenger serving, traffic signals, and stop signs. Models $Delay_5$ and $Delay_6$ estimated the delay experienced by a bus when one traffic lane was blocked. The difference between these two models was that Model $Delay_6$ estimated delay for street segments with more heavy vehicles. These models are given below.

$$Delay_1 = 0.4855 + 0.0287 \times DENS.LT + 0.0168 \times DENS.TH + 0.9654 \times LENGTH - 1.1969 \times M/T + 0.1130 \times STATION \quad (40)$$

$$Delay_2 = 0.1403 + 5.772 \times 10^{0.7} \times (DENSITY)^3 + 0.3079 \times (LENGTH)^3 + 0.1174 \times (STATION)^2 + 0.080 \times T/M \quad (41)$$

$$Delay_3 = 0.1403 + 0.0046 \times (HVDNSTY)^3 + 0.3079 \times (LENGTH)^3 + 0.1174 \times (STATION)^2 + 0.0801 \times T/M \quad (42)$$

$$Delay_4 = 0.2845 + 2.343 \times 10^{0.4} \times (BUSTOP)^3 + 0.5823 \times (LENGTH)^3 + 6.709 \times 10^{0.7} \times (DENSITY)^3 + 0.0733 \times T/M \quad (43)$$

$$Delay_5 = 0.2460 + 1.2126 \times 10^{0.6} \times (DENSITY)^3 + 0.3189 \times (LENGTH)^3 + 0.1416 \times (STATION)^2 + 0.0707 \times T/M \quad (44)$$

$$Delay_6 = 0.4283 + 0.0116 \times (HVDNSTY)^3 + 0.6510 \times (LENGTH)^3 + 1.0398 \times (BUSTOP)^3 + 0.0618 \times T/M \quad (45)$$

where

BUSTOP = number of stops made by a bus on a link, including traffic lights, stop signs, and bus stops;
DENSITY = total traffic density on each link, including heavy vehicles (veh/lane/km);
DENS.LT = left-trun vehicle density (veh/lane/km);
DENS.TH = through vehicle density (veh/lane/km);
HVDNSTY = heavy-vehicle density per link (veh/lane/km);
LENGTH = link length in kilometers;
M/T = bus efficiency ratio estimate (%); and
STATION = number of bus stations per link.

Variable *M/T* was equal to moving time divided by total time. Moving time was the sum of the time that all vehicles spent moving on the link, calculated as vehicle miles divided by the free flow speed on the link. Total time was the actual total travel time that is an average of travel times from all vehicles on the link. In most of the equations, variable *T/M* was used, which was the inverse of variable *M/T*. After the bus delay was estimated with one of the six regression models, the total bus travel time was calculated as the travel time without delay plus the estimated bus delay.

The significant amount of data required is a major obstacle for implementing traffic simulation packages like CORSIM to estimate bus delay for planning applications in the past. The data needed may be generally classified into the following categories:

- Geometric data (e.g., exclusive turn lanes);
- Demand data (e.g., intersection turning movements);
- Intersection data (cycle length, phase timing, etc.); and
- Other.

With the advent of recent emerging technologies in computer and communication, it is now possible to gather the data needed for computer simulation easier and less costly. For example, Roadway Characteristics Inventory (RCI) provides geometric data such as the presence of exclusive turn lanes and number of lanes at intersections located on roads in the Highway Performance Monitoring System (HPMS) [RCI03]. Although the highway data for most intersections located on the off-system roads are currently unavailable, the 2000 Highway Capacity Manual (HCM2000) provides practical guidelines to assist transportation planners in determining the most probable geometric characteristics such as exclusive turn lanes at a given intersection [HCM2000].

HCM2000 also provides a method to estimate turning movements from approach and departure volumes for each leg of the intersection. With the guidelines and methods in the HCM2000 to help determine geometric characteristics, traffic demand, and signal phasing, traffic simulation such as CORSIM may be utilized to quantify delays at signalized intersections for both highway vehicles and transit buses. CORSIM may also be employed for future year delay forecasts if simplifying assumptions are made and default values of the required input variables are available. Florida Quality/Level of Service (Q/LOS) Handbook may serve as a primary reference for necessary assumptions and default values, which are well accepted in Florida for planning purposes. The handbook incorporates the analytical techniques in HCM2000 and actual roadway, traffic, and signalization data in Florida to allow a quick estimate of transportation quality/level of service level [QLOS22]. In the handbook, extensive statewide averages for roadway, traffic, and signalized control types of variables are provided at two levels of analysis: generalized planning and conceptual planning. For generalized planning, simple statewide averages are utilized. For conceptual planning, weighted averages by roadway segment lengths are employed. However, the handbook recommends the use of median values, instead of averages, when extreme outlying values are observed in the statewide data.

2.11 Summary

The literature reviewed in this study indicates that it remains a challenge to estimate travel time as well as speed for a bus operated in a mixed traffic for planning purpose. Traditionally, models with deterministic parameters were implemented to estimate transit travel time at route level. With the advanced technologies developed in the last decade or two, computer simulation and the deployment of ATIS components may provide real time information to assist in collecting data of better quality at a large scale and in evaluating and monitoring the operation of a transit system. However, before adequate resources become available to transit agencies, more detailed and portable models need to be developed at a less aggregate level such as bus stop to better estimate transit vehicle delay. In the next chapter, the procedure for and results from a transit travel time survey conducted in Broward County, Florida are described. The data collected were used in the subsequent tasks to develop a door choice model to predict the dwell time that may be observed at a bus stop under typical operating conditions.

3. STUDY AREA AND DATA COLLECTION

Dwell time at a bus stop is highly correlated with the number of boarding and alighting passengers since a higher demand at a bus stop means longer dwell time for passengers to get on and off the bus. With more resource devoted to the improvement of public transit service, ridership is expected to increase. Consequently, dwell time at a bus stop should be modeled in terms of ridership to allow bus travel time to be accurately estimated. In a typical bus operation, passengers may board a bus through only the front door but may choose to get off the vehicle at either the front or rear door. As a result, bus dwell time is mainly influenced by three factors: the number of passengers alighting through the front and rear doors and boarding through the front door. For example, dwell time will be longer if all passengers only alight and board through the front door of a bus vehicle. On the other hand, if a proportion of alighting passengers choose to get off a bus at the rear door, the dwell time could be reduced due to a better utilization of both exits on a bus. In this study, a transit dwell time survey was conducted to collect data on the durations and number of passengers boarding and alighting through the front and rear doors on a bus vehicle. The Broward County Transit (BCT) system was selected as the study area. Based on the input from the BCT staff, Routes 1, 22, and 40 were selected for collecting bus dwell time data. Figure 2 shows the alignments of the three selected routes in Broward County.

Two survey units, each of two people, conducted the dwelling time survey on June 2 (Wednesday), 3 (Thursday), and 8 (Tuesday), 2004. The ride check approach described in the TCQSM was adopted for collecting the bus travel time data [KIT99]. Each survey unit rode transit vehicles over an entire route for several trips at different times of day. To record locations of a bus at a given time, a GPS receiver was used. The GPS receiver has a 12/24 clock capable to provide regular and military time reading precision of one second.

Figure 3 shows the survey form designed for Surveyor 1 in each survey unit, who was responsible for collecting the following data:

- type of delay encountered, i.e., delay at a bus stop or signalized intersection;
- time when a bus completely stops at a bus stop or signalized intersection;
- time when the front door is open at a bus stop;
- number of alighting passengers and the time when alighting completes at the front door;
- number of boarding passengers and the time when boarding completes at the front door;
- time when the front door closes; and
- time when a bus clears out of the bus station or signalized intersection to traverse on the regular moving lane on the street.

Note that items 3 to 6 in the above list are not associated with the delays at signalized intersections. Figure 4 shows the survey form designed for Surveyor 2, who was responsible to collect the following data:

- type of delay encountered;
- number of alighting passengers and the time when alighting completes at the rear door;
- GPS readings at bus stop or intersection; and
- notes of atypical delays, e.g., incidents, encountered at a particular location.

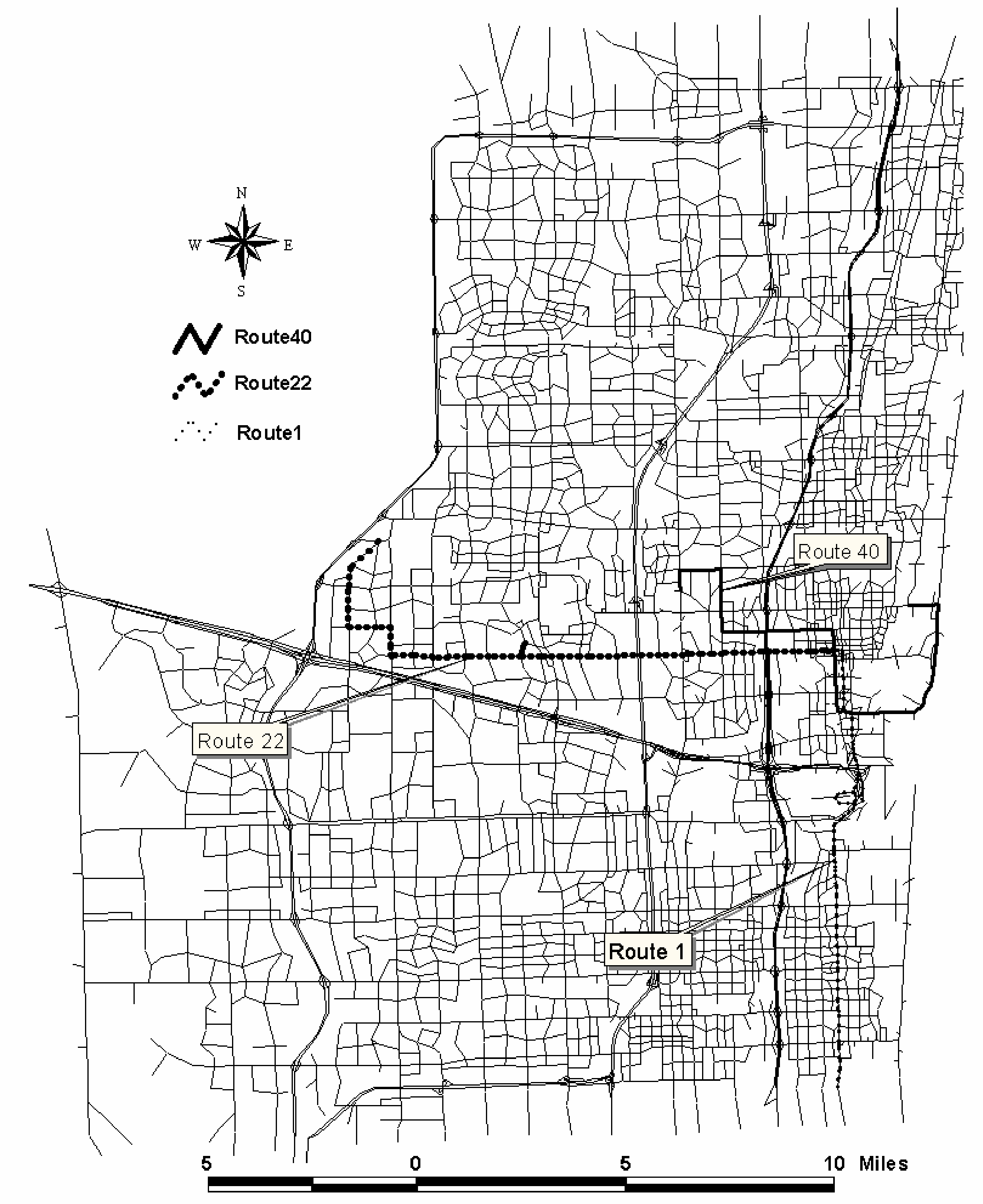

Figure 2. Transit Routes Sampled in Broward County Travel Time Survey

BROWARD COUNTY TRANSIT DATA COLLECTION (Front Door)

Route ________ Vehicle ID ________ Date ________ Surveyor: ________
Weather ________ Page ________ Direction ________

When bus stops, circle "S" for Bus Stop, " I " for Intersection, or leave blank for others.

ID	Delay*	Arrival time	Door open	Off	On	Door Close	Departure time
1	S, I			/	/		
2	S, I			/	/		
3	S, I			/	/		
4	S, I			/	/		
5	S, I			/	/		
6	S, I			/	/		
7	S, I			/	/		
8	S, I			/	/		
9	S, I			/	/		
10	S, I			/	/		
11	S, I			/	/		
12	S, I			/	/		
13	S, I			/	/		
14	S, I			/	/		
15	S, I			/	/		
16	S, I			/	/		
17	S, I			/	/		
18	S, I			/	/		
19	S, I			/	/		
20	S, I			/	/		
21	S, I			/	/		
22	S, I			/	/		
23	S, I			/	/		
24	S, I			/	/		
25	S, I			/	/		
26	S, I			/	/		
27	S, I			/	/		
28	S, I			/	/		
29	S, I			/	/		
30	S, I			/	/		
31	S, I			/	/		
32	S, I			/	/		
33	S, I			/	/		
34	S, I			/	/		

Weather: 1.Clear 2. Cloudy 3. Light Rain 4. Heavy Rain

Remark: 1. Parked Cars 2. Pedestrains 3. Wheelchair lift 4. Incident 5. Other (please specify)

Notice:

1. Record the cause & duration of delay when speed is lower than 15 mph.
2. Record how many cycle failure occurs at intersections.
3. Make sure the record IDs in the tables for the front and rear doors are matched.

Figure 3. Transit Travel Time Survey Form (Front Door)

BROWARD COUNTY TRANSIT DATA COLLECTION (Rear Door)

Route ________ Vehicle ID ________ Date ________
Weather ________ Page ________ Direction ________
Surveyor: ________

When bus stops, circle "S" for Bus Stop, "I" for Intersection, or leave blank for others.

ID	Delay *	Off	GPS		Remark
			Longitude	Latitude	
1	S, I	/			
2	S, I	/			
3	S, I	/			
4	S, I	/			
5	S, I	/			
6	S, I	/			
7	S, I	/			
8	S, I	/			
9	S, I	/			
10	S, I	/			
11	S, I	/			
12	S, I	/			
13	S, I	/			
14	S, I	/			
15	S, I	/			
16	S, I	/			
17	S, I	/			
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27	S, I	/			
28	S, I	/			
29	S, I	/			
30	S, I	/			
31	S, I	/			
32	S, I	/			
33	S, I	/			
34	S, I	/			

Weather: 1.Clear 2. Cloudy 3. Light Rain 4. Heavy Rain
Remark: 1. Parked Cars 2. Pedestrains 3. Wheelchair ramp 4. Incident 5. Other (please specify)
Notice:
1. Record the cause & duration of delay when speed is lower than 15 mph.
2. Record how many cycle failure occurs at intersections.
3. Make sure the record IDs in the tables for the front and rear doors are matched.

Figure 4. Transit Travel Time Survey Form (Rear Door)

The location information collected during the survey was utilized in the in-house geocoding process to identify the location of transit vehicles at a bus stop or intersection. A pre-test survey was launched on June 2 (Wednesday), 2004 to collect bus travel time data for Routes 1 and 22. After the pre-test survey was performed, the responsibilities of each surveyor were adjusted based on feedbacks from the field surveyors. According to the observations made by the surveyors in both units during the pre-test survey, the bus arrival and door open times were nearly identical. Similar observations were also made regarding the times when the front door closed and when the bus departed. Subsequently, Surveyor 1 was relieved the responsibility of recording the door open/close times when a bus was operating in a typical situation. However, Surveyor 1 was still required to record the door open/close times when there was a significantly long duration between bus arrival and door opening or between door closing and bus departure.

Following the pre-test survey, more surveys were conducted on Routes 1, 22, and 40 on June 3 (Thursday) and June 8 (Tuesday). The survey schedule for each of the two dates was given in Table 13. The schedule was determined mainly by considering the schedules of the selected bus routes as well as the feasibility of a time window that allowed the members of a survey unit to rest for at least 30 minutes before continuing the survey on the next bus trip.

Table 13. Transit Dwell Time Survey Schedule

Time	Date		
	06/02/04 (Wed.)	06/03/04 (Thu.)	06/08/04 (Tue.)
6:30 ~ 9:30		6:45 Route1-NB 7:25 Route40-EB 8:05 Route22-WB 8:40 Route 40-WB	7:00 Route22-EB 8:15 Route1-SB
9:30 ~ 15:00	13:45 Route1-NB 13:40 Route22-EB	9:05 Route22-EB 10:15 Route1-SB 10:55 Route 40-EB 13:10 Route 40-WB	
15:00 ~ 19:30	15:30 Route1-SB 15:55 Route 22-WB	14:30 Route1-NB 14:55 Route 40-EB 16:00 Route1-SB 16:40 Route40-WB	15:40 Route22-EB 17:05 Route22-WB

Notes: Route 1-NB: Aventura Mall to Central Terminal
Route 1-SB: Central Terminal to Aventura Mall
Route 22-EB: Sawgrass Mills Mall to Central Terminal
Route 22-WB: Central Terminal to Sawgrass Mills Mall
Route 40-EB: Lauderhill Mall to Galleria Mall
Route 40-WB: Galleria Mall to Lauderhill Mall

Table 14 summaries the number of trips sampled during different time periods for the three selected routes. The time periods were defined as morning-peak (AM), off-peak, and afternoon-peak (PM), which are 6:30 to 9:30 AM, 9:30 AM to 3:00 PM, and 3:00 to 7:30 PM, respectively.

Table 14. Transit Dwell Time Survey Periods

	Direction	AM Peak	PM Peak	Off Peak
Route 1	N	1	1	1
	S	1	2	1
Route 22	E	1	1	2
	W	1	2	0
Route 40	E	1	1	1
	W	1	1	1

4. SURVEY RESULTS

This section summarizes the survey results. After the survey was completed, the transit travel time data were entered into a database in MS-Excel format. Each record contains the following information about the delay encountered during a sampled bus trip on a given route:

- Record ID
- Route ID (1, 22, or 40)
- Direction (E, W, N, or S)
- Bus vehicle ID
- Sample date
- Delay type (S for stop delay; I for intersection delay)
- Latitude and longitude of the location where a delay occurred
- Bus arrival time
- Front door open time
- Number of passengers alighting through front door
- Ending time for alighting through front door
- Number of passengers boarding through front door
- Ending time for boarding at front door
- Number of passengers alighting through rear door
- Ending time for alighting at rear door
- Front door close time
- Bus departure time

Based on the coordinate information from the GPS receivers, the survey data were matched with the bus stop locations from a GIS bus stop layer. Originally, a total of 1,045 records were collected during the survey. Among these records, 256 records were related to intersection delays and were excluded from the remaining bus dwell time analysis. An additional 57 records contained special remarks indicating irregular conditions during the data collection process. Table 15 provides the number of records for each remark code. As shown in Table 15, a total of 16 records could not be geocoded due to missing GPS readings, which occurred near the terminal area of Ft. Lauderdale International Airport. Loading/unloading bicycle unto a bus vehicle was also observed at 12 bus stops during the survey. The survey results show that the number of records in each remark category was insignificant and these records were excluded from the remaining analysis.

Overall, 732 records contained information on delays at bus stops. A total of 692 records remained after excluding those collected at the bus terminals. This exclusion was necessary because at a terminal where a bus trip starts, passenger boarding/alighting was not observed. At such terminals, passenger boarding/alighting patterns may also be different from those at a typical bus stop because of the prolonged period between a bus' arrival from a previous trip and departure for the next trip.

Table 15. Remark Codes for Transit Dwell Time Survey

Remark	Description	Number of Records
1	Speed slower than 15 mph	6
2	Traffic congestion	4
3	Roadway construction	0
4	Lifting wheelchair	2
5	Loading/unloading bicycle	12
6	Elder passenger getting on/off a bus	1
7	Bus station located in front of a intersection stop line	7
8	Driver left the vehicle	2
9	Blocked by other buses	2
10	Open bridge	0
11	No signal from GPS receiver	16
12	Unreasonable long delay observed at a time point	3
13	Delayed for more than 1 signal cycle at an intersection	0
14	Emergency vehicles	0
15	Stop without opening the doors	2
Total		57

Data validation was performed to assure that the data were correctly entered into the database by cross-examining the beginning and ending times of a specific event such as alighting or boarding through a given door. After the errors in the data entry process were identified and corrected, the data were then used in the dwell time analysis. Table 16 gives the sample sizes by route and by survey period before and after the records of the terminals were excluded. The numbers of samples collected during the AM peaks for the three selected routes are relatively close to those collected during off peak. More PM samples were collected for Routes 1 and 22 since an additional bus trip (see Table 14) was sampled for each of these two routes.

Table 16. Sample Sizes for Dwell Time Survey by Route and Period

Data Set	Number of Records											
	Total			Route 1			Route 22			Route 40		
	AM	PM	Off	AM	PM	Off	AM	PM	Off	AM	PM	Off
Original	214	329	189	75	129	68	49	102	41	90	98	80
Validated	203	313	176	71	123	63	45	95	37	87	95	76

Figures 5 to 7 illustrate the average durations in seconds for a passenger to alight through the front door, alight through the real door, and board through the front door, respectively. To plot the charts, the elapsed times to alight or board a bus through a specific door at a given bus stop were first calculated. For example, the alighting duration at a given door was obtained by subtracting the door open time from the ending time of the event. As stated in the previous chapter, the difference between bus arrival time and door open time was negligible. Therefore, bus arrival time was used when door open time was not specified. For the boarding time duration, it was calculated as the difference between the beginning time of alighting through the front door and the ending time of boarding. The average was then obtained by dividing the resulted durations with the number of passengers.

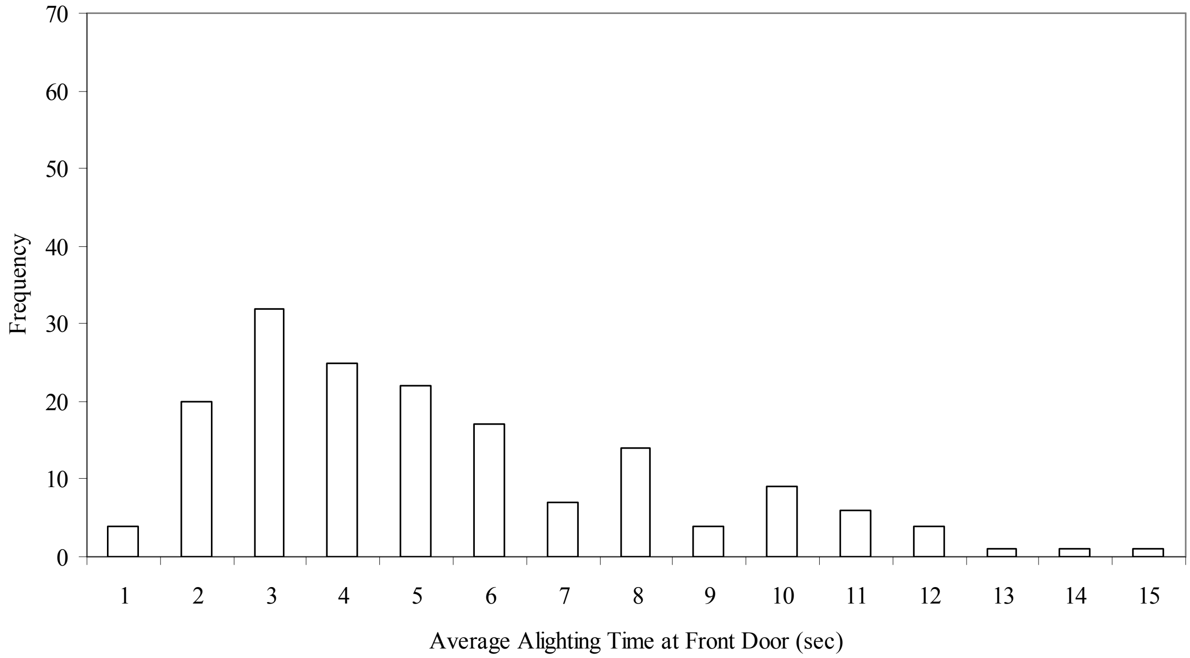

Figure 5. Average Sampled Alighting Time per Passenger (in Seconds) at Front Door

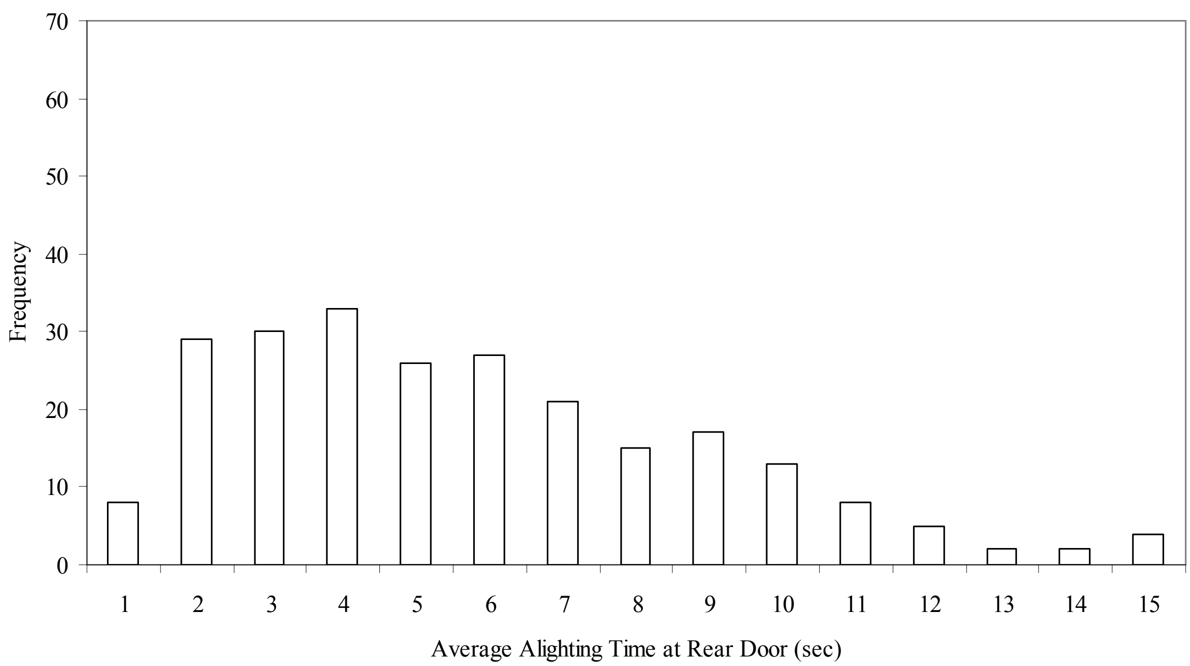

Figure 6. Average Sampled Alighting Time per Passenger (in Seconds) at Rear Door

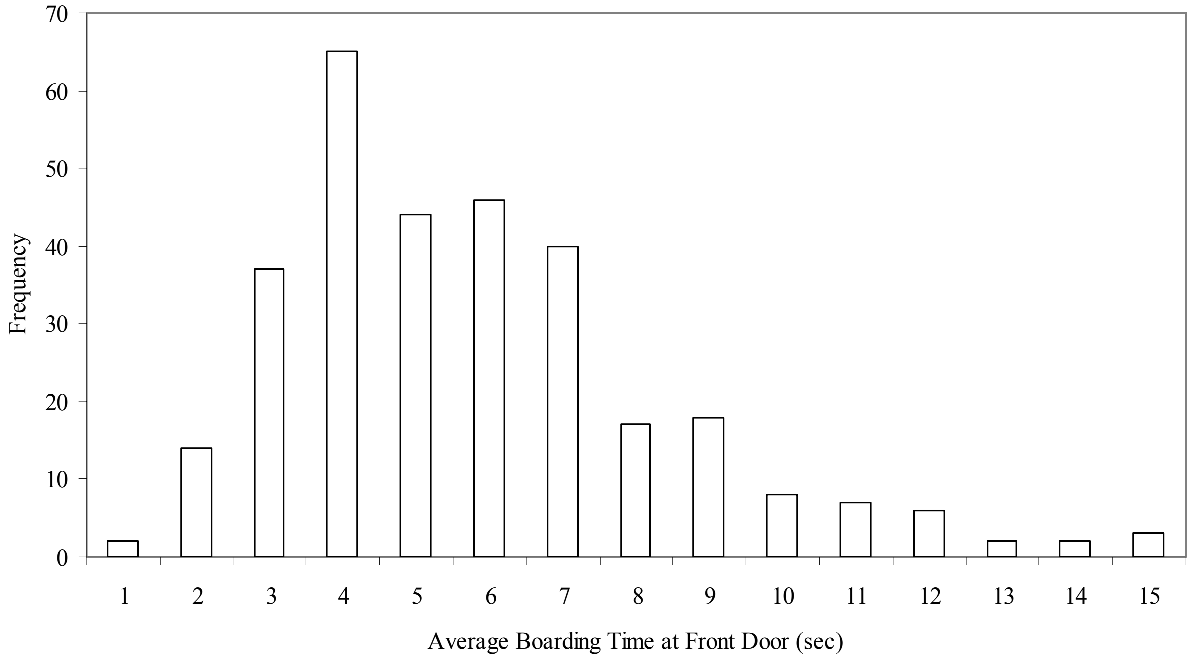

Figure 7. Average Sampled Boarding Time per Passenger (in Seconds) at Front Door

Note that Figures 5 to 7 do not include the records with an average boarding or alighting time per passenger longer than 16 seconds.

Table 17 illustrates the effect of these extreme observations. In the table, Data 1 and 2 refer to the data sets with and without the extreme observations, respectively. The mean and standard deviation are the overall average boarding or alighting time for the stops in the data set. Data 1 had significant greater mean and standard deviation values for alighting duration at both front and rear doors. As a result, this study focused on analyzing the records in Data 2.

Table 17. Average Sampled Durations for Alighting/Boarding at Front and Rear Doors

Statistic	Front Off		Front On		Rear Off	
	Data 1	Data 2	Data 1	Data 2	Data 1	Data 2
Number of Records	172	168	312	311	254	240
Mean (sec)	5.70	5.33	4.99	4.94	7.14	5.69
Standard Deviation	4.01	3.14	2.72	2.59	7.16	3.27

5. BUS DWELL TIME ESTIMATION

This chapter presents the models developed in this study to estimate the bus dwell time at a given bus stop and transit link travel time. The study calibrated a door choice model for alighting passengers at a given bus stop, assuming that passengers board only through front door. The door choice model quantifies dwell time based on ridership, time of day, and average boarding/alighting duration per passenger. A computer program was also developed for calculating transit link time as the sum of highway travel time, dwell time, and deceleration and acceleration delays. In the following sections, the results from examining the distributions of the elapsed time for a passenger to alight and board a bus vehicle are presented. The findings from the calibrated door choice model are also described.

5.1 Distributions of Average Alighting Time per Passenger

The data from the transit travel time survey were used to estimate the dwell time at a bus stop. The average duration for a passenger to board a bus through the front door at a given stop was first computed. This mathematic mean was used as the time needed for a passenger to board a bus through the front door. The elapsed times for passengers to alight from a bus through the front and rear doors were similarly calculated. Figures 8 to 12 illustrate the frequency distributions for the alighting durations at front door, alighting time at rear door, combined alighting time at front and rear door, boarding time at front door, and combined boarding and alighting time, respectively. SAS (Statistics Analysis Software) Version 9.0 was used to fit the observed durations into the gamma, lognormal, and Weibull distributions. The probability density functions for these distributions are given as follows:

gamma:
$$p(x)=\begin{cases}\dfrac{h\times 100\%}{\Gamma(\alpha)\sigma}\left(\dfrac{x-\theta}{\sigma}\right)^{\alpha-1}\exp\left(-\left(\dfrac{x-\theta}{\sigma}\right)\right) & \text{for } x>\theta \\ 0 & \text{for } x\le\theta\end{cases} \tag{47}$$

lognormal:
$$p(x)=\begin{cases}\dfrac{h\times 100\%}{\sigma\sqrt{2\pi}\,(x-\theta)}\exp\left(-\dfrac{\left(\log(x-\theta)-\zeta\right)^2}{2\sigma^2}\right) & \text{for } x>\theta \\ 0 & \text{for } x\le\theta\end{cases} \tag{48}$$

Weibull:
$$p(x)=\begin{cases}\dfrac{c\times h\times 100\%}{\sigma}\left(\dfrac{x-\theta}{\sigma}\right)^{c-1}\exp\left(-\left(\dfrac{x-\theta}{\sigma}\right)^{c}\right) & \text{for } x>\theta \\ 0 & \text{for } x\le\theta\end{cases} \tag{49}$$

where

- θ = threshold parameter;
- α = shape parameter ($\alpha > 0$);
- σ = scale parameter for a gamma distribution ($\sigma > 0$);
- ζ = scale parameter for a lognormal distribution ($-\infty < \zeta < \infty$);
- c = scale parameter for a Weibull distribution ($c > 0$); and
- h = width of histogram interval.

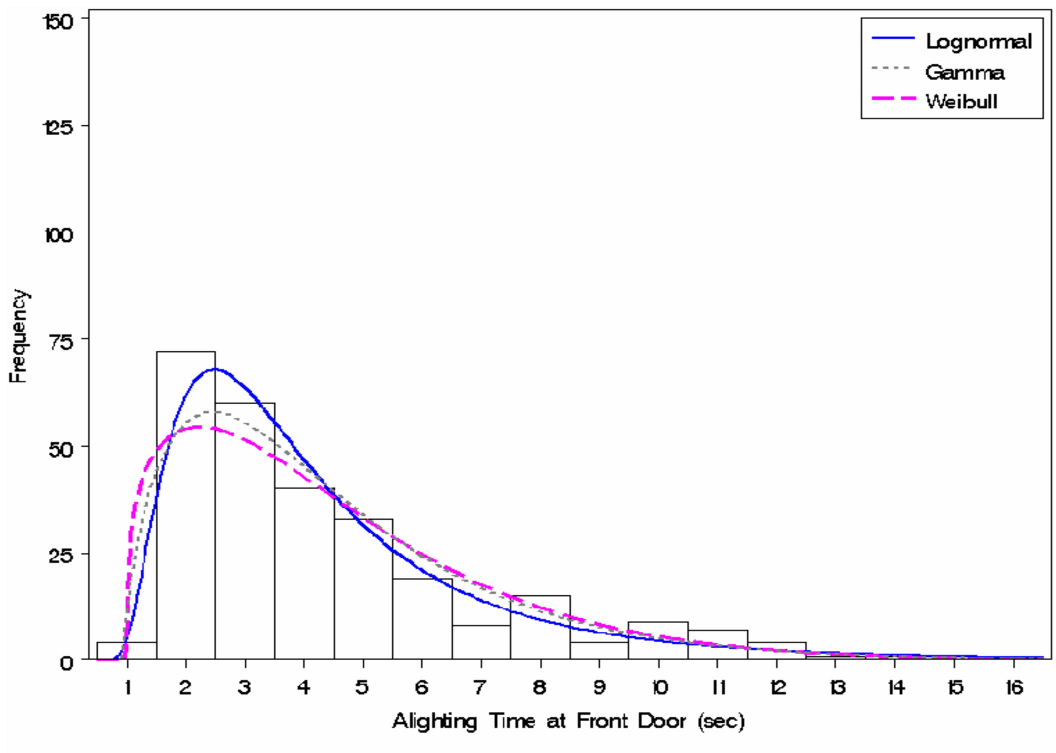

Figure 8. Passenger Alighting Time Distribution at Front Door

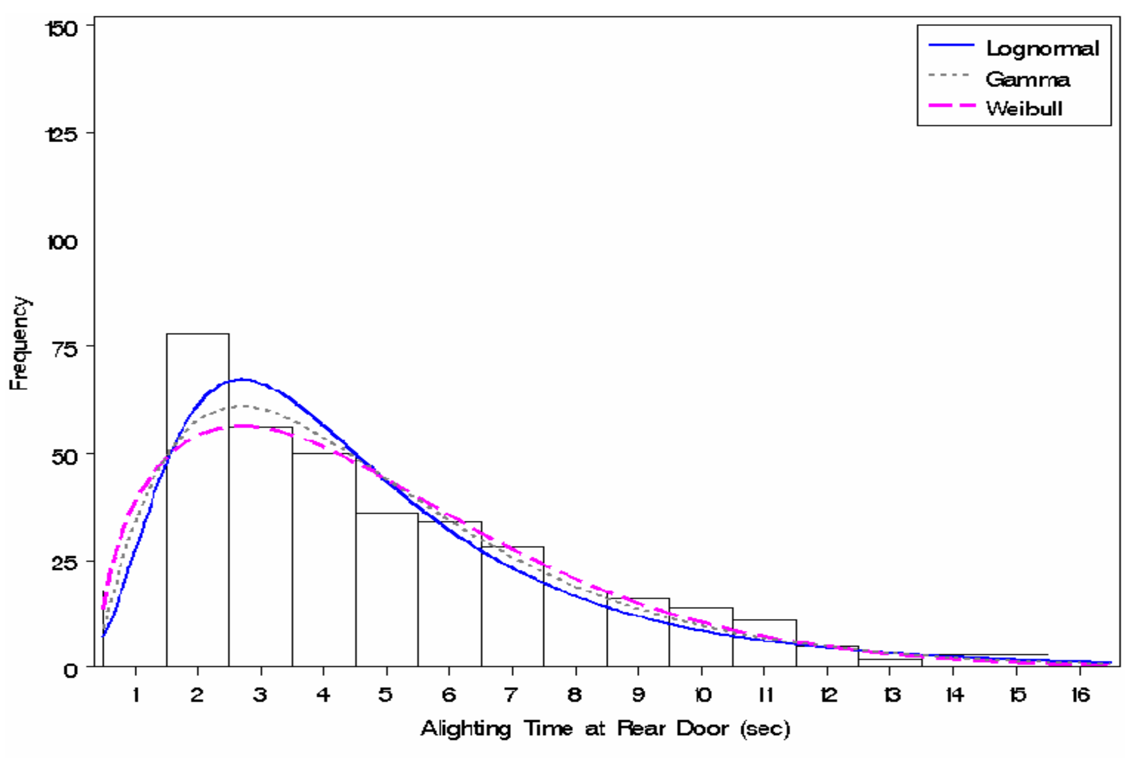

Figure 9. Passenger Alighting Time Distribution at Rear Door

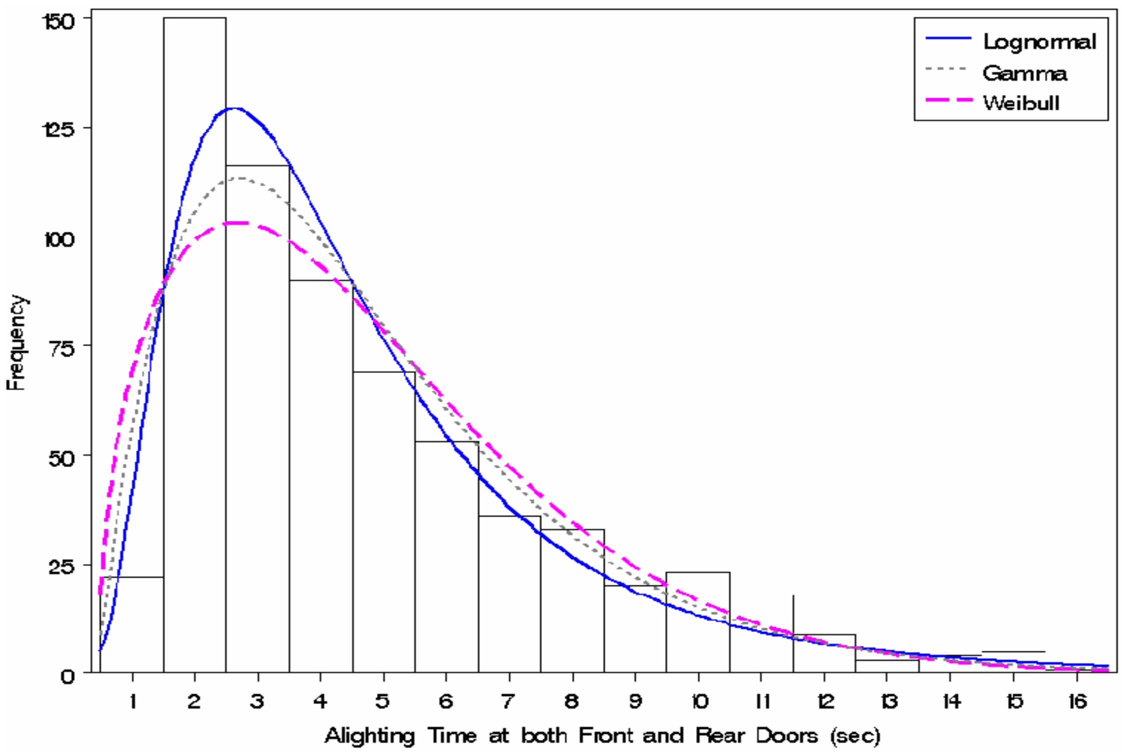

Figure 10. Passenger Alighting Time Distribution at Both Front and Rear Doors

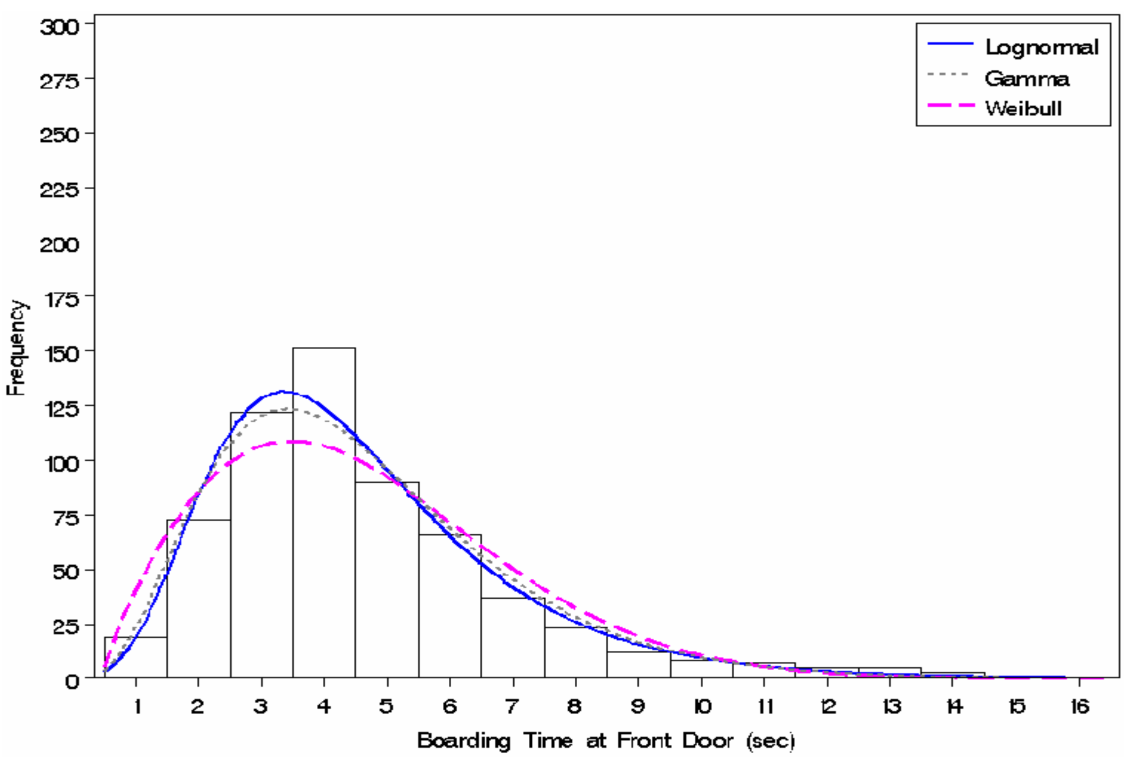

Figure 11. Passenger Boarding Time Distribution at Bus Front Door (sec)

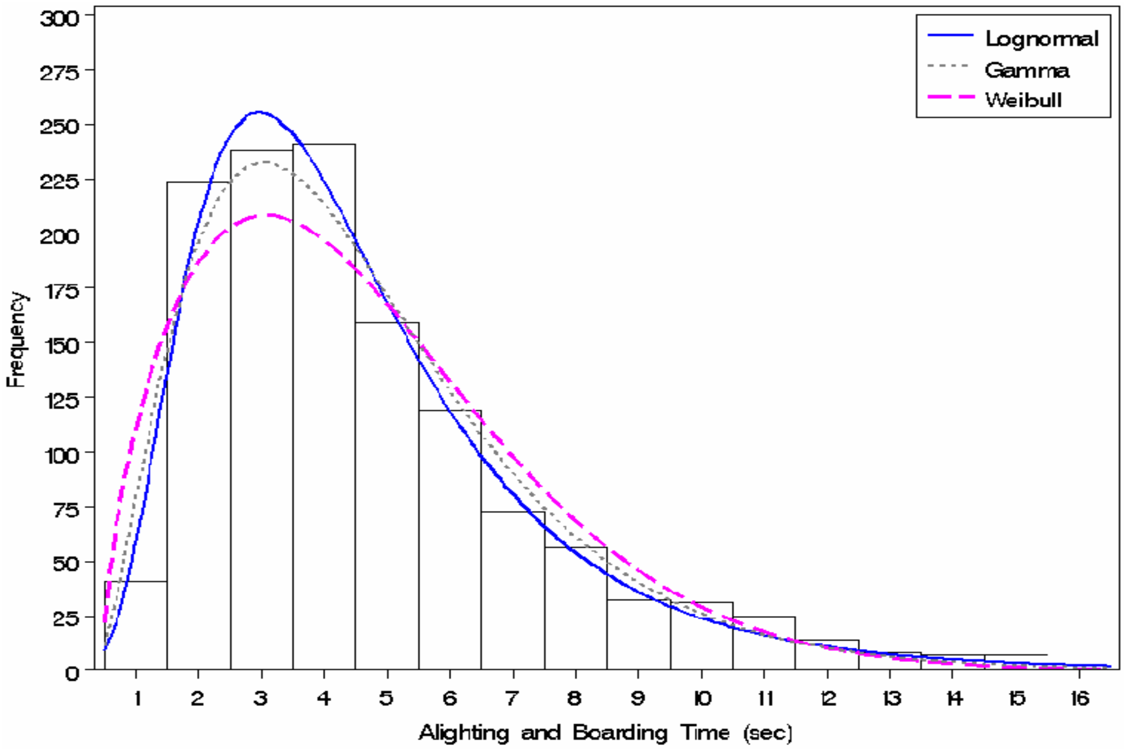

Figure 12. Passenger Boarding/Alighting Time Distribution (sec)

From the figures, the lognormal curves appear to fit the elapsed times better than the other distributions. When combining the alighting durations observed from both exit doors, none of the distribution provided an acceptable fit. As a result, the time required for a passenger to alight from a bus should be modeled explicitly for each door. The same conclusion also applies to the data from combining from both alighting and boarding activities. Table 18 provides the statistics for the observed elapsed times and the parameters estimated by maximum likelihood for the fitted lognormal distributions for front-off, front-on, and rear-off passengers.

Table 18. Observed and Fitted Lognormal Parameters for Alighting/Boarding Durations

	Statistic	Front Off	Front On	Rear Off
Survey	Sample Size (passenger)	281	623	373
	Mean (sec)	4.47	4.59	4.90
	Standard Deviation	2.88	2.41	3.14
Fitted Lognormal	θ	0.61	-0.91	-0.36
	α	1.10	1.62	1.48
	σ	0.69	0.41	0.60
	Mean (sec)	4.44	4.57	4.91
	Standard Deviation	3.00	2.33	3.49

5.2 Door Choice Model for Alighting Passengers

A binary choice model for an alighting passenger to choose either the front or rear door was developed. The model form is given below.

$$P(Y=1)=\frac{e^U}{1+e^U} \tag{50}$$

where

$P(Y{=}1)$ = probability for choosing the front door to get off the bus; and
U = utility function for an alighting passenger.

Seven variables were compiled and applied in the calibration of the door choice model. They are:

- *ON*: total number of boarding passengers at a given stop;
- *TOTALOFF*: total number of alighting passengers at a given stop;
- *ONBOARD*: total passengers onboard before bus doors were open at a given stop;
- *TIMEPOINT*: dummy variable for a given bus stop, 1 for time point and 0 otherwise;
- *AM*: dummy variable, 1 for records observed during AM peak and 0 otherwise;
- *PM*: dummy variable, 1 for records observed during PM peak and 0 otherwise; and
- *Off*: dummy variable, 1 for records observed during off peak and 0 otherwise.

A time point refers to a location on a bus route that is assigned a fixed scheduled time that is part of a larger line schedule. The above variables were created for every alighting passenger recorded at each bus stop specified in Data 2 (see Table 17). For example, the following two records may be created for a given bus top observed with two alighting passengers:

0	5	15	1	1	0	0
1	5	15	1	1	0	0

The first record specifies the following information for a sampled passenger:

- Passenger alighted through the rear door (i.e., $Y = 0$);
- Five passengers boarded the bus at the stop;
- 15 passengers were onboard before the door opened; and
- Sample was collected during the AM peak.

The second record shows that the passenger made a different choice of the door to alight from the bus. A total of 902 passenger records were created. LIMDEP (LIMited DEPendent variable models) Version 8.0 was used to calibrate the choice model. The restricted log likelihood, $\log(L_0)$, is equal to -624.3315 and is computed as follows:

$$\text{Log } L_0 = n_0 \times \log P_0 + n_1 \times \log P_1 \tag{51}$$

where

n_0, n_1 = number of individuals choosing rear (0) and front (1) doors; and
P_0, P_1 = observed proportion of individuals in the sample choosing rear (0) and front (1) doors.

A total of 127 models specified with every possible combination of the seven explanatory variables were calibrated and examined. Table 19 shows the calibration results for the models with the parameter coefficients that are significantly different from zero. In the table, *L* is the value of the log likelihood function.

Table 19. Calibration Results for Door Choice Models

Model #	Variable	$\hat{\beta}$	*P*-value	*L*
1	ON	-0.0246	0.0467	-623.1899
2	ONBOARD	-0.0046	0.0217	-622.5688
3	TIMEPOINT	-0.6318	0.0009	-619.4701
4	OFF	-0.3060	0.0366	-623.0086
5	ONBOARD	-0.0027	0.1970	-618.6365
	PM	-0.5523	0.0059	
6	ONBOARD	-0.0086	0.0037	-614.5125
	TIMEPOINT	-0.5806	0.0041	
	PM	0.3972	0.0042	
7	ONBOARD	-0.0153	0.0001	-617.0013
	AM	0.3126	0.0581	
	PM	0.5487	0.0009	
8	TOTALOFF	0.0292	0.0291	-612.1020
	ONBOARD	-0.0134	0.0003	
	TIMEPOINT	-0.7939	0.0005	
	PM	0.4410	0.0017	
9	ONBOARD	-0.0137	0.0007	-612.7249
	TIMEPOINT	-0.5824	0.0041	
	AM	0.3135	0.0591	
	PM	0.5716	0.0006	
10	ON	-0.0390	0.0551	-614.4191
	TOTALOFF	0.0356	0.0332	
	ONBOARD	-0.0198	0.0001	
	AM	0.3887	0.0224	
	PM	0.6120	0.0003	
11	TOTALOFF	0.0363	0.0084	-609.2059
	ONBOARD	-0.0213	<0.0001	
	TIMEPOINT	-0.8389	0.0002	
	AM	0.4098	0.0165	
	PM	0.6777	0.0001	

Table 19 shows that Model 11 is the best in explaining the variation in the door choices by passengers alighting from a bus since it has the highest *L* value. The model shows that the number of passengers utilizing the front door to get off the bus is positively related to the total number of alighting passengers. In other words, a person is more likely to get off the vehicle through the front door when there is a larger number alighting passengers at a given bus stop. The time of day effect, i.e., AM or PM peaks, also appears in favor of getting off through the front door. The rear door was a better choice when there were more onboard passengers. When the bus stop was a time point, which generally indicated a larger number of alighting and boarding passengers, passengers are more likely to get off the bus from the rear door. Table 20 gives the actual and predicted frequencies for the calibration of the binary choice model from the best model. The model correctly predicted alighting through the rear door for about two thirds of the time and alighting through the front door about one half of the time.

Table 20. Actual and Predicted Frequencies from the Best Model

Door Choice	Observed	Model Predicted Correctly	Model Predicted Incorrectly
Rear	471	310	161
Front	431	214	217
Total	902	524	378

5.3 Model Implementation

One way to implement the door choice model to better estimate the dwell time at a bus stop is through Monte Carlo simulation. For this purpose, the number of alighting passengers must be known. The steps to implement the model to estimate the dwell time at a given bus stop are as follows:

1. Estimate the proportion of alighting passengers getting off a bus at both exists using the model described in Section 5.2.
2. Calculate the number of alighting passengers through both doors in integer.
3. Determine the elapsed times for boarding and alighting from a bus from the corresponding lognormal distributions.
4. Sum the elapsed time needed for each activity at each door;
5. Determine the total dwell time at a bus stop as the maximum passenger activity duration at the front door, i.e., front-off plus front-on, and at the rear door, i.e., rear-off.

In Step 3, the time needed for a passenger to board or alight from a bus may be estimated as follows:

- Generate a random number, U, between 0 and 1 from a uniform distribution, $U(0, 1)$;
- Return $x = F^{-1}(U)$, the inverse function of $F(x)$.

$F(x)$ is the cumulative distribution function (CDF) of the corresponding lognormal function for a passenger activity at a given door. The CDF is given as follows:

$$F(x) = \Phi\left(\frac{\log(x-\theta)-\zeta}{\sigma}\right) \quad \text{for } x > \theta \qquad (52)$$

Note that the shortest duration for a passenger to board or alight from a bus was 0.5 second from the field observations. As a result, the numbers enumerated from the lognormal distribution should be discarded if they are less than 0.5 second.

Due to the considerable simulation time and technical knowledge required for a user to understand the methodology, the Monte Carlo simulation was not adopted in this study for practical applications. Instead, the mean alighting and boarding times calculated from the survey data were used as default to estimate the dwell time at a bus stop. In other words, the mean values are used to multiply the number of persons boarding and alighting from a bus vehicle to arrive at the total dwell time at a given bus stop. Users have the option to provide their own values for these two required parameters.

5.4 Computer Applications for FSUTMS

To implement the door choice model calibrated in this study in the estimation of bus dwell time, a Visual Basic.net (VB.net) program, DwellTime.exe, was developed. The program requires the following input:

- Average boarding time per passenger;
- Average alighting time per passenger; and
- Passenger activity log file.

The passenger activity log file is a comma delimited text file currently specified with the following data attributes:

- Stop ID;
- TOTALOFF (total number of alighting passengers at a given stop);
- ONBOARD (total passengers on board before bus doors were open at a given stop);
- TIMEPOINT (1 if a bus stop is a time point, 0 otherwise);
- AM (1 if a bus is operated between 6:30 and 9:30 AM, 0 otherwise); and
- PM (1 if a bus is operated between 3:00 and 7:30 PM, 0 otherwise).

To run the program, users need to type the command, either at the Start menu or under the DOS prompt, as follows:

Path\DwellTime.exe *,*, input path and file name, output path and file name

The first two parameters in the above command specify the values for the mean alighting and boarding time. The *'s indicate the default values will be used in the calculation. The input path and file name determine where the passenger activity file is stored. The user then specifies the path and name for the output file. Currently, the program only creates output file in Microsoft Excel format. Table 21 shows an example output of the bus dwell time calculation, where the first six columns are the mirror output of the values specified in the passenger activity log file. The estimated dwell time is given in the last column. Appendix I provides the VB source code.

Table 21. Example Output of DwellTime Module

Node	Alighting	Boarding	Time Point	AM	PM	Front-Off %	Rear-Off %	Front-Off	Rear-Off	Front-Off Time	Boarding Time	Total at Front	Rear-Off Time	Dwell Time
-4128	0	15	0	0	0	42.08	57.92	0	0	0.00	74.10	74.10	0.00	74.10
-4117	0	1	0	0	0	49.47	50.53	0	0	0.00	4.94	4.94	0.00	4.94
-4106	0	1	0	0	0	49.47	50.53	0	0	0.00	4.94	4.94	0.00	4.94
-4105	0	4	0	0	0	47.87	52.13	0	0	0.00	19.76	19.76	0.00	19.76
-4104	2	0	0	0	0	51.81	48.19	1	1	5.54	0.00	5.54	5.54	5.54
-4102	2	0	0	0	0	51.81	48.19	1	1	5.54	0.00	5.54	5.54	5.54
-4396	4	2	0	0	0	52.56	47.44	2	2	11.08	9.88	20.96	11.08	20.96
-4394	4	2	0	0	0	52.56	47.44	2	2	11.08	9.88	20.96	11.08	20.96
-4392	1	0	0	0	0	50.91	49.09	1	0	5.54	0.00	5.54	0.00	5.54
-4390	1	7	0	0	0	47.18	52.82	0	1	0.00	34.58	34.58	5.54	34.58
-4388	1	1	0	0	0	50.37	49.63	1	0	5.54	4.94	10.48	0.00	10.48

Notes:

Front-Off %: percentage estimated from the door choice model for alighting passengers through the front door of a bus vehicle.
Rear-Off %: same as "Front_Off %," but for the rear door of a bus vehicle.
Front-Off: resulting number of passengers alighting through the front door of a bus vehicle.
Rear-Off: same as "Front_Off," but for the rear door of a bus vehicle.
Front-Off Time: alighting time at the front door in second by multiplying the number of alighting passengers with the average alighting time per passenger.
Boarding Time: number of boarding passengers times the average boarding time per passenger in second through front door.
Total at Front: "Front_Off Time" + "Boarding Time."
Rear-Off Time: same as "Front_Off Time," but for the rear door of a bus vehicle.
Dwell Time: the larger number of "Total at Front" and "Rear-Off Time."

Figure 13 shows the estimated and surveyed total dwell time and the corresponding ridership for each of the three surveyed bus routes. It may be seen that the durations of total sampled dwell time at the route level were between 1.5 to 15 minutes and increased with the route ridership. Note that the results presented in Figure 13 were based on the samples obtained from relatively lightly used bus routes. For example, the smallest observed ridership was 25 persons and the peak load factor (calculated as the total passengers on board divided by bus seating capacity, which is 40) was merely 0.375. The dwell time component may not be ignored if ridership is significant. Figure 13 also shows that the dwell-time model may have a more simplistic structure than the true model, i.e., it is underspecified, since the total dwell durations were consistently underestimated. Therefore, additional explanatory variables need to be identified and incorporated into the dwell time model.

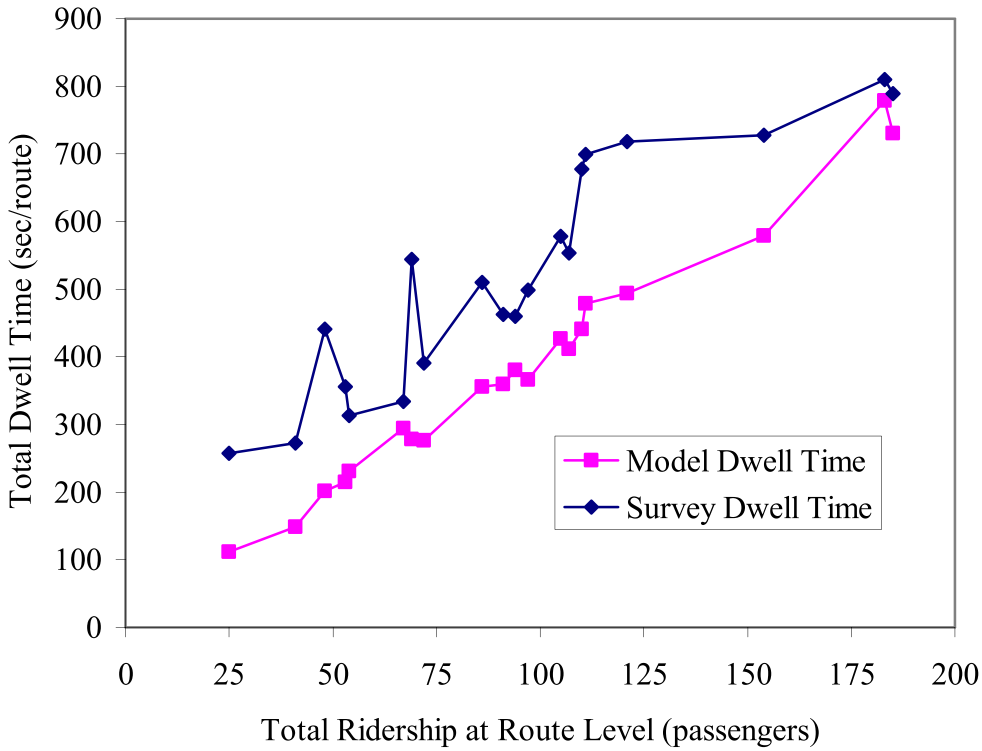

Figure 13. Estimated versus Surveyed Total Dwell Time at the Route Level

Note that the DwellTime module estimates bus dwell time at a bus stop only and does not consider the delay caused by the deceleration from normal operating speed to a complete stop and the acceleration from zero back to normal speed. Another VB application, TLT.exe, was developed to separately calculate the overall travel time on a transit link considering deceleration and acceleration delays and dwell time at a bus stop. Figure 14 shows the time-speed diagram for transit bus operation (refer to Table 3 for the deceleration and acceleration rates for a bus vehicle). The figure indicates that it takes 47 seconds for a bus vehicle to accelerate from zero to a speed limit of 45 mph and 18 seconds to decelerate to a complete stop. The distances that a bus travels during the acceleration-deceleration phase add up to more than 1,600 feet. As a result, if the distance between bus stops is short, bus vehicles will not be able to accelerate to the normal operating speed. To better estimate transit speed traversing on a roadway, this study considered the operating characteristics depicted in Figure 14 in calculating the transit link time in the TLT module.

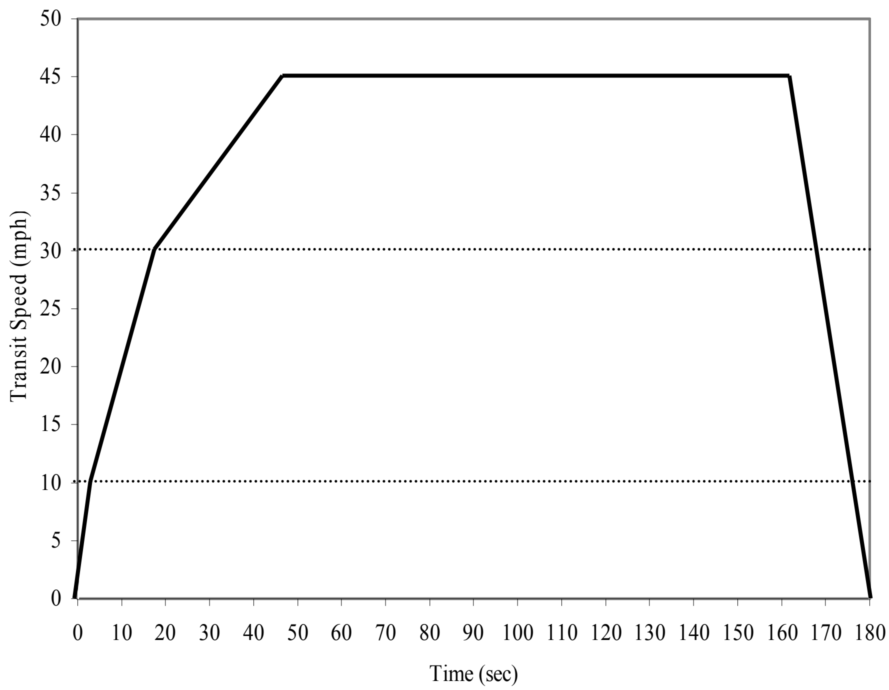

Figure 14. Transit Speed and Time Diagram

Figure 15 shows the graphical user interface (GUI) of the program. The TLT module requires the following input in addition to those for the DwellTime module:

- List of nodes on a given transit route;
- Highway link file (i.e., LINKS.YYA);
- Highway node file (i.e., XY.YYA); and
- Speed and capacity lookup table (i.e., SPDCAP.YYA).

The file names in parentheses are the program defaults. The module is designed to perform the following tasks:

1. Obtain transit links specified for a given bus route;
2. Calculate transit link distance from the coordinates in the XY file;
3. Retrieve area/facility types from the LINKS file;
4. Obtain the corresponding highway free-flow speed from the SPDCAP file as the maximum operating speed for bus vehicles;
5. Run DwellTime to obtain the estimated dwell time for each stop; and
6. Calculate travel time for a transit link.

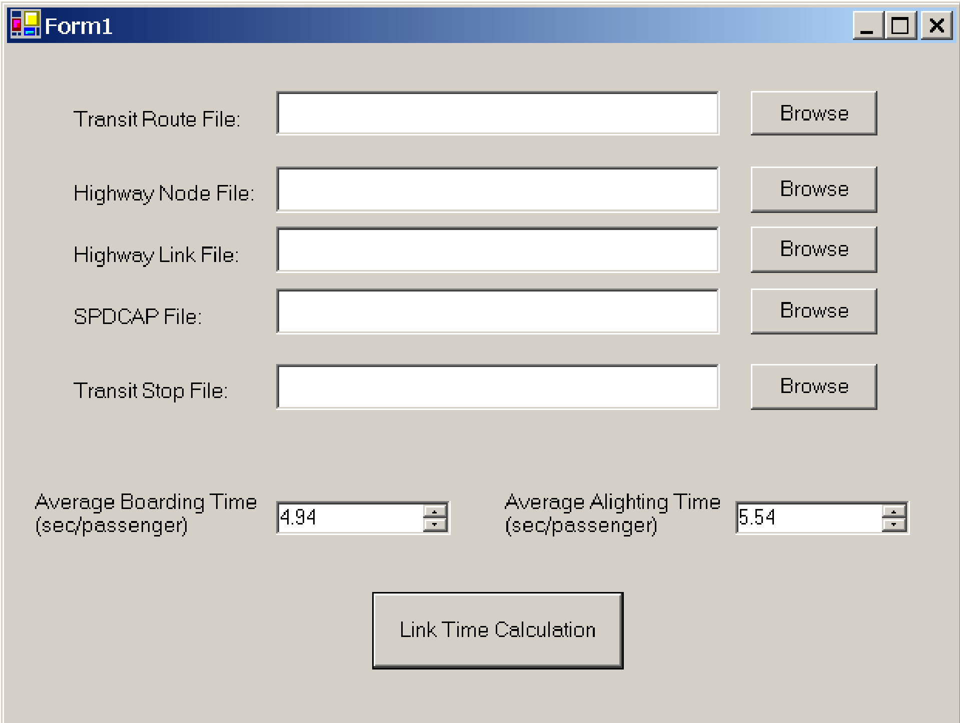

Figure 15. GUI for Transit Link Time (TLT) Calculator

For a link with both of its beginning and ending nodes designated as bus stops, i.e., specified in the route file with a negative sign, the link travel time is calculated as the sum of the following time components:

- Accelerate to top speed;
- travel at top speed;
- Decelerate to a complete stop; and
- Dwell time at the bus stop (ending node).

In the TLT module, the maximum speed is currently set at the highway speed specified in the SPDCAP file. For a short roadway segment with a bus stop designated at one or both ends, a bus vehicle could not reach the maximum speed. Therefore, the top speed was the lower value of the maximum speed and the speed for a bus vehicle to operate under typical acceleration and deceleration rates shown in Table 3. The components of the deceleration duration and bus dwell time calculated from the TLT module are associated with the stop specified at the ending node of a transit link. This means that deceleration delay and dwell time will not be incorporated into the link time estimation if the ending node is not a bus stop. If the beginning node of a transit link is not a bus stop, no acceleration delay will be added to the link time calculation.

Figure 16 shows the bus speeds estimated by the TLT module and those obtained from the current default transit/highway speed curve, i.e., Curve 10 (see Table 7), for a roadway segment with area type 42 and facility type 25 on one of the sampled transit route. The segment consists of eleven highway links, each with a free-flow highway speed of 39 mph. As previously mentioned, the dwell times on these links were underestimated by the DwellTime component, therefore, the model would overestimate transit speeds on these selected links. It may be seen from Figure 16, the current approach gives an even higher transit speed, thus significantly overestimating transit speeds for most of the links on the bus route. In comparison, the speeds estimated by the TLT module were varied in terms of stop location and ridership while constant speeds were obtained from the current default approach.

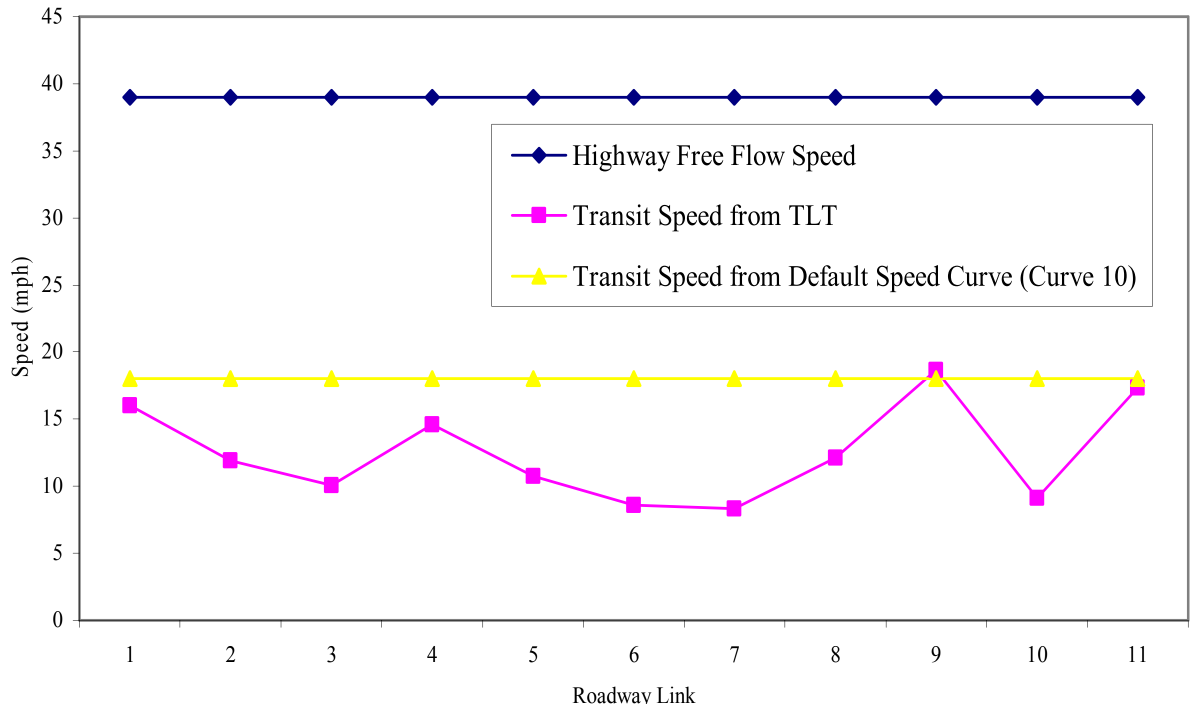

Figure 16. Highway Speeds and Transit Speeds Estimated by TLT Module and FSUTMS Speed Curve (Curve 10)

Figure 17 shows the transit travel time and dwell time estimated by the TLT module for every link described in Figure 16, where the transit link time was the sum of transit travel time and dwell time. Although dwell time may not appear to be a significant component of transit link time, it should not be disregarded for links with high transit boarding/alighting activities, e.g., link 10. Figure 17 also suggests a non-linear relationship between transit and highway link times.

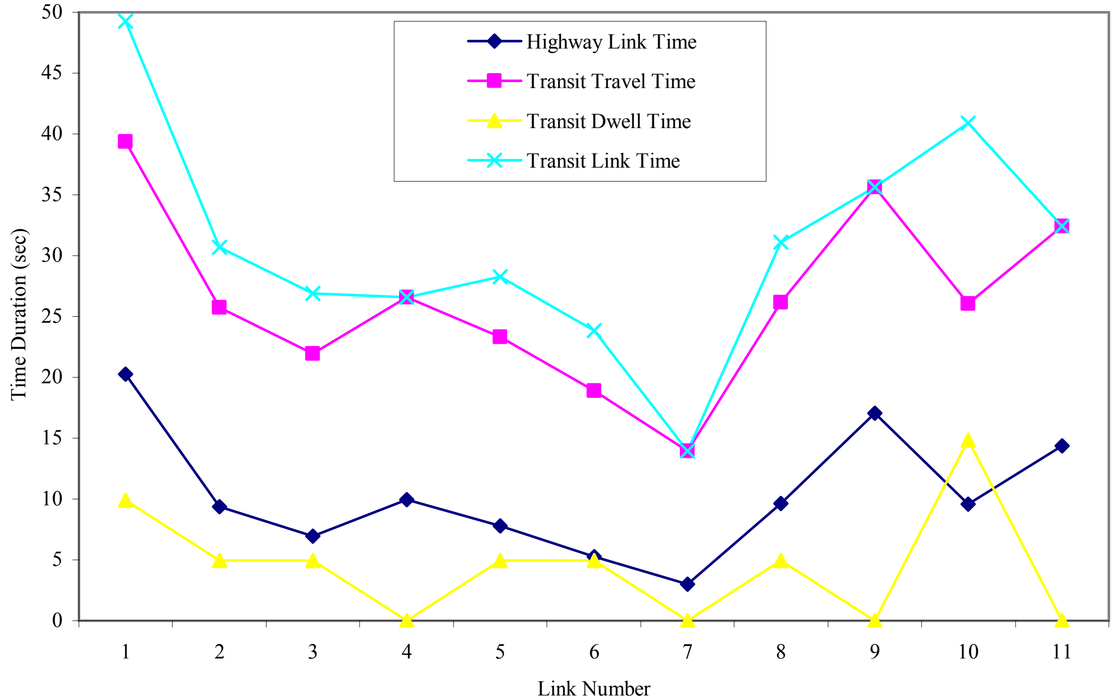

Figure 17. **Highway Link Time and Components of Transit Link Time**

6. SUMMARY AND CONCLUSIONS

Current FSUTMS model uses a set of highway-transit speed curves based on facility type and area type to model the relationship between highway speed and transit speed. This method suffers from several drawbacks such as the considerable vagueness in the definition of area types and that ridership is not considered. As a result, such an approach is unable to reflect appropriately delays at bus stops due to passenger loading and alighting. Delay at bus stops, however, may vary considerably at different locations due to passenger volume or bus stop density.

This study was aimed at improving the estimation of transit travel time by examining various components in transit travel time that is not already considered as part of highway travel time. These components include transit vehicle acceleration and deceleration rates and dwell time. To estimate dwell time, a travel time survey was conducted to manually collect the delay data at the bus stops on selected bus routes in Broward County. In addition to the time that is spent by each passenger to board or alight from a bus and the number of onboard, alighting, and boarding passengers, whether only one door or both doors of a bus is utilized for boarding and alighting also affects the dwell time. The survey data were used to calibrate a door choice model for alighting passengers at a given bus stop, assuming that passengers board only through the front door. The door choice model quantifies dwell time based on ridership, time of day, and average boarding/alighting duration per passenger. A computer program was also developed for calculating transit link time as the sum of highway travel time, dwell time, and deceleration and acceleration delays. The method is easy to understand and may be implemented in the current practice without significant effort. To implement the model in FSUTMS, an iterative process that calculates transit link time based on boarding and alighting data from the previous iteration is necessary because ridership data are required as input to the door choice model.

The dwell time model in this study was developed assuming typical operating conditions of a bus vehicle. Other delays caused by, e.g., loading bicycles and operating wheelchair lifts were not considered due to the limited observations collected in the survey. Because of the difficulty in precisely measuring elapsed time, the duration for a passenger to board or alight from a bus was taken as the average time that a passenger took to get on or off a bus at a given stop. In the future, with the help of APTS technologies, more detailed data may be collected to arrive at a more accurate distribution of passenger boarding and alighting time and to account for variations in the data.

The conclusions of this study are based on the analysis of the transit travel time data collected in Broward County, Florida. One limitation of the study is that demographics and climate are not considered in modeling the dwell time. When demographics changes significantly, e.g., when a large portion of the passengers are senior citizens, dwell time may also change. Therefore, data may need to be collected for areas with different user characteristics to determine the effects of local conditions and to obtain good estimates of dwell time thus transit travel time.

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APPENDIX A. COMPUTER APPLICATION SOURCE CODE

A.1 DwellTime Component

```
'***************************************************
' Transit Dwell Time Calculation Program
' Lehman Center for Transportation Research (LCTR)
' Department of Civil & Environmental Engineering
' Florida International University (FIU)
' Programmed by Haitao Zhang in VB.net
' Designed by Drs. Min-Tang Li & Fang Zhao
'***************************************************

Imports System.IO
Imports Microsoft.VisualBasic

Module Module1
   Sub Main()
      Dim AM As Integer 'dummy variable, 1 for records observed during AM
                        'peak and zero otherwise
      Dim AvgBoardTime As Double 'average boarding time
      Dim AvgAlightTime As Double 'average alighting time
      Dim Board As Integer 'passengers numbers of boarding from front door
      Dim BoardTime As Double 'total boarding time
      Dim DwellTime As Double 'total dwell time at a bus stop
      Dim Epower As Double 'exponential function of utility function for an
                           'alighting passenger
      Dim EXL As New Excel.Application()
      Dim FindDwell As Boolean
      Dim FrontOff As Integer 'number of passengers alighting at front door
      Dim FrontOffTime As Double 'total alighting time at front door
      Dim i As Integer 'loop counter
      Dim j As Integer 'loop counter
      Dim Percent As Double 'probability for choosing front door to alight
      Dim PM As Integer 'dummy variable, 1 for records observed during PM
                        'peak and zero otherwise
      Dim RearOff As Integer 'number of alighting passengers at rear door
      Dim RearOffTime As Double 'total alighting time at front door
      Dim Row As Integer = 1 'row in excel worksheet
      Dim Separator As String = "," 'separator sign in command line
      Dim Sr As StreamReader
      Dim StrVar As String 'read one line from the file at a time
      Dim StrArray() As String 'string array between separator
      Dim Timepoint As Integer 'dummy variable for a given bus stop, 1 for
                               'time point and zero otherwise
      Dim TotalOff As Integer 'total number of alighting passengers at a
                              'given stop
      Dim UtilityFunction As Double 'utility function for an alighting
                                    'passenger
      Dim WSheet As New Excel.Worksheet()
      Dim commands As String = Microsoft.VisualBasic.Command()
      Dim args() As String = commands.Split(Separator.ToCharArray)

      Sr = File.OpenText(args(2))
      WSheet = EXL.Workbooks.Add.Worksheets.Add
      With WSheet
```

```
    .Cells(Row, 1).value = "Node"
    .Cells(Row, 2).value = "Alighting"
    .Cells(Row, 3).value = "Boarding "
    .Cells(Row, 4).value = "Time Point"
    .Cells(Row, 5).value = "AM"
    .Cells(Row, 6).value = "PM"
    .Cells(Row, 7).value = "Front-Off %"
    .Cells(Row, 8).value = "Rear-Off %"
    .Cells(Row, 9).value = "Front-Off"
    .Cells(Row, 10).value = "Rear-Off"
    .Cells(Row, 11).value = "Front-Off Time"
    .Cells(Row, 12).value = "Boarding Time"
    .Cells(Row, 13).value = "Total at Front"
    .Cells(Row, 14).value = "Rear-Off Time"
    .Cells(Row, 15).value = "Dwelling Time"
End With

Do
    StrVar = Sr.ReadLine

    If StrVar <> Nothing Then
        Row += 1
        StrArray = Split(StrVar, ",")
        For j = 1 To 6
            With WSheet
                .Cells(Row, j).Value = StrArray(j - 1)
            End With
        Next j
    End If

    Loop Until StrVar = Nothing
    Sr.Close()
    AvgBoardTime = 4.94
    AvgAlightTime = 5.54
    If args(0) = "*" Then
        AvgAlightTime = 5.54
    Else
        AvgAlightTime = CDbl(args(1))
    End If
    If args(1) = "*" Then
        AvgBoardTime = 4.94
    Else
        AvgBoardTime = CDbl(args(0))
    End If
    For i = 2 To Row
        FindDwell = False
        Do Until FindDwell = True
            TotalOff = WSheet.Cells(i, 2).value
            Board = WSheet.Cells(i, 3).value
            Timepoint = WSheet.Cells(i, 4).value
            AM = WSheet.Cells(i, 5).value
            PM = WSheet.Cells(i, 6).value
            UtilityFunction = 0.0363 * TotalOff - 0.0213 * Board - 0.8389
            * Timepoint + 0.4098 * AM + 0.6777 * PM
            Epower = Math.Exp(UtilityFunction)
            Percent = Epower / (1 + Epower)
            WSheet.Cells(i, 7).value = Percent * 100
```

```
            WSheet.Cells(i, 8).value = (1 - Percent) * 100
            FrontOff = TotalOff * Percent
            RearOff = TotalOff - FrontOff
            BoardTime = Board * AvgBoardTime
            FrontOffTime = FrontOff * AvgAlightTime
            RearOffTime = RearOff * AvgAlightTime

            With WSheet
               .Cells(i, 9).value = FrontOff
               .Cells(i, 10).value = RearOff
               .Cells(i, 11).value = FrontOffTime
               .Cells(i, 12).value = BoardTime
               .Cells(i, 13).value = FrontOffTime + BoardTime
               .Cells(i, 14).value = RearOffTime
            End With

            If RearOffTime > FrontOffTime + BoardTime Then
               DwellTime = RearOffTime
               FindDwell = True
            Else
               DwellTime = FrontOffTime + BoardTime
               FindDwell = True
            End If
         Loop

         With WSheet
            .Cells(i, 15).value = DwellTime
         End With
      Next

      With WSheet
         .Columns("A:O").EntireColumn.AutoFit()
         .Columns("B:O").EntireColumn.HorizontalAlignment =
         Excel.XlHAlign.xlHAlignRight
         .Columns("G:H").entireColumn.NumberFormat = "0.00"
         .Columns("K:O").entireColumn.NumberFormat = "0.00"
      End With

      WSheet.SaveAs(args(3))
      EXL.Workbooks.Close()

   End Sub
End Module
```

A.2 TLT Component

```
'**************************************************
' Transit Link Travel Time Calculation Program
' Lehman Center for Transportation Research (LCTR)
' Department of Civil & Environmental Engineering
' Florida International University (FIU)
' Programmed by Haitao Zhang in VB.net
' Designed by Drs. Min-Tang Li & Fang Zhao
'**************************************************

Imports System.IO
Public Class Form1
   Inherits System.Windows.Forms.Form
   Dim EXL As New Excel.Application() '
   Dim fn As String 'Flie name string
   Dim fnLink As String 'Link file name string
   Dim fnNode As String 'Node file name string
   Dim fnRoute As String 'Route file name string
   Dim fnSpeed As String 'Speed file name string
   Dim fnStop As String 'Stop file name string
   Dim fnSave As String 'Save Excel file name string
   Dim WSheet As New Excel.Worksheet() 'Excel worksheet

   Private Sub btnOpen1_Click(ByVal sender As System.Object, ByVal e As
   System.EventArgs) Handles btnOpen1.Click
   ' Open transit route file
      Call Openfile(OpenFileDialog1, "Text files (*.txt)|*.txt|All files
      (*.*)|*.*", "Open Route File", TextBox1) ' fnRoute,
      fnRoute = fn
   End Sub

   Private Sub btnOpen2_Click(ByVal sender As System.Object, ByVal e As
   System.EventArgs) Handles btnOpen2.Click
   'open node file
      Call Openfile(OpenFileDialog2, "XY files (XY.*)|XY.*|All files
      (*.*)|*.*", "Open Node File", TextBox2) 'fnNode,
      fnNode = fn
   End Sub

   Private Sub btnOpen3_Click(ByVal sender As System.Object, ByVal e As
   System.EventArgs) Handles btnOpen3.Click
   'open link file
      Call Openfile(OpenFileDialog3, "Links files (Links.*)|Links.*|All files
      (*.*)|*.*", "Open Link File", TextBox3) 'fnLink,
      fnLink = fn
   End Sub

   Private Sub btnOpen4_Click(ByVal sender As System.Object, ByVal e As
   System.EventArgs) Handles btnOpen4.Click
   'open speed file
      Call Openfile(OpenFileDialog4, "Speed files (SPDCAP.*)|SPDCAP.*|All
      files (*.*)|*.*", "Open Speed File", TextBox4) 'fnSpeed,
      fnSpeed = fn
   End Sub
```

```
Private Sub BtnOpen5_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles BtnOpen5.Click
'open stop file
   Call Openfile(OpenFileDialog5, "Text files (*.txt)|*.txt|All files
   (*.*)|*.*", "Open Stop File", TextBox5) 'fnStop,
   fnStop = fn
End Sub

'Perform calculation
Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button1.Click
   Dim AM As Integer 'dummy variable, 1 for records observed during AM
                     'peak and zero otherwise
   Dim AvgAlighting As Double 'average alighting time
   Dim AvgBoarding As Double 'average boarding time
   Dim Atype As Integer 'parameter to store link area type
   Dim boardDuration As Double 'total boarding time
   Dim Dwell As Double 'total dwell time at a bus stop
   Dim epower As Double 'exponential function of utility function for an
                        'alighting passenger
   Dim Fill As Boolean 'boolean variable, ture for find link facility
                       'type, area type and number of lanes and false
                       'otherwise
   Dim FindDwell As Boolean 'boolean variable, ture for total dwell time
                            'is calculated and false otherwise
   Dim FronOff As Integer 'passengers numbers of alighting from front door
   Dim FronoffDuration As Double 'total alighting time from front door
   Dim Ftype As Integer 'parameter to store link facility type
   Dim i As Integer 'variable for loop count
   Dim infoSr As StreamReader 'StreamReader for stop txt file
   Dim infoStr As String 'read one line from the stop txt file at a time
   Dim infoArray() As String 'string array between separator
   Dim j As Integer 'variable for loop count
   Dim length As Integer 'parameter to store the length of link array
   Dim line6 As String 'string of the sixth line of the route file
   Dim Line6Array() As String 'string array of the sixth line of the route
                              'file
   Dim lineCount As Integer = 0 'parameter to store number of lines
                                'already read from the txt file
   Dim linkArray() As String 'link string array between separator
   Dim LinkDistance As Double 'parameter to store link distance
   Dim LN As Integer 'parameter to store link number of lanes
   Dim LinkSpeed As Double 'parameter to store link speed
   Dim LinkSr As StreamReader 'StreamReader for link txt file
   Dim linkstr As String 'read one line from the link txt file at a time
   Dim Nlane As Integer 'parameter to store link speed
   Dim NodeA As Integer 'parameter to store NodeA ID
   Dim NodeAXcor As Double 'parameter to store the X coordinate of Node A
   Dim NodeAYcor As Double 'parameter to store the Y coordinate of Node A
   Dim NodeB As Integer 'parameter to store NodeB ID
   Dim NodeBXcor As Double 'parameter to store the X coordinate of Node B
   Dim NodeBYcor As Double 'parameter to store the Y coordinate of Node B
   Dim onBoard As Integer 'passengers numbers of boarding from front door
   Dim operator As String 'operator in the speed txt file to adjust speed
   Dim Percent As Double 'probability for choosing the front door to get
                         'off the bus
   Dim PM As Integer 'dummy variable, 1 for records observed during PM
```

```
                  'peak and zero otherwise
Dim rangestr1 As String 'String to define excel selection range
Dim rangestr2 As String 'String to define excel selection range
Dim rangestr3 As String 'String to define excel selection range
Dim rangestr4 As String 'String to define excel selection range
Dim Rearoff As Integer 'passengers numbers of alighting from rear door
Dim rearoffDuration As Double 'total alighting time from rear door
Dim row As Integer = 1 'Define the row number in the excel file
Dim SpeedSr As StreamReader 'StreamReader for speed txt file
Dim speedstr As String 'read one line from the speed txt file at a time
Dim SpdAtype As Integer 'parameter to store area type in the speed txt
                        'file
Dim SpdFtype As Integer 'parameter to store facility type in the speed
                        'txt file
Dim SpdNlane As Integer 'parameter to store number of lanes in the
                        'speed txt file
Dim Speed As Double 'parameter to store link speed
Dim SumFmla As String 'Sum formula string to calculate total travel
                      'time
Dim sr As StreamReader 'StreamReader for route txt file
Dim strVar As String 'read one line from the route txt file at a time
Dim strArray() As String 'route string array between separator
Dim Timepoint As Integer 'dummy variable for a given bus stop, 1 for
                         'time point and zero otherwise
Dim totalOff As Integer 'total number of alighting passengers at a
                        'given stop
Dim UtilityFunction As Double 'utility function for an alighting
                              'passenger

sr = File.OpenText(fnRoute)

'Read the route text file
Do
   strVar = sr.ReadLine
   lineCount += 1
   If lineCount = 6 Then 'Manipulate the first data line in the route
                         'text file
      Line6Array = Split(strVar, "=")
      line6 = Line6Array(1)
      strArray = Split(line6, ",")
      WSheet = EXL.Workbooks.Add.Worksheets.Add
      With WSheet 'Write the first row of the excel file as the column
                  'title
         .Cells(row, 1).value = "Node A"
         .Cells(row, 2).value = "Node B"
         .Cells(row, 3).value = "X Coordination of Node A "
         .Cells(row, 4).value = "Y Coordination of Node A "
         .Cells(row, 5).value = "X Coordination of Node B "
         .Cells(row, 6).value = "Y Coordination of Node B "
         .Cells(row, 7).value = "Distance of A & B"
         .Cells(row, 8).value = "Facility Type"
         .Cells(row, 9).value = "Area Type"
         .Cells(row, 10).value = "Number of Lanes"
         .Cells(row, 11).value = "Link Speed"
         .Cells(row, 12).value = "Travel Time"
         .Cells(row, 13).value = "Dwelling Time"
         .Cells(row, 14).value = "Link Time"
```

```
            For j = 0 To strArray.Length - 2
               row += 1
               .Cells(row, 1).Value = strArray(j)  'Write the nodes(NodeA)
                                                    'to the first column of
                                                    'excle file
            Next j
         End With
      End If
      If lineCount > 6 Then 'Manipulate the other data line except the
                            'first line in the route text file
         strArray = Split(strVar, ",")
         With WSheet
            For j = 0 To strArray.Length - 2
               row += 1
               .Cells(row, 1).Value = strArray(j) 'Write the nodes(NodeA)
                                        'to the first column of excle file
            Next j
         End With
      End If
   Loop Until strVar = Nothing
   sr.Close()
   rangestr1 = "A3:A" & row
   rangestr2 = "A" & row

   With WSheet ' Get the NodeB Number
      .Range(rangestr1).Copy()
      .Range("B2").Select()
      .Paste()
      .Range(rangestr2).Clear()
   End With

   For i = 2 To row - 1
      NodeA = CInt(Microsoft.VisualBasic.Right(CStr(WSheet.Cells(i,
      1).value), 4))
      NodeB = CInt(Microsoft.VisualBasic.Right(CStr(WSheet.Cells(i,
      2).value), 4))
      Call CoordinateA(NodeA, i)
      Call CoordinateB(NodeB, i)
      Fill = False
      LinkSr = File.OpenText(fnLink)

      'Find the link information of facility type, area type, number of
      'lane from the link text file (links.99B) and write to the Excle
      'file
      Do Until Fill = True
         linkstr = LinkSr.ReadLine.TrimEnd
         linkArray = Split(linkstr)
         length = linkArray.Length()
         If linkArray(1) = "1" Then ' One-way link
            If (((linkArray(2) = CStr(NodeA)) And (linkArray(3) =
            CStr(NodeB))) Or ((linkArray(2) = CStr(NodeB)) And
            (linkArray(3) = CStr(NodeA)))) Then
               Ftype = CInt(linkstr.Substring((linkstr.Length) - 4, 2))
               Atype = CInt(linkstr.Substring((linkstr.Length) - 2, 2))
               LN = CInt(linkstr.Substring(48, 1))
               WSheet.Cells(i, 8).Value = Ftype
               WSheet.Cells(i, 9).Value = Atype
```

```
            WSheet.Cells(i, 10).Value = LN
            Fill = True
         End If
      Else 'Two way link
         If (NodeA < NodeB) Then ' To follow the format of link text
                              'file: the smaller Node number come first
            If ((linkArray(3) = CStr(NodeA)) And (linkArray(4) =
            CStr(NodeB))) Then
               Ftype = CInt(linkstr.Substring((linkstr.Length) - 4, 2))
               Atype = CInt(linkstr.Substring((linkstr.Length) - 2, 2))
               LN = CInt(linkstr.Substring(48, 1))
               WSheet.Cells(i, 8).Value = Ftype
               WSheet.Cells(i, 9).Value = Atype
               WSheet.Cells(i, 10).Value = LN
               Fill = True
            End If
         Else ' To follow the format of link text file: the smaller
              ' Node number comes first
            If ((linkArray(3) = CStr(NodeB)) And (linkArray(4) =
            CStr(NodeA))) Then
               Ftype = CInt(linkstr.Substring((linkstr.Length) - 4, 2))
               Atype = CInt(linkstr.Substring((linkstr.Length) - 2, 2))
               LN = CInt(linkstr.Substring(69, 1))
               WSheet.Cells(i, 8).Value = Ftype
               WSheet.Cells(i, 9).Value = Atype
               WSheet.Cells(i, 10).Value = LN
               Fill = True
            End If
         End If
      End If
   Loop
LinkSr.Close()
Next

' Calculate link distance
For i = 2 To row - 1
   NodeAXcor = WSheet.Cells(i, 3).Value
   NodeAYcor = WSheet.Cells(i, 4).Value
   NodeBXcor = WSheet.Cells(i, 5).Value
   NodeBYcor = WSheet.Cells(i, 6).Value
   WSheet.Cells(i, 7).Value = CalculateDistance(NodeAXcor, NodeAYcor,
   NodeBXcor, NodeBYcor)
Next i

'Find the free-flow speed of the link based on facility type, area
'type, number of lane of the link from SPDCAP.99B and write to the link
'speed file?
For i = 2 To row - 1
   With WSheet
      Atype = WSheet.Cells(i, 9).Value
      Ftype = WSheet.Cells(i, 8).Value
      Nlane = WSheet.Cells(i, 10).Value
   End With

   SpeedSr = File.OpenText(fnSpeed)
   While SpeedSr.Peek <> -1
      speedstr = SpeedSr.ReadLine
```

```
      operator = speedstr.Substring(18, 1)
      If operator = " " Then
         SpdAtype = CInt(speedstr.Substring(0, 2))
         SpdFtype = CInt(speedstr.Substring(4, 2))
         SpdNlane = CInt(speedstr.Substring(9, 1))
         If ((Atype = SpdAtype) And (Ftype = SpdFtype) And (Nlane =
         SpdNlane)) Then
            Speed = CDbl(speedstr.Substring(19, 4))
         End If
      Else 'Speeed need to be modified based on the operator,
           'coefficient and area type, facility type and lane range
         If (Nlane >= CInt(speedstr.Substring(9, 1)) And Nlane <=
         CInt(speedstr.Substring(11, 1))) Then
            If (Atype >= CInt(speedstr.Substring(0, 2)) And Atype <=
            CInt(speedstr.Substring(2, 2))) Then
               If (Ftype >= CInt(speedstr.Substring(4, 2)) And Ftype <=
               CInt(speedstr.Substring(6, 2))) Then
                  Select Case operator
                     Case "+"
                        Speed = Speed + CDbl(speedstr.Substring(19, 4))
                     Case "-"
                        Speed = Speed - CDbl(speedstr.Substring(19, 4))
                     Case "*"
                        Speed = Speed * CDbl(speedstr.Substring(19, 4))
                     Case "¡Á"
                        Speed = CDbl(speedstr.Substring(19, 4))
                  End Select
               End If
            End If
         End If
      End If
   End While

   SpeedSr.Close()
   With WSheet
      .Cells(i, 11).Value = Speed
   End With

Next

'Calculate link travel time base on the node type
'Negative node number represent STOP, Positive node number represent
'INTERSECTION
For i = 2 To row - 1
   LinkSpeed = WSheet.Cells(i, 11).Value
   LinkDistance = WSheet.Cells(i, 7).Value
   If ((WSheet.Cells(i, 1).value < 0) And (WSheet.Cells(i, 2).value <
   0)) Then 'Node A and Node B are both stops
      WSheet.Cells(i, 12).Value = CalculateTravelTime1(LinkSpeed,
      LinkDistance)
   ElseIf (((WSheet.Cells(i, 1).value < 0) And (WSheet.Cells(i,
   2).value > 0))) Then 'Node A is stop and Node B is intesection
      WSheet.Cells(i, 12).Value = CalculateTravelTime2(LinkSpeed,
      LinkDistance)
   ElseIf (((WSheet.Cells(i, 1).value > 0) And (WSheet.Cells(i,
   2).value < 0))) Then 'Node A is intesections and Node B is top
```

```
      WSheet.Cells(i, 12).Value = CalculateTravelTime3(LinkSpeed,
      LinkDistance)
   Else 'Node A and Node B are both intesections
      WSheet.Cells(i, 12).Value = CalculateTravelTime4(LinkSpeed,
      LinkDistance)
   End If
Next

' Start to calculate dwell time for the stops
AvgBoarding = CDbl(AvgBoardingTime.Value)
AvgAlighting = CDbl(AvgAlightingTime.Value)
infoSr = File.OpenText(fnStop)

For i = 2 To row - 1
   FindDwell = False
   Do Until FindDwell = True
      infoStr = infoSr.ReadLine
      infoArray = Split(infoStr, ",")
      totalOff = CInt(infoArray(1))
      onBoard = CInt(infoArray(2))
      Timepoint = CInt(infoArray(3))
      AM = CInt(infoArray(4))
      PM = CInt(infoArray(5))
      UtilityFunction = 0.0363 * totalOff - 0.0213 * onBoard - 0.8389 *
      Timepoint + 0.4098 * AM + 0.6777 * PM
      epower = Math.Exp(UtilityFunction)
      Percent = epower / (1 + epower)
      FronOff = totalOff * Percent
      Rearoff = totalOff - FronOff
      boardDuration = onBoard * AvgBoarding
      fronoffDuration = FronOff * AvgAlighting
      rearoffDuration = Rearoff * AvgAlighting

      If rearoffDuration > fronoffDuration + boardDuration Then
         Dwell = rearoffDuration
         FindDwell = True
      Else
         Dwell = fronoffDuration + boardDuration
         FindDwell = True
      End If
   Loop

   With WSheet
      .Cells(i, 13).value = Dwell
   End With
Next

For i = 2 To row - 1
   WSheet.Cells(i, 14).value = WSheet.Cells(i, 12).value +
   WSheet.Cells(i, 13).value
Next

rangestr1 = "N2:N" & row - 1

With WSheet
   .Range(rangestr1).Select()
   rangestr2 = CStr(row - 2)
```

```
      SumFmla = "=(SUM(R[-" & rangestr2 & "]C:R[-1]C))/60"
      .Cells(row, 14).FormulaR1C1 = SumFmla 'total travel time for the
      whole route
      .Columns("C:N").EntireColumn.AutoFit() 'Format the cell
   End With

   'Save the excel file
   If MessageBox.Show("Link Time Calculation is Finished! Do You Want to
   Save It?", "My Application", MessageBoxButtons.YesNo,
   MessageBoxIcon.Que
      With SaveFileDialog1
         .Filter = "Excel files (*.xls)|*.xls|All files (*.*)|*.*"
         .FilterIndex = 1
         .InitialDirectory =
         System.AppDomain.CurrentDomain.BaseDirectory()
         .Title = "Save File"
      End With
      SaveFileDialog1.ShowDialog()
      fnSave = SaveFileDialog1.FileName
      Try
         'Saving .xls file as Test.xls
         WSheet.SaveAs(fnSave)
         EXL.Workbooks.Close()
         Catch
      End Try
   Else
      EXL.Workbooks.Close()
   End If
End Sub

' Subroutine to Open input file
Private Sub Openfile(ByVal OpenFileDialog As System.Object, ByVal Filter
As String, ByVal Title As String, ByVal TextBox As System.Object)
   With OpenFileDialog
      .Filter = Filter
      .FilterIndex = 1
      .InitialDirectory = System.AppDomain.CurrentDomain.BaseDirectory()
      .Title = Title
   End With
   OpenFileDialog.ShowDialog()
   fn = OpenFileDialog.FileName
   TextBox.Text = fn
End sub

' Subroutine to get the X and Y coordinates of Node A from node text
' file(XY.99B)
Private Sub CoordinateA(ByVal NodeA As Integer, ByVal i As Integer)
   Dim CoordinateArray() As String 'node string array between separator
   Dim sr1 As StreamReader 'StreamReader for node txt file
   Dim strLine As String 'read one line from the node file at a time
   Dim Xcor As Double 'X coordinate
   Dim Ycor As Double 'Y coordinate

   sr1 = File.OpenText(fnNode)
   While sr1.Peek <> -1
      strLine = sr1.ReadLine().Trim()
      CoordinateArray = Split(strLine, " ")
```

```
      If CoordinateArray(0) = CStr(NodeA) Then
         Xcor = CDbl(CoordinateArray(1))
         Ycor = CDbl(CoordinateArray(2))
         With WSheet
            .Cells(i, 3).Value = Xcor
            .Cells(i, 4).Value = Ycor
         End With
      End If
   End While
End Sub

' Subroutine to get the X and Y coordinate of Node B from node text
' file(XY.99B)
Private Sub CoordinateB(ByVal NodeB As Integer, ByVal i As Integer)
   Dim CoordinateArray() As String 'node string array between separator
   Dim sr1 As StreamReader 'StreamReader for node txt file
   Dim strLine As String 'read one line from the node file at a time
   Dim Xcor As Double 'X coordinate
   Dim Ycor As Double 'Y coordinate

   sr1 = File.OpenText(fnNode)
   While sr1.Peek <> -1
      strLine = sr1.ReadLine().Trim()
      CoordinateArray = Split(strLine, " ")
      If CoordinateArray(0) = CStr(NodeB) Then
         Xcor = CDbl(CoordinateArray(1))
         Ycor = CDbl(CoordinateArray(2))
         With WSheet
            .Cells(i, 5).Value = Xcor
            .Cells(i, 6).Value = Ycor
         End With
      End If
   End While
End Sub

'Link distance function
Function CalculateDistance(ByVal NodeAXcor As Double, ByVal NodeAYcor As
Double, ByVal NodeBXcor As Double, ByVal NodeBYcor As Single) As Double
   Dim Distance As Double

   Distance = (((NodeBXcor - NodeAXcor) ^ 2 + (NodeBYcor - NodeAYcor) ^
   2) ^ 0.5) / 100)
   Return Distance
End Function

'Travel time when Node A (accelerate) and Node B(decelerte) are both stops
Function CalculateTravelTime1(ByVal LinkSpeed As Double, ByVal
LinkDistance As Double) As Double
   Dim t1 As Double 'travel time for the acceleration section
   Dim t2 As Double 'travel time for the constant speed section
   Dim t3 As Double 'travel time for the deceleration section
   Dim t11 As Double 'travel time for section before speed accelerating to
                     '10
   Dim t12 As Double 'travel time for section before speed accelerating to
                     '30
   Dim t13 As Double 'travel time for section before speed accelerate to
                     'link speed
```

```
Dim TravelTime As Double 'To store travel time
Dim s1 As Double 'travel distance during t1
Dim s2 As Double 'travel distance during t2
Dim s3 As Double 'travel distance during t3
Dim s11 As Double 'travel distance during t11
Dim s12 As Double 'travel distance during t12
Dim s13 As Double 'travel distance during t13
Dim Vt13 As Double 'Velocity during t13
Dim Vt12 As Double 'Velocity during t12
Dim Vt11 As Double 'Velocity during t11

t3 = (LinkSpeed / 2.5)
s3 = (((LinkSpeed * t3) / 3600) - (0.5 * 2.5 * (t3 ^ 2) / 3600))
If LinkSpeed <= 10 Then 'Acceleration rate 2.5 mphps
   t11 = (LinkSpeed / 2.5)
   s11 = ((0.5 * 2.5 * (t11 ^ 2)) / 3600)
   t12 = 0
   s12 = 0
   t13 = 0
   s13 = 0
   If (LinkDistance >= s11 + s3) Then 'Accelerated to a speed and have
                                      'the constant speed segment
      t1 = t11
      s1 = s11
      s2 = LinkDistance - s1 - s3
      t2 = (s2 / LinkSpeed)
      TravelTime = t1 + t2 + t3
   Else
      Vt11 = (9000 * LinkDistance) ^ 0.5
      t11 = Vt11 / 2.5
      t3 = Vt11 / 2.5
      TravelTime = t11 + t3
   End If
ElseIf (LinkSpeed <= 30) Then 'Acceleration rate 1.5 mphps
   t11 = 4
   s11 = 0.0056
   t12 = ((LinkSpeed - 10) / 1.5)
   s12 = (((10 * t12) / 3600) + (0.5 * 1.5 * (t12 ^ 2) / 3600))
   If (LinkDistance >= s11 + s12 + s3) Then 'Accelerated to and have a
                                            'constant speed segment
      t1 = t11 + t12
      s1 = s11 + s12
      s2 = LinkDistance - s1 - s3
      t2 = (s2 / LinkSpeed)
      TravelTime = t1 + t2 + t3
   ElseIf (LinkDistance >= 0.0112) Then 'no constanst speed segment and
                                      'acceleration rate in 10-30 range
      Vt12 = ((13.17 + 3600 * LinkDistance) * 1.875) ^ 0.5
      t12 = (Vt12 - 10) / 1.5
      t3 = Vt12 / 2.5
      TravelTime = t11 + t12 + t3
   Else 'no constanst speed segment and acceleration rate in 0-10 range
      Vt11 = (9000 * LinkDistance) ^ 0.5
      t11 = Vt11 / 2.5
      t3 = Vt11 / 2.5
      TravelTime = t11 + t3
   End If
```

```
   Else 'Acceleration rate 0.5m.p.h.p.s
      t11 = 4
      s11 = 0.0056
      t12 = 13.33
      s12 = 0.07405
      t13 = ((LinkSpeed - 30) / 0.5)
      s13 = (((30 * t13) / 3600) + (0.5 * 0.5 * (t13 ^ 2) / 3600))
      If (LinkDistance >= s11 + s12 + s13 + s3) Then 'Accelerated to and
                                         'have a constant speed segment
         t1 = t11 + t12 + t13
         s1 = s11 + s12 + s13
         s2 = LinkDistance - s1 - s3
         t2 = (s2 / LinkSpeed)
         TravelTime = t1 + t2 + t3
      ElseIf (LinkDistance >= 0.1297) Then 'no constanst speed segment and
                                         'acceleration rate in 30-50 range
         s13 = LinkDistance - s11 - s12
         Vt13 = ((613 + 3600 * LinkDistance) / 1.2) ^ 0.5
         t13 = (Vt13 - 30) / 0.5
         t3 = Vt13 / 2.5
         TravelTime = t11 + t12 + t13 + t3
      ElseIf (LinkDistance >= 0.0112) Then 'no constanst speed segment and
                                         'acceleration rate in 10-30 range
         Vt12 = ((13.17 + 3600 * LinkDistance) * 1.875) ^ 0.5
         t12 = (Vt12 - 10) / 1.5
         t3 = Vt12 / 2.5
         TravelTime = t11 + t12 + t3
      Else 'no constanst speed segment and acceleration rate in 0-10 range
         Vt11 = (9000 * LinkDistance) ^ 0.5
         t11 = Vt11 / 2.5
         t3 = Vt11 / 2.5
         TravelTime = t11 + t3
      End If
   End If
   Return TravelTime
End Function

'Travel time when Node A is a stop(accelerate) and Node B is an
'intesection(assuming no deceleration)
Function CalculateTravelTime2(ByVal LinkSpeed As Double, ByVal
LinkDistance As Double) As Double
   Dim TravelTime As Double 'parameter to store travel time
   Dim t11 As Double 'travel time for section before speed accelerating to
                     '10
   Dim t12 As Double 'travel time for section before speed accelerating to
                     '30
   Dim t13 As Double 'travel time for section before speed accelerating to
                     'link speed
   Dim t1 As Double 'travel time for the acceleration section
   Dim t2 As Double 'travel time for the constant speed section
   Dim s1 As Double 'travel distance during t1
   Dim s2 As Double 'travel distance during t2
   Dim s11 As Double 'travel distance during t11
   Dim s12 As Double 'travel distance during t12
   Dim s13 As Double 'travel distance during t13
   Dim Vt13 As Double 'Velocity during t13
   Dim Vt12 As Double 'Velocity during t12
```

```
Dim Vt11 As Double 'Velocity during t11
If LinkSpeed <= 10 Then
   t11 = (LinkSpeed / 2.5)
   s11 = ((0.5 * 2.5 * (t11 ^ 2)) / 3600)
   t12 = 0
   s12 = 0
   t13 = 0
   s13 = 0
   If (LinkDistance >= s11) Then
      t1 = t11
      s1 = s11
      s2 = LinkDistance - s1
      t2 = (s2 / LinkSpeed)
      TravelTime = t1 + t2
   Else
      t11 = (2880 * LinkDistance) ^ 0.5
      TravelTime = t11
   End If
ElseIf (LinkSpeed <= 30) Then
   t11 = 4
   s11 = 0.0056
   t12 = ((LinkSpeed - 10) / 1.5)
   s12 = (((10 * t12) / 3600) + (0.5 * 1.5 * (t12 ^ 2) / 3600))
   If (LinkDistance >= s11 + s12) Then
      t1 = t11 + t12
      s1 = s11 + s12
      s2 = LinkDistance - s1
      t2 = (s2 / LinkSpeed)
      TravelTime = t1 + t2
   ElseIf (LinkDistance >= 0.0056) Then
      Vt12 = ((39.52 + 10800 * LinkDistance) ^ 0.5)
      t12 = (Vt12 - 10) / 1.5
      TravelTime = t11 + t12
   Else
      Vt11 = (2880 * LinkDistance) ^ 0.5
      t11 = Vt11 / 2.5
      TravelTime = t11
   End If
Else
   t11 = 4
   s11 = 0.0056
   t12 = 13.33
   s12 = 0.07405
   t13 = ((LinkSpeed - 30) / 0.5)
   s13 = (((30 * t13) / 3600) + (0.5 * 0.5 * (t13 ^ 2) / 3600))
   If (LinkDistance >= s11 + s12 + s13) Then
      t1 = t11 + t12 + t13
      s1 = s11 + s12 + s13
      s2 = LinkDistance - s1
      t2 = (s2 / LinkSpeed)
      TravelTime = t1 + t2
   ElseIf (LinkDistance >= 0.07965) Then
      s13 = LinkDistance - s11 - s12
      Vt13 = ((613.26 + 3600 * LinkDistance) ^ 0.5)
      t13 = (Vt13 - 30) / 0.5
      TravelTime = t11 + t12 + t13
   ElseIf (LinkDistance >= 0.0056) Then
```

```
         Vt12 = ((39.52 + 10800 * LinkDistance) ^ 0.5)
         t12 = (Vt12 - 10) / 1.5
         TravelTime = t11 + t12
      Else
         Vt11 = (2880 * LinkDistance) ^ 0.5
         t11 = Vt11 / 2.5
         TravelTime = t11
      End If
   End If
   Return TravelTime
End Function

'Travel time when Node A is an intersection(assuming constant speed no
'acceleration) and Node B is a stop(decelerate)
Function CalculateTravelTime3(ByVal LinkSpeed As Double, ByVal
LinkDistance As Double) As Double
   Dim TravelTime As Double 'parameter to store travel time
   Dim t2 As Double 'travel time for the constant speed section
   Dim t3 As Double 'travel time for the deceleration section
   Dim s2 As Double 'travel distance during t2
   Dim s3 As Double 'travel distance during t3
   Dim Vt3 As Double 'Velocity during t3

   s3 = (0.2 * (LinkSpeed ^ 2)) / 3600
   t3 = 0.4 * LinkSpeed
   If (LinkDistance >= s3) Then
      s2 = LinkDistance - s3
      t2 = (s2 / LinkSpeed)
      TravelTime = t3 + t2
   Else
      Vt3 = (18000 * LinkDistance) ^ 0.5
      t3 = Vt3 / 1.5
      TravelTime = t3
   End If
   Return TravelTime
End Function

'Travel time when Node A and Node B are both stops
Function CalculateTravelTime4(ByVal LinkSpeed As Double, ByVal
LinkDistance As Double) As Double
   Dim TravelTime As Double
   TravelTime = (LinkDistance / LinkSpeed)
   Return TravelTime
End Function
```