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Development of Bus-Stop Time Models in Dense Urban Areas: A Case Study in Washington DC

MNTRC Report 12-48

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REPORT 12-48

DEVELOPMENT OF BUS-STOP TIME MODELS IN DENSE URBAN AREAS: A CASE STUDY IN WASHINGTON DC

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16. Abstract

Bus transit reliability depends on several factors including the route of travel, traffic conditions, time of day, and conditions at the bus stops along the route. The number of passengers alighting or boarding, fare payment method, dwell time (DT), and the location of the bus stop also affect the overall reliability of bus transit service. This study defines a new variable, Total Bus Stop Time (TBST) which includes DT and the time it takes a bus to safely maneuver into a bus stop and the re-entering the main traffic stream. It is thought that, if the TBST is minimized at bus stops, the overall reliability of bus transit along routes could be improved.

This study focused on developing a TBST model for bus stops located near intersections and at mid-blocks using ordinary least squares method based on data collection at 60 bus stops, 30 of which were near intersections while the remaining were at mid-blocks in Washington DC. The field data collection was conducted during the morning, mid-day, and evening peak hours. The following variables were observed at each bus stop: bus stop type, number of passengers alighting or boarding, DT, TBST, number of lanes on approach to the bus stop, presence of parking, and bus pad length. The data was analyzed and all statistical inferences were conducted based on 95% confidence interval. The results show that the TBST could be used to aid in improving planning and scheduling of transit bus systems in an urban area.

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EXECUTIVE SUMMARY

The primary goal of transit agencies is to provide reliable, efficient, and productive transportation service. Transit reliability has been defined many times; for example in 1978, Abkowitz et al[1] defined transit reliability as the availability and stability of transit service attributes and their effects on travel behavior and on transit agencies' performance travel behavior and on transit agencies performance. Two years later, Turnquist and Blume[2] described transit reliability as keeping transit vehicles on-schedule with uniform headways and consistent travel times. More recently, Kimple[3] stated that transit reliability is a multidimensional phenomenon; consequently, there is not a single measure that can adequately address service quality.

Bus transit reliability depends on several factors, including the route of travel, traffic conditions, time of day, and conditions at the bus stops along the route. The number of passengers alighting or boarding, fare payment method, dwell time, and the location of the bus stop also affect the overall reliability of bus transit service. Several research studies have been conducted on bus dwell time (DT), which is defined as the time interval between the opening and closing of the vehicle's doors to serve passengers at a transit stop. This study defines a new variable: Total Bus Stop Time (TBST) which, in addition to DT, includes the time required for a bus to safely maneuver into a transit stop and the time consumed reentering the main traffic stream. It is thought that if the TBST is minimized, the overall reliability of bus transit along routes could be improved.

It is clear that providing a reliable transit service is necessary in order to maintain an efficient and attractive system that increases users' satisfaction and loyalty. Furthermore, reliable transit improves internal efficiency, reduces operating costs, and improves revenues by attracting and retaining users. Therefore, improving reliability is a benefit for both users and transit agencies, as it enables cities to achieve broader goals.

This study was aimed at developing DT and TBST models for bus stops located at intersections and at midblock. The TBST models were developed using nonlinear optimization methods. The study involved data collection at sixty bus stops, thirty of which were located at intersections, while the remaining bus stops were at midblock. The data was obtained for the morning, midday and evening peak hours during the period from January 2014 through September 2014. Data on the following variables were obtained at each bus stop: bus stop type, number of passengers alighting or boarding, DT, TBST, number of lanes on approach to the bus stop, presence of parking, and bus pad length. The data was analyzed and all statistical inferences were conducted based on 95% confidence level.

The results of the data analyzed showed that, on average, both TBST and DT were higher at bus stops at intersections than at those located midblock. While the mean TBST was approximately 48 seconds at the bus stops at intersections, for the midblock bus stops, the mean DT and TBST were 21 and 35 seconds, respectively. The overall mean DT was determined to be 29 seconds.

The regression models for the TBST and DT were determined to be statistically significant at the 95% confidence level based on the R^2, *F*-Statistics, and model validation tests. The models could explain 67% to 96% of the variations in the data based on the R^2 and adjusted R^2 values. Tests including Kolmogorov-Smirnoff, normal probability, and residual plots were used to confirm the appropriateness of the models. The models were developed by bus stop type and by time of day. The following tables present the models:

TBST MODELS

Table 1. Summary of TBST Regression Analysis by Time of Day at Intersections

Time Period	Model Equation	R^2	Adj. R^2	ANOVA F-value	ANOVA *p*-value
Morning	$TBST_{AM} = 1.40(D_T) - 1.90(P_B) - 1.19(P_K) + 2.45(L_N) - 0.001(B_P) - 0.02(P_A) + 14.6$	0.67	0.59	7.81	0.00
Midday	$TBST_{MID} = 1.12(D_T) + 0.26(P_B) - 1.87(P_K) + 0.52(L_N) - 0.002(B_P) - 0.15(P_A) + 17.23$	0.96	0.95	96.89	0.00
Evening	$TBST_{PM} = 1.17(D_T) - 0.02(P_B) - 1.55(P_K) - 2.07(L_N) + 0.0002(B_P) - 0.42(P_A) + 21.72$	0.95	0.93	70.51	0.00

Table 2. Summary of TBST Regression Analysis by Time of Day at Midblock

Time Period	Model Equation	R2	Adj. R^2	ANOVA F-value	ANOVA *p*-value
Morning	$TBST_{AM} = 1.73(D_T) - 2.19(P_B) + 3.91(P_K) - 0.15(L_N) + 0.002(B_P) - 1.21(P_A) - 0.0009$	0.73	0.65	10.17	0.00
Midday	$TBST_{MID} = 1.12(D_T) + 0.04(P_B) - 0.86(P_K) + 0.50(L_N) + 0.005(B_P) - 0.27(P_A) + 8.71$	0.98	0.97	164.16	0.00
Evening	$TBST_{PM} = 1.12(D_T) + 0.19(P_B) - 0.50(P_K) - 0.19(L_N) + 0.004(B_P) - 0.07(P_A) + 7.94$	0.99	0.99	360.27	0.00

DT MODELS

Table 3. Summary of DT Regression Analysis by Time of Day at Intersections

Time Period	Model Equation	R^2	Adj. R^2	ANOVA F-value	ANOVA *p*-value
Morning	$DT_{AM} = 3.42(P_B) - 2.05(P_K) - 1.34(L_N) - 0.0005(B_P) + 1.11(P_A) + 14.13$	0.73	0.67	12.82	0.00
Midday	$DT_{MID} = 5.37(P_B) + 7.01(P_K) + 4.52(L_N) + 0.002(B_P) + 2.26(P_A) - 20.70$	0.82	0.78	21.53	0.00
Evening	$DT_{PM} = 4.31(P_B) - 1.86(P_K) + 0.29(L_N) - 0.003(B_P) + 2.88(P_A) + 4.50$	0.95	0.93	70.51	0.00

Table 4. Summary of DT Regression Analysis by Time of Day at Midblock

Time Period	Model Equation	R^2	Adj. R^2	ANOVA F-value	ANOVA *p*-value
Morning	$DT_{AM} = 3.00(P_B) + 4.52(P_K) + 1.43(L_N) - 0.004(B_P) + 1.69(P_A) - 1.31$	0.89	0.86	37.09	0.00
Midday	$DT_{MID} = 4.75(P_B) - 4.61(P_K) + 2.20(L_N) + 0.0005(B_P) + 1.05(P_A) + 8.15$	0.73	0.67	13.00	0.00
Evening	$DT_{PM} = 3.26(P_B) + 1.51(P_K) + 0.16(L_N) + 0.001(B_P) + 1.63(P_A) + 0.87$	0.92	0.90	54.22	0.00

The TBST models were then optimized to yield the maximum values based on the upper confidence limits of the DTs for each bus stop type and time of day. Because DT was determined to be the independent variable with the most statistically significant impact on the TBST, this constraint was used. From the results, the following maximum TBSTs were observed for each bus stop type by time of day:

Table 5. Maximum TBST

Bus Stop Type	Time Period	Maximum TBST (secs)
Intersections	AM	42.5
	MID	47.1
	PM	66.8
Midblock	AM	36.0
	MID	33.2
	PM	31.2

The results suggest that to sustain or improve bus reliability at bus stops at intersections, during the morning, midday, and evening peak periods, buses should spend no more than 43, 47 and 67 seconds, respectively. Similarly, the total time at midblock bus stops should be no more than 36, 34, and 32 seconds, respectively.

Due to potential changes in traffic patterns and varying land uses near bus stops, the models need updating and validation on a 3-to-5-year cycle. These models are based on data that was limited to DC bus routes and street characteristics; therefore, they may not be appropriate for predicting TBST or DT in other jurisdictions.

I. INTRODUCTION

The overall reliability of a transit bus system depends on several factors along the route of travel. These include but are not limited to scheduled arrivals, traffic congestion, weather conditions, dwell times at bus stops, and the number of passengers boarding and alighting. Dwell time (DT) is defined as the time that a transit vehicle is stopped for the purpose of serving passengers and encompasses the total passenger service time between the opening and closing of doors.[4] The DT at bus stops represents a significant portion of route operating time and its variability. It is linked to the reliability of the service being provided. Planning and managing bus schedules necessitate being able to estimate the total time buses spend at bus stops, not just the time consumed in the boarding and alighting of passengers. The time consumed in the safe maneuver of buses into a bus stop and the time required to merge back into traffic are also important elements in urban bus transit schedule development. Those times, along with the DT, comprise the total bus stop time (TBST), which is likely to be affected by bus-specific activities and systems and by traffic operational conditions along bus transit corridors and at bus stops.

Since TBST affects overall transit reliability, it is one of the variables regional bus transit systems, such as the Washington Metropolitan Area Transit Authority (WMATA), must measure. As part of its initiatives to provide timely information regarding bus arrivals and travel times, WMATA provides real-time information on bus arrival times for many routes. Patrons can use smart phones, standard computers, or a variety of other portable information devices to access the information. WMATA recently incorporated Automatic Vehicle Location (AVL) and Automatic Passenger Counting (APC) systems to improve the bus information system. The reliability of a bus route service is generally gauged by determining if the transit system is compliant with its advertised schedules. Since TBST is a factor in reliability assessments, it is critical to predict its value along bus transit corridors. This research uses data for WMATA's bus stops along heavily traveled corridors for the purpose of developing and optimizing DT and TBST models.

II. RESEARCH OBJECTIVES

The demand for public transit services in the District of Columbia is driven by the steadily increasing population of residents, commuters, and visitors. The cost of automobile ownership, including the cost of gasoline and parking, has stimulated commuter interest in public transit. Consequently, there is an increasing need for more reliable transit systems in the Washington DC Metropolitan Area.

WMATA attempts to fulfill the demand by providing regional rail transit service and bus service along heavily traveled corridors in the Metropolitan Area. Both rail and bus services are monitored by WMATA via its protocol for collecting and analyzing related data. The time it takes for a transit bus to maneuver to a stop position for passengers to alight and board and the time required for the bus to reenter traffic affect overall bus service reliability. This research is intended to develop DT and TBST models by time of the day that could be used to improve overall bus transit reliability. The following objectives form the basis of this research:

- Identify variables influencing DT and, subsequently, TBST.
- Develop DT and TBST models for bus stops at intersections and at midblock.
- Optimize the TBST models to improve bus transit schedule planning and efficiency.

The results will contribute toward the provision of a reliable bus transit service highly valued by the community.

III. LITERATURE REVIEW

There is a trend toward an increasing population density in already crowded urban areas due to thriving employment opportunities. Urban transit systems are generally recognized as both an efficient mode of travel and a strategy for reducing air pollution and dependency on petroleum-based fuels for transportation. The overall effectiveness of transit service relies heavily on the quality of the network's routing structure, schedules, management, and reliability of service. Since urban streets pose a number of challenges for bus drivers trying to maintain schedules, a full understanding of actual-versus-anticipated travel times and the practices or events that save time or cause it to be lost during service are constant concerns of transit operators. These fluctuations are relevant both in the context of multimodal transit or single-mode transit systems, as transfers and wait times are critical to passengers. Street traffic, pedestrian and bike transport, weather, crashes, traffic control, and various curb-lane activities are among the many unpredictable conditions randomly affecting the docking and undocking of buses at curbside bus stops. The ability to effect seamless and efficient transit vehicle access and egress is one of the most significant factors used in establishing predictable transport times. In many ways predictable timing is more important than trip duration.

The docking and undocking phases of bus transit in large urban transit systems are affected by many unpredictable variables, such as the mix of street traffic, location of bus stops, turns at intersections, traffic control devices, timing/coordination of traffic control devices, physical design configuration of bus stops, and curbside parking activities, to mention a few.

Knowledge of the magnitude variability of the access, dwell, and departure intervals of transit vehicles over the entire daily service period plays a critical role in schedule design and operation management.

The authors reviewed previous studies that focused on understanding the total time involved in transit stops, including arrival, dwell time, and departure from curbside bus stops. Literature on bus dwell times and their associated models are generally sparse, and measurements in a form directly usable for our purposes do not exist. Related studies were based on small sample sizes. These studies are not directly relevant and tend to be route-specific, analyzing other issues causing bus delays.[5] Some studies on dwell time have also used ordinary least squares (OLS) regression to relate dwell time to passenger boarding and alighting under selected operating conditions that were likely to affect dwell time. A study conducted by Milkovits[6] developed dwell time models for heavy rail, light rail, and bus transit systems.

Kraft and Bergen[7] found that passenger service time requirements for morning and evening peaks were similar, and midday requirements were greater than those in peak periods. This research determined boarding times exceed alighting times, and that rear door and front door alighting times were the same and concluded that dwell time was equal to 2 seconds plus 4.5 seconds for each boarding passenger who paid with cash and required change, and 1.5 seconds plus 1.9 seconds for each passenger who had exact fare.

Another study conducted by Kraft identified seven major groups of factors that affect dwell time: human, modal, operating policies, operating practices, mobility, climate, and other system elements.[8] The study suggested that specific bus stop characteristics such as curb-lane usage, right-lane volume, right-lane configuration, vehicle classifications, gaps in traffic, parking, length of maneuvering space for the bus, could affect the time the bus spends at the bus stop.

A 1983 study conducted by Levinson[9] determined that dwell time was equal to 5 seconds plus 2.75 seconds per boarding or alighting passenger. Similarly, in the same year, Guenthner and Sinha[10] reported a 10- to 20-second penalty for each stop, plus a 3- to 5-second penalty for each passenger boarding or alighting. Unfortunately, both studies resulted in low explanatory power, even though the research controlled for factors such as lift activity, fare structure, and number of doors.

S. Chen, R Zhou, Y. Zhou, and B. Mao, concerned about the magnitude of bus delays at bus stops and the impact on service, conducted a field research on the behavior of buses at bayside and curbside bus stops on the streets of Beijing, China.[11] The authors postulated that as a bus enters a bus stop for discharging and picking up passengers the vehicle would go through an arrival stage that would involve a careful maneuvering of the vehicle toward the designated stop position while avoiding parked vehicles, physical items, and pedestrians. That arrival pattern was conceived to be different from arrival of vehicles in bus rapid transit systems (BRT) where the guideways would be free from obstacles. The dwell times at street bus stops are usually limited to time needed for the doors to open and close in service of passengers. Leaving time was described as time between closures of the doors to the return of a bus to the traffic stream. In 2011, the researchers collected video data on twelve buses during the morning rush-hour and the period from 12 noon to 2:00 p.m. They also observed the number of passengers on board, boarding, and alighting. In total, 300 events were recorded. The researchers found that dwell time correlates with passenger activities at the doors, despite the magnitude of load factors. Boarding and alighting times for curbside bus stops were observed to increase when the load factor is greater than 0.55. The researchers recommended further work on the arrival and departure intervals at bus stops. Linear regression models were developed to estimate the expected docking time at curbside bus stops when the load factor is below 0.55 and above 0.77.

Generally, bus stop docking time for BRT is not obscured by unrelated activities near the stops. However, due to concern regarding the length of the docking period, which includes the dwell time, a study was launched in 2006 to evaluate travel time of the Metropolitan Area Express (MAX) system in Las Vegas.[12] Repeated accumulation of dust and dirt on the pavement in the docking area obscured the visibility of pavement markings and stimulated interest in a technology-based solution. An optical guidance system was used to facilitate the docking of buses into bus bays, although the trained drivers demonstrated sufficient capability to park their buses into the marked bays. The guidance system involved automatic vehicle location sensors. Although the system reduced the time consumed in maneuvering buses in and out of positions at the BRT stations, management determined its cost to be prohibitive.

In 2013, S. Robinson[13] conducted a study in London introducing a new metric called "time lost serving stop" – defined as the time that typical bus would save if a bus stop were not present. That study sought to examine the impact on dwell time of time lost decelerating to serve a bus stop and accelerating to traffic speed upon leaving. Data developed here was taken from the iBus system, an Automatic Vehicle Location (AVL) system installed on more than 8,000 bus units in the city of London. The systems logged the speed, location, and odometer values of vehicles, as well as the times when doors were opened and closed. In that study, a bus was considered to be at a bus stop when it entered the stopping zone, which was defined as 50 meters before and 30 meters after the flagpole, as shown in Figure 1.

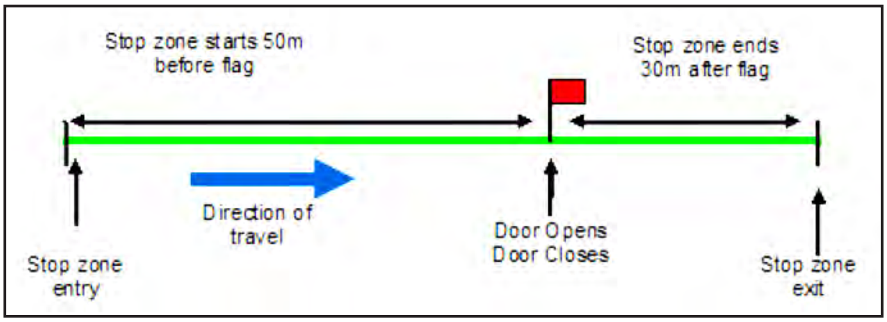

Figure 1. Bus Stopping Zone in London's iBus System

Comparing the results using two different approaches, peak-to-peak speed and shifted speed, Robinson evaluated over 50,000 bus stop events from the iBus system to estimate the mean time lost in serving bus stops along Route 45. The peak-to-peak speed approach used the peak speed before and after the stop.

The shifted speed approach assumed that the bus would be traveling at the highest peak speed if the bus stop had not been present. Both approaches presented a directly proportional relationship between the two variables: speed and distance. The results indicated that the shifted speed approach was more realistic, and it was used to determine that the mean time lost in arriving, serving, and departing from a bus stop was 11.6 seconds – considerably longer than the time the doors would remain open.

Hooi Ling Khoo[14] developed bus dwell time statistical models using dwell time data from 20 bus stops in the Klang Valley region in Malaysia in 2010 and 2011. The researcher wanted to determine the statistical distribution that could best explain and describe dwell time variability, and used regression models to assess the degree of influence of the factors considered. The bus stops selected for the study were chosen based on the type of location, number of bus routes served, and an estimation of the passenger demand. Both field crew and video recording were used to collect dwell time data for peak and off-peak hours. The peak hours were from 8 a.m. to 9 a.m. and from 5 p.m. to 6 p.m., while the off-peak period was from 9 a.m. to 10 a.m. and from 4 p.m. to 5 p.m.

The dwell time was computed using the following equation:

$$t^i = t^i_{depart} - t^i_{arrive}$$

where,

- t^i is the dwell time for bus
- t^i_{depart} is the time bus departs from the bus stop and
- t^i_{arrive} is the time bus arrives at the bus stop.

The dwell time data was analyzed to determine if it fit a particular statistical distribution. In addition, multiple regression analysis was conducted identifying factors most influencing dwell time. Factors considered in the analysis were time of day (peak hour/off-peak hour), platform crowding level, payment method, and the number of passengers boarding and alighting. The results of the statistical analysis indicated the dwell times measured during peak hours tended to vary far more than during off-peak hours due to rush-hour traffic congestion. Results also showed mean dwell time for less crowded platforms was lower than it was for more crowded platforms. Thus, crowding level could influence dwell time. Results also indicated certain payment methods have positive effects on peak-hour dwell times. Off-peak dwell times were significantly influenced by both payment method and the number of passengers boarding/alighting. The study confirmed passengers boarding and alighting have a major impact on dwell time variability and that the extent of variation depended on the time of day.

Rajbhandari et al.[15] considered passenger demand as the principal determinant for dwell time. In their study, the importance of dwell time was highlighted by claiming that the reduction of bus dwell time and travel time could save more time than that achieved by installing bus priority systems. The authors considered the impact on dwell time of factors such as the number of mobility-impaired passengers, the length of time the door was opened for passengers to enter, and the time it took passengers to alight from a packed bus as factors. The number of passengers boarding and alighting was found to follow an exponential distribution, while the dwell time per stop was found to follow a lognormal distribution.

Using ordinary least squares (OLS) methods, four models were developed with single and multiple independent variables. The accuracy of the models was assessed using the R^2 values obtained. The following table summarizes the models developed, with *a, b,* and *c* representing constants. Based on the data, the key variable affecting bus dwell time was determined to be the number of passengers boarding and alighting.

Table 6. Summary of Developed Models

Model	Equation
A	$DT = a + b$ (Total)
B	$DT = a + b$ (Ons) $+ c$ (Offs)
C	$DT = a + b$ (Total) $+ c$ (Total)(S)
D	$DT = a$ (Total)^{b}

Gardner and Cornwell addressed the importance of public transport systems by conducting a study to establish busway ‘capacity’ and investigated factors influencing busway performance.[16] They concluded that a busway is a useful traffic management measure. An added complementary measure for improving bus operations could result in a higher performance of transit systems. Bus stop performance was cited as one area for improvement, since bus dwell time is a major factor in evaluating bus transit service. The dwell time survey conducted by the researchers confirmed that boarding times were usually longer than alighting times. Authors observed when the ratio of passengers boarding to the number of spaces available on the bus was relatively smaller, boarding times were relatively low and regular. When the bus was packed, boarding times per passenger increased rapidly due to the increased time required for boarding passengers to clear the payment area and find seats or standing positions. Thus the authors claimed that boarding time relationships beyond a certain threshold are likely nonlinear.

SUMMARY

The literature review showed that although the number of passengers boarding and alighting has a major impact on dwell time, there are other secondary factors that could affect DT and TBST in urban areas. The factors include time of the day; methods of payment, time lost serving a stop, crowding level, and bus stop location-type.

Rajbhandari et al. included the number of mobility-impaired passengers, the amount of time a driver leaves the door open for passengers to enter, and the time it takes a passenger to get off a packed bus. From the literature, it can be concluded that by taking secondary factors into consideration, advancements could be made in the determination and optimization of bus DT and TBST models in DC.

IV. RESEARCH METHODOLOGY

BUS STOPS SELECTED FOR THE STUDY

Sixty bus stops on heavily traveled bus routes within the city limits of the District of Columbia were selected for this study. The selection was based on the Stop Usage Report released by WMATA in January 2014.[17] This report ranked the bus stops based on the number of passengers boarding and alighting at each stop. The top-ranked bus stops in WMATA's Report were selected to ensure the occurrence of bus-stopping events during data collection. Two types of bus stops were identified in this study: (1) bus stops located at intersections and (2) bus stops located midblock.

Separate analyses were conducted due to differences in passenger and traffic dynamics for each type of bus stop. Sixty bus stops were selected: thirty located at intersections and another thirty located midblock. The selected bus stops are presented in Appendix 1 and displayed in Figure 2. At some intersections and street blocks, multiple bus stops were selected and this accounted for the symbols on the map not adding up to thirty for each type.

Data Collection

Prior to the conduct of this research, WMATA installed a pilot automatic passenger counting (APC) system and routinely used automated vehicle location (AVL) systems. The team relied on the APC/AVL systems as the primary source for bus and passenger data. Comparison of data using the APC/AVL and field data for the trial sample of study-related locations revealed major differences that could not be reconciled such as missing records in the APC and AVL data base when compared to the records obtained in the field data collection. The team concluded it was necessary to collect field data manually.

Field data collection at the sixty bus stops was conducted on weekdays from March 2014 through June 2014. The data collection schedule was organized to achieve a robust sample, where the research team conducted the data collection at the same bus stop for the three periods in a day: morning (7:00 a.m. to 10:00 a.m.), midday (12:00 p.m. to 2:30 p.m.) and evening (4:00 p.m. to 6:00 p.m.). These times were selected under the assumption that there will be sufficient passenger boarding and alighting events. The following characteristics associated with each of the bus stops were specified:

- Number of lanes
- Type of lanes
- Presence of bus pad and bus pad's length and width
- Presence of on-street parking

Prior to the commencement of the data collection effort, several preliminary runs were conducted to familiarize the team with the data collection process. Data collection sheets were prepared and used for entering information, such as the names of the students performing the data collection, bus stop ID number, and the dates and times the data collection began and ended.

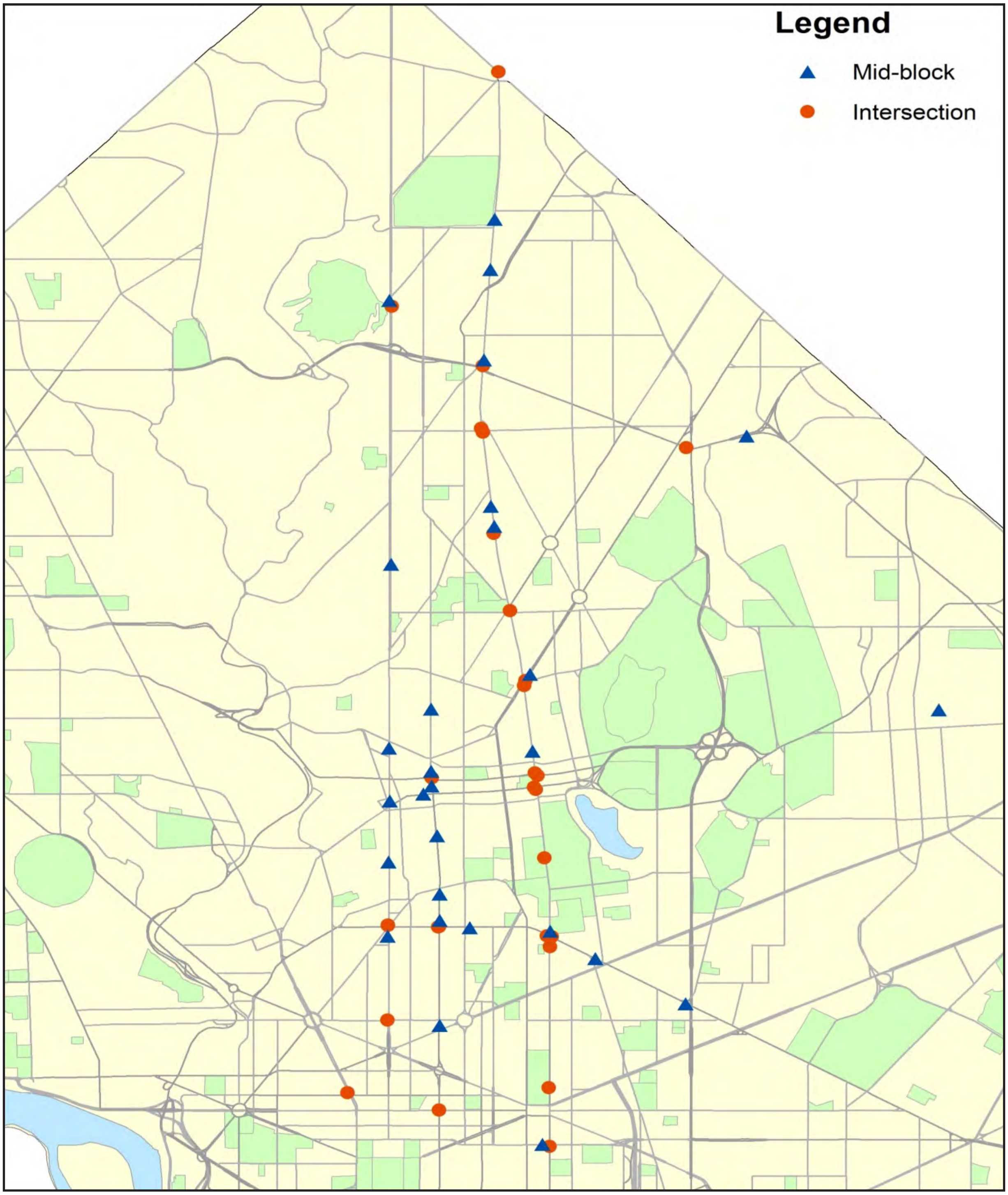

Figure 2. Selected Bus Stop Locations in the District of Columbia

The data fields for data collection included the following 10 entries:

- Bus route number
- S_1: Time the bus arrived to the bus pad
- X: Number of passengers boarding
- Y: Number of passengers alighting
- D_1: Time door opens
- D_2: Time door closes
- S_2: Time bus pulls away from the bus pad after the doors closed
- Presence of street parking adjacent to the bus stop
- Number of "approach" lanes to the bus stop
- Bus pad's length

Times were obtained by using stopwatches the time lap feature to enable easy data collection. A sample data collection form is provided in Appendix 2. At least ten bus stop events were recorded per period. Data collection was not conducted during periods of adverse weather conditions, such as rain or snow events.

The data set included 1,783 bus stop events at 60 bus stops. Field data collection sheets were returned and reviewed. The data was imported to Microsoft Excel and SPSS for analysis.

COMPUTING DT AND TBST

The team used Microsoft Excel software to calculate the DT and TBST at each bus stop. On-street parking near the bus stop was coded as permitted ("1") or not permitted ("2").

STATISTICAL ANALYSES, REGRESSION ANALYSES, AND OPTIMIZATION

Statistical Analyses

The team derived subsequent descriptive statistics determining the mean, median, and standard deviation, among others. This was conducted for the two bus stop types and for the three time periods.

Model Development

After taking into consideration the data characteristics, the generalized regression model for Total Bus Stop Time was determined to assume the following form:

$$TBST = D_T.k_1 + P_{\mathrm{b}}.k_2 + P_k.k_3 + L.k_4 + P_a.k_5 + B_p + \varepsilon$$

where:

TBST = Total bus stop time in seconds (s).

D_t = Dwell time in seconds (s).

P_b = Number of passengers boarding.

P_k = Presence of on-street parking.

L = Number of approach lanes.

B_p = Bus pad length in inches (in).

P_a = Number of passengers.

TBST is the dependent variable, while D_t, P_b, P_k, L, B_p *and* P_a are the independent variables. In addition, k_1, k_2, k_3, k_4 and k_5 are the regression coefficients with an associated error of ε [$\varepsilon \sim N(0, \sigma^2)$].

The generalized regression model for the DT was also determined as:

$$D_t = P_a.k_1 + P_b.k_2 + L.k_3 + P_k.k_4 + B_p + \varepsilon$$

Regression Analysis

Standard multivariate regression analysis was employed to develop the TBST and DT models for the bus stops for the morning, midday, and, evening peak hours.

The statistical analyses were conducted using MiniTab and confirmed with SPSS and Microsoft Excel. The statistical significance of the regression coefficients of the resulting model(s) were tested at 5% level of significance. In addition, the overall statistical significance of each regression model for each bus stop type was tested using the *F*-test (ANOVA) at a 5% significance level.

Regression Model Validation Methods

The following methods were employed to validate the developed models: R^2 and adjusted R^2, *F*-Test, residual plots, normal probability plots, and Kolmogorov Smirnov Test. The first two are based on two sums of squares: sum of squares total (SST) and sum of squares error (SSE). SST measures how far the data are from the mean and SSE measures how far the data are from the model's predicted values. Different combinations of these two values provide different information about the validity of the regression model compared to the mean model.

a) **R^2 and Adjusted R^2:** These parameters were used to determine the goodness of fit of the model. R^2 scale is intuitive: it ranges from zero to one, where zero indicates no improved prediction over the mean model and one indicates perfect prediction. Improvement in the regression model results in proportional increases in R^2.

   One pitfall of R^2 is that it can only increase as predictors are added to the regression model. This increase is artificial when predictors are not actually improving the model's fit. To remedy this, a related statistic, adjusted R^2, incorporates the model's degrees of freedom. Adjusted R^2 decreases as predictors are added if the increase in model fit does not offset the loss of degrees of freedom. Likewise, it will increase as predictors are added if the increase in model fit is worthwhile. Adjusted R^2 should always be used with models having more than one predictor variable. It is defined as the proportion of total variance that is explained by the model.

b) ***F*-test:** The *F*-test evaluates the null hypothesis that all regression coefficients are equal to zero, versus the alternative that at least one does not. An equivalent null hypothesis is that R^2 (or adjusted R^2) equals zero. A significant *F*-test indicates the observed R^2 (or Adjusted R^2) is reliable and not a spurious result of oddities in the data set. Thus, the *F*-test determines whether the proposed relationship between the response variable predictors is statistically reliable. This is useful particularly when the research objective is to develop a predictive model.

c) **Residual plots:** Regression models were checked for homoscedasticity (constant variance). The residuals from a fitted model are the differences between the observed variables and the corresponding predicted values using the regression function developed. Mathematically, the definition of the residual for the i^{th} observation in the data set is defined as:

$$e_i = y_i - f(x_i; \hat{\beta}),$$

   with y_i denoting the i^{th} response in the data set and x_i the vector of explanatory variables, each set at the corresponding values found in the i^{th} observation in the data set. If the model of the data were correct, the residuals would approximate the random errors that make the relationship between the explanatory variables and the response variable a statistical relationship. Therefore, if the residuals appear to behave randomly, that would indicate the model fits the data well. On the other hand, if a non-random structure were evident in the residual plots, this would be a sign that the model fits the data poorly.

d) **Normal probability plots:** Normal probability plots a graphical technique that indicates whether a data set is approximately normally distributed – were used to validate the model. In a normal probability plot, if all the data points fall near the line, an assumption of normality is reasonable. Otherwise, the points will curve away from the line, and an assumption of normality is not justified.

e) **Kolmogorov-Smirnov Test:** The two-sample Kolmogorov-Smirnov test (KS test) predicts whether dependent variables from the models were similar to the observed dependent variables, given the same set of independent variables. The null hypothesis was the two data sets were similar or had the same continuous distribution, while the alternative hypothesis was that they were not similar or had different continuous distributions. The KS test has the advantage of making no assumptions about the distribution of data, and it computes a D-statistic with an associated *p*-value. If the *p*-value were greater than the level of significance, then the null hypothesis – that the predicted and observed dependent datasets were statistically the same – should not be rejected.

The KS test was used to evaluate the hypothesis that there is no difference between the cumulative distribution functions (CDFS) of the two-sample data vectors (predicted and actual dependent variables). The two-sided test uses the maximum absolute difference between the CDFS of the distributions of the two sample sets. The test statistic is:

$$D^* = \max_X(|F_1(x) - F_2(x)|),$$

where is the proportion of x_1 values less than or equal to x and is the proportion of x_2 values less than or equal to x.

Optimization

A nonlinear programming process was used to optimize the objective function. Using MiniTab, the TBST was set as a nonlinear objective function and was subject to linear equality and inequality constrains in order to yield the minimal value as a result. Typically, the nonlinear problem is defined by a system of equalities and inequalities – collectively termed constraints – over a set of unknown real variables, along with an objective function to be maximized or minimized, where some of the constraints or the objective functions are nonlinear.[15] The problem can be stated simply as:

max f(x) to maximize a function

$x \in X$

or

min f(x) to minimize a function

$x \in X$

where,

$f: R^n \longrightarrow R$

$x \in R^n$

subject to the following constraints:

$h_i (x) = 0, \qquad k \in K = 1, \ldots,q$

$g_i (x) \leq 0, \qquad p \in P = 1, \ldots,m$

The potential outcomes of the nonlinear optimization could be one of the following:

- Feasible, that is, for an optimal solution *x* subject to constraints, the objective function *f* is either maximized or minimized.
- Unbounded, that is, for some *x* subject to constraints, the objective function *f* is either ∞ or -∞.
- Infeasible, that is, there is no solution *x* that is subject to constraints.

V. RESULTS

STATISTICAL ANALYSIS

Summaries of the descriptive statistical analyses are presented by bus stop location-type and time period. Detailed results of the descriptive statistics are presented in Appendix 3. The key descriptive statistics are the means, standard deviations and 95% confidence intervals.

Descriptive Statistics by Bus Stop Location-type

This section summarizes the descriptive statistics for the variables corresponding to each bus stop location-type.

Midblock Bus Stops

The summary of the descriptive statistics for midblock bus stops by time of the day is presented in Table 7. From the table, it can be observed that the average DT during the day ranged from 19.7 to 22.1 seconds while the TBST ranged from 33.3 to 36.7 seconds. In addition, the longest mean DT (22.1 seconds) and TBST (36.7 seconds) were observed during the midday period. Throughout the three time periods, the average number of passengers boarding and alighting was three. There were three lanes per approach at all the midblock bus stop locations. In addition, the average bus pad length at midblock bus stops was approximately 79 feet (948.6 inches).

Table 7. Summary of Descriptive Statistics for Midblock Bus Stops

	Midblock								
	AM			Midday			PM		
Variable	Mean	S.Dev	95% C.Int	Mean	S.Dev	95% C.Int	Mean	S.Dev	95% C.Int
TBST(sec)	33.9	18.5	2.1	36.7	24.9	2.8	33.3	19.8	2.3
D Time (sec)	20.3	16.4	1.9	22.1	22.1	2.5	19.7	17.2	2.0
P Boarding	3	4	0.5	3	4.3	0.5	3	4	0.4
P Alighting	3	4	0.5	3	3.5	0.4	3	4	0.4
BP Length (in)	948.6	253.4	28.9	948.6	253.4	28.9	948.6	253.4	28.9

Bus Stops Located at Intersections

Table 8 presents the descriptive statistics for the pertinent variables at the bus stops located at intersections. The results show that, on average, the TBST ranged from 42.4 to 50.7 seconds while the DT ranged from 22.7 seconds to 32.5 seconds. The highest mean TBST and DT were also observed during the midday periods. On average, up to five passengers boarded the buses at the bus stops for the periods observed, while three passengers alighted during the same period. In addition, all the bus stops at intersections had two lanes per approach. The average bus pad length at the intersections was determined to be approximately 97 feet (1,161.4 inches).

Table 8. Summary of Descriptive Statistics for Bus Stops Located at Intersections

	Intersections								
	AM			Midday			PM		
Variable	Mean	S.Dev	95% C.Int	Mean	S.Dev	95% C.Int	Mean	S.Dev	95% C.Int
TBST (secs)	42.4	25.3	2.9	50.7	34.3	3.9	49.6	33.3	3.8
D Time (secs)	22.7	20.4	2.3	32.5	31.3	3.6	31.2	30.4	3.5
P Boarding	4	4.0	0.5	4	4.7	0.5	5	6.3	0.7
P Alighting	3	3.8	0.4	3	3.8	0.43	3	4.5	0.5
BP Length (in)	1161.4	714.2	81.4	1161.3	714.3	81.4	1159.1	717.7	82.1

Descriptive Statistics by Time of the Day

Figure 3 presents the mean DT values for bus stops located at intersections and at midblock by time of the day. In the figure, it can be observed that the mean DT values at midblock stops were generally lower than those for the bus stops located at intersections for the three periods observed. Furthermore, the figure shows that the peak DT value was observed during the midday period.

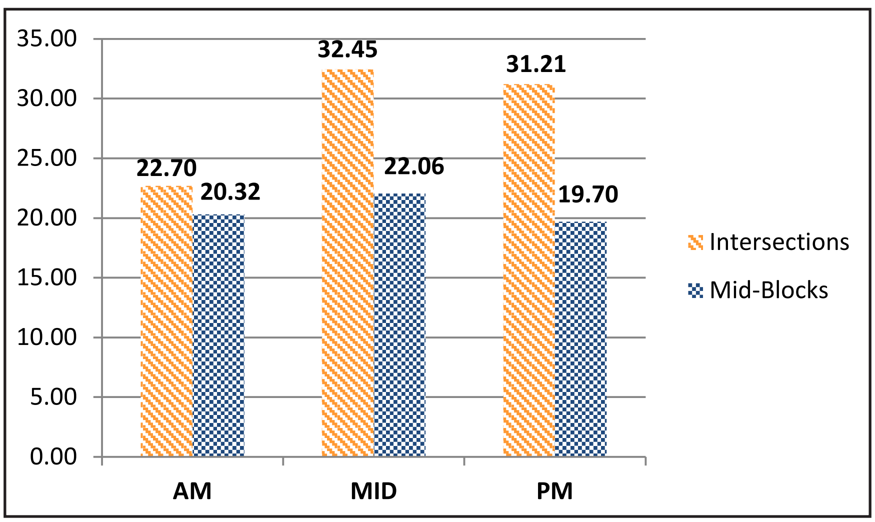

Figure 3. Mean DT Values by Time of Day by Bus Stop Location-type

The mean TBST values by time of the day by bus stop location-type are presented in Figure 4. From the figure, it can be observed that the mean TBST values of buses at midblock bus stops are lower than the mean TBST of buses at bus stops located at intersections for the observed periods. The peak TBSTs for both bus stop location-types were observed during midday.

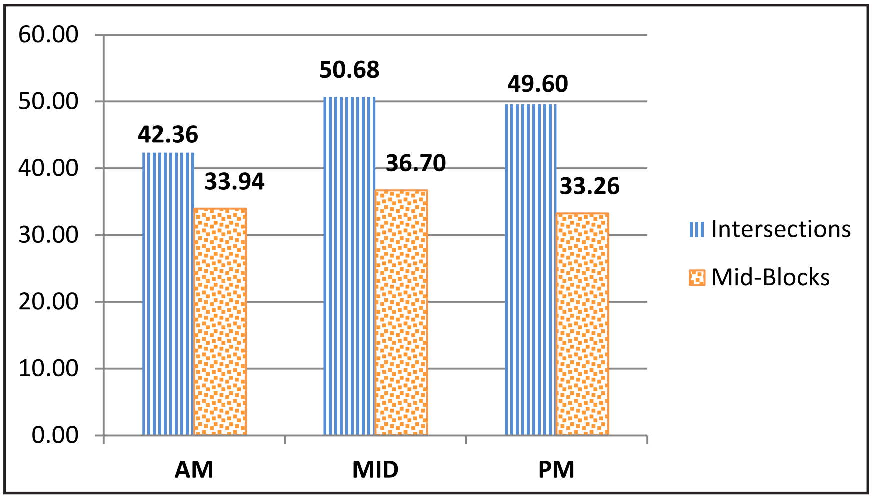

Figure 4. Mean TBST Values by Time of Day by Bus Stop Location-type

REGRESSION ANALYSIS

Regression models were developed by bus stop location-type and by time of the day using the data obtained for sixty bus stops. The TBST model was determined as follows:

$$TBST = f(DT, P_b, P_a, P_k, L_n, B_p)$$

while the DT model was determined based on

$$DT = f(\, P_b, P_a, P_k, L_n, B_p)$$

with independent variables previously defined.

The adequacy and significance of the regression models were tested at a significance level of 5%. Summaries of the regression analyses are presented in Table 9 through Table 12. The detailed results of the regression analyses are presented in Appendix 4.

The results shown in Table 9 and Table 10 for the TBST models indicate that the models could explain relatively high percentages of the variations in the data, based on the R^2 values (67-96%). For both bus stop types, the morning period shows a lower explanatory power compared to the models for the remaining two. In addition, the *p*-values for the regression models' *F*-statistics were determined to be less than 0.05, indicating that the coefficients are not equal to zero at 5% level of significance.

The results shown in Table 11 and Table 12 for the DT models also indicate that the models could explain relatively high percentages of the variations in the data, based on the R^2 values (73-95%). The highest R^2 values for the DT models were observed during the p.m. periods for both bus stop types. Further, the *p*-values for the regression models' *F*-statistics were determined to be less than 0.05, indicating that the coefficients are not equal to zero at 5% level of significance.

The *p*-values of t-statistics of the models' coefficients (for both bus types and periods) indicate that DT was the most significant independent variable that predicts the TBST. The remaining coefficients all indicated $p > 0.05$.

TBST Models

Table 9. Summary of TBST Regression Analysis by Time of Day at Intersections

Time Period	Model Equation	R^2	Adj. R^2	ANOVA	
				F-value	*p*-value
Morning	$TBST_{AM} = 1.40(D_T) - 1.90(P_B) - 1.19(P_K) + 2.45(L_N) - 0.001(B_P) - 0.02(P_A) + 14.6$	0.67	0.59	7.81	0.00
Midday	$TBST_{MID} = 1.12(D_T) + 0.26(P_B) - 1.87(P_K) + 0.52(L_N) - 0.002(B_P) - 0.15(P_A) + 17.23$	0.96	0.95	96.89	0.00
Evening	$TBST_{PM} = 1.17(D_T) - 0.02(P_B) - 1.55(P_K) - 2.07(L_N) + 0.0002(B_P) - 0.42(P_A) + 21.72$	0.95	0.93	70.51	0.00

Table 10. Summary of TBST Regression Analysis by Time of Day at Midblock

Time Period	Model Equation	R2	Adj. R^2	ANOVA	
				F-value	*p*-value
Morning	$TBST_{AM} = 1.73(D_T) - 2.19(P_B) + 3.91(P_K) - 0.15(L_N) + 0.002(B_P) - 1.21(P_A) - 0.0009$	0.73	0.65	10.17	0.00
Midday	$TBST_{MID} = 1.12(D_T) + 0.04(P_B) - 0.86(P_K) + 0.50(L_N) + 0.005(B_P) - 0.27(P_A) + 8.71$	0.98	0.97	164.16	0.00
Evening	$TBST_{PM} = 1.12(D_T) + 0.19(P_B) - 0.50(P_K) - 0.19(L_N) + 0.004(B_P) - 0.07(P_A) + 7.94$	0.99	0.99	360.27	0.00

DT Models

Table 11. Summary of DT Regression Analysis by Time of Day at Intersections

Time Period	Model Equation	R^2	Adj. R^2	ANOVA	
				F-value	*p*-value
Morning	$DT_{AM} = 3.42(P_B) - 2.05(P_K) - 1.34(L_N) - 0.0005(B_P) + 1.11(P_A) + 14.13$	0.73	0.67	12.82	0.00
Midday	$DT_{MID} = 5.37(P_B) + 7.01(P_K) + 4.52(L_N) + 0.002(B_P) + 2.26(P_A) - 20.70$	0.82	0.78	21.53	0.00
Evening	$DT_{PM} = 4.31(P_B) - 1.86(P_K) + 0.29(L_N) - 0.003(B_P) + 2.88(P_A) + 4.50$	0.95	0.93	70.51	0.00

Table 12. Summary of DT Regression Analysis by Time of Day at Midblock

Time Period	Model Equation	R^2	Adj. R^2	ANOVA	
				F-value	*p*-value
Morning	$DT_{AM} = 3.00(P_B) + 4.52(P_K) + 1.43(L_N) - 0.004(B_P) + 1.69(P_A) - 1.31$	0.89	0.86	37.09	0.00
Midday	$DT_{MID} = 4.75(P_B) - 4.61(P_K) + 2.20(L_N) + 0.0005(B_P) + 1.05(P_A) + 8.15$	0.73	0.67	13.00	0.00
Evening	$DT_{PM} = 3.26(P_B) + 1.51(P_K) + 0.16(L_N) + 0.001(B_P) + 1.63(P_A) + 0.87$	0.92	0.90	54.22	0.00

MODEL VALIDATION

Residual and Normal Probability Plots

For a valid regression model, the residuals would approximate the random errors that establish the relationship between the explanatory variables and the response variables. Therefore, if the residuals appear to behave randomly, it suggests that the model fits the data well. The normal probability plots were also used to determine the validity of the models. If all the data points fall near the line, an assumption of normality is reasonable, otherwise, the points will curve away from the line. Figures 5 and 6 are the respective residual plots and normal probability plots for the regression model for bus stops located at intersections by midday. The remaining plots by bus stop type and time period are presented in Appendix 4.

For all the models by bus stop type and time period, the residual plots showed evenly distributed random plots about the zero line, confirming that the models fit the data sets well. Also, the normal probability plots show a line along the points, thus an assumption of normality would be reasonable for the data sets. Thus, from the figures, it can be concluded that the models adequately predict TBST and DT.

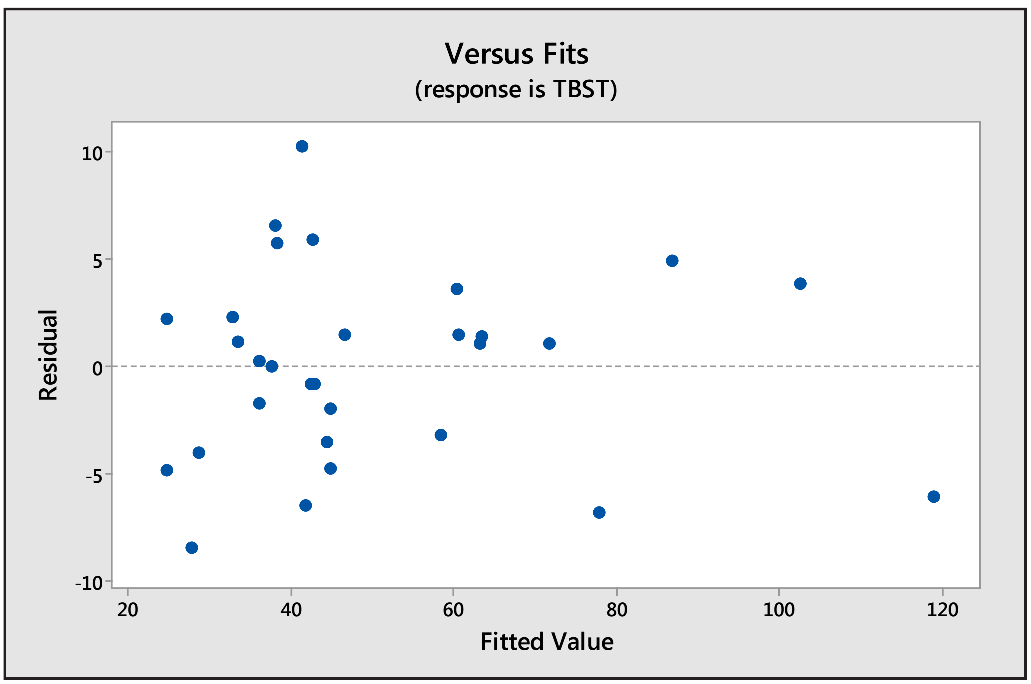

Figure 5. Residual Plot for Bus Stops Located at Intersections (Midday)

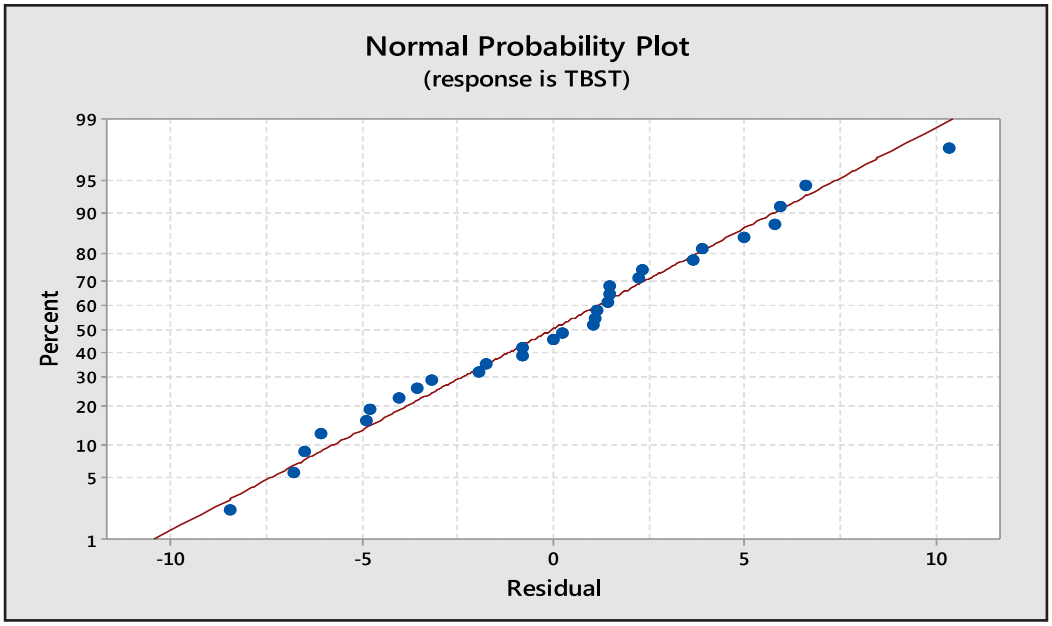

Figure 6. Normal Probability Plot for Bus Stops Located at Intersections (Midday)

Kolmogorov-Smirnov Test

Figure 7 and Figure 8 present the outputs of the results of the KS tests for TBST and DT for the midday period for bus stops at intersections. The D-statistics and corresponding *p*-values, for each model presented in Appendix 5 show that the models adequately predict the observed values.

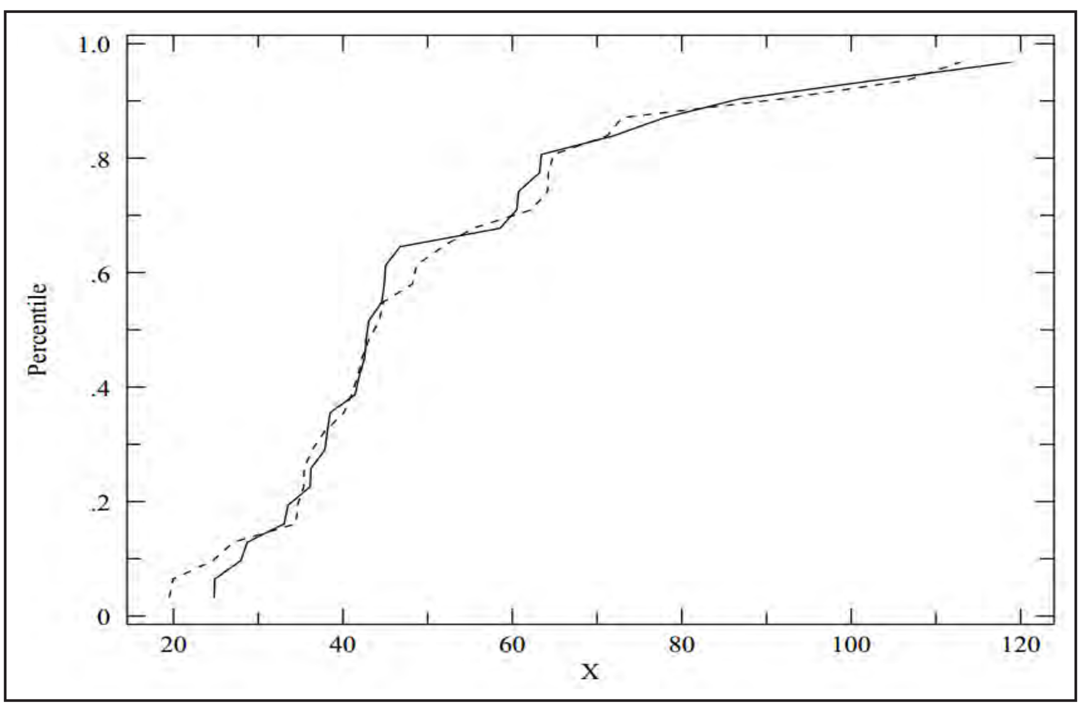

Figure 7. KS-test Comparison Percentile Plot for Bus stops Located at Intersections for TBST (Midday)

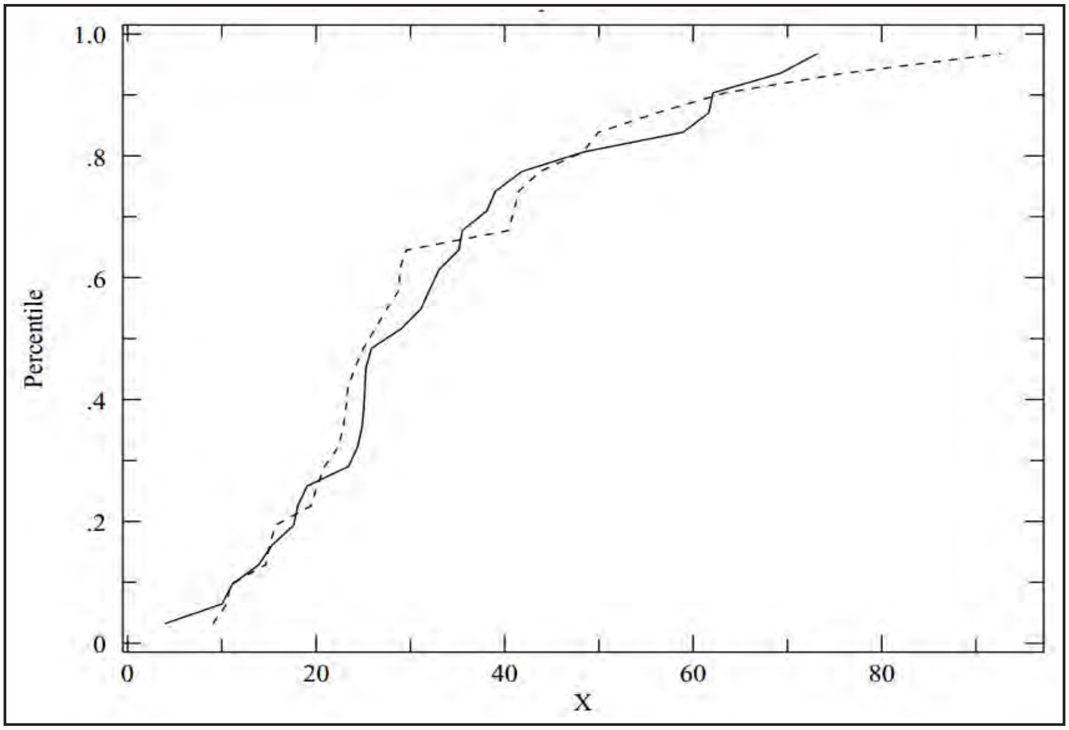

Figure 8. KS-test Comparison Percentile Plot for Bus stops Located at Intersections for DT (Midday)

OPTIMIZATION

Optimization was performed using the MiniTab software to minimize TBST. Since DT was the only variable significantly contributing to the TBST models, DT was the only variable subject to constraint. It was assumed that to improve reliability, the TBST needs to be minimized at each bus stop and by time of day. To achieve this, the maximum mean DT at each bus stop was used to obtain the maximum TBST. The maximum mean DT used was the upper limit of the 95% confidence interval.

Table 13 presents the summary of the optimization results. For bus stops located at intersections, the maximum suggested TBST was observed in the evening period. Based on the upper 95% confidence limit of DT (27.8 seconds), the maximum TBST should be no more than 66.8 seconds. In contrast, for midblock bus stops, the maximum TBST (36 seconds) took place during in the morning period, based on the upper 95% confidence limit of the DT of 18.5 seconds.

Table 13. Summary of Optimal TBST

Bus Stop Type	Time Period	DT (s)	Max. TBST (s)
Intersections	AM	20.4	42.5
	MID	28.9	47.1
	PM	27.8	66.8
Midblock	AM	18.5	36.0
	MID	19.6	33.2
	PM	17.7	31.2

The results indicate the maximum TBST for bus stops located at intersections range from 42 to 67 seconds, based on DT values ranging from 20 to 29 seconds. On the other hand, the maximum TBST for midblock bus stops was lower (31 to 36 seconds), corresponding to lower maximum DTs of 17 to 19 seconds.

VI. DISCUSSION OF RESULTS

From among the studies in the literature review, those using DT models to target the improvement of bus performance in various jurisdictions were identified. The studies revealed that, in predicting DT, it may be worthwhile to include secondary factors in addition to the number of passengers boarding and alighting. These factors include time of the day, type of bus fare payment, time lost serving stops, crowding level, and the physical characteristics and locations of the bus stops served.

The TBST and DT models developed for WMATA's transit buses in the District of Columbia were based on the following independent variables: number of passengers alighting and boarding, bus pad length, presence of on-street parking and number of approach lanes. For the DT models developed for bus stop location-types (midblock and at-intersection) and for time of day (morning, midday and evening peak hours), the prominent independent variables were simply the number of passenger alighting and boarding. In the case of the TBST models, also based on bus stop location-type and time of day, the significant variable was DT.

From the results of the analysis for midblock bus stops, the maximum average DT and TBST were 22.1 and 36.7 seconds, respectively, which were observed during the midday peak period. For bus stops located at intersections, the average DT was 22.7 seconds in the morning, 32.5 seconds during midday and 31.2 in the evening period. The corresponding average TBSTs recorded for bus stops at the intersections were 42.4, 50.7 and 49.6 seconds for the morning, midday, and evening periods, respectively. Again, the maximum TBST was also recorded during midday.

The mean TBST and DT at intersections were generally higher at the bus stops at intersections than at those located at midblock. This could be attributed to the potential influence of intersection interactions, including traffic, signal operations, pedestrian crossing, congestion, parking maneuvers, etc. The overall mean DT was determined to be 29 seconds, while the mean TBST was approximately 48 seconds at the bus stops at intersections. For midblock bus stops, the overall mean DT and TBST were 21 and 35 seconds, respectively.

Regression models by bus stop location-type yielded statistically significant regression models within the margin of error (5% level of significance), with high R^2 and adjusted R^2 values for DT and TBST (73%-95% and 67%-99%, respectively). The results of the ANOVA tests also showed statistically significant *F*-statistics ($p < 0.05$). For all the DT models, the number of passengers alighting and boarding significantly contributed to the model based on the significance of their coefficients. In the case of the TBST models, only DT contributed significantly to the model at a 5% level of significance, in addition to statistically significant regression coefficients (from the t-tests, with $p < 0.05$).

Residual plots for all the models also showed randomness about the zero line, indicating their viability, in addition to the normal probability plots showing points near a straight line. Moreover, the KS Test results indicated that the models adequately predicted the observed values. Finally, after optimizing TBST, the results indicated:

- The maximum TBST for bus stops located at intersections should be approximately 67 seconds during the evening period.

- During morning and midday periods at these locations, the maximum TBSTs suggested were approximately 43 and 47 seconds, respectively.

- For midblock bus stops, the maximum TBST suggested was 36 seconds for the morning period, while the maximum midday and evening TBST were 33.2 and 31.2 seconds, respectively.

VII. CONCLUSIONS AND RECOMMENDATIONS

The study showed that both bus DTs and TBSTs differ based on the bus stop location-type. As expected, TBSTs were generally higher than DTs, regardless of the time of day and bus stop location-type. Furthermore, the results also indicate that DTs and TBSTs were highest during midday periods.

The proposed regression models have a high explanatory power over the observed data. The models can therefore be used to adequately predict DTs and TBSTs at various bus stops and by time of the day at the 95% confidence level. The concept of total bus stop time prediction will provide bus transit decision makers additional metrics to enable them to improve bus schedule planning and overall reliability.

- For bus stops near intersections, it is recommended that buses spend no more than 43, 47, and 67 seconds TBST (from exiting the stream of traffic to successfully reintegrating with it) during the morning, midday and evening peak periods, respectively.

- Similarly, buses at midblock bus stops should spend no more than 36, 33, and 31 seconds TBST for the morning, midday and evening periods, respectively.

Thirty bus stops located at intersections and thirty midblock bus stops were used for this study. Due to potential changes in traffic patterns and land uses near bus stops, these models should be updated and validated on a 3- to 5-year cycle. It should be noted that the models are based on data collected at a specific jurisdiction and, as such, may not accurately predict TBST or DT other jurisdictions.

APPENDIX 1: BUS STOP LOCATIONS

Table 14. Locations of Bus Stops at Intersections

#	Location	Direction	Bus Stop ID
1	14th St & Irving St, NW	E	1003161
2	14th St & K St, NW	N	1001209
3	14th St & U St, NW	E	1001677
4	14th St & U St, NW	S	1001696
5	16th St & P St, NW	N	1001428
6	16th St & Sheridan St, NW	S	1002898
7	16th St & U St, NW	N	1001666
8	7th St &H St, NW	N	1003418
9	7th St & H St, NW	S	1001132
10	7th St & L St, NW	N	1001293
11	7th St & Pennsylvania Ave, NW	E	1003033
12	7th St & Pennsylvania Ave, NW	N	1000930
13	7th St & T St, NW	S	1001640
14	Columbia Rd & Georgia Ave, NW	W	1001985
15	Connecticut Ave & L St, NW	N	1001276
16	Georgia Ave & Columbia Rd, NW	S	1001986
17	Georgia Ave & Decatur St, NW	S	1002495
18	Georgia Ave & Eastern Ave, NW	S	1003614
19	Georgia Ave & Florida Ave, NW	W	1001653
20	Georgia Ave & Florida Ave, NW	E	1001655
21	Georgia Ave & Howard Pl, NW	N	1001803
22	Georgia Ave & Irving St, NW	N	1002006
23	Georgia Ave & Kennedy St, NW	N	1002599
24	Georgia Ave & Kennedy St Rd, NW	S	1002617
25	Georgia Ave & New Hampshire Ave, NW	S	1003655
26	Georgia Ave & Rock Creek Rd, NW	S	1002691
27	Georgia Ave & Upshur St, NW	N	1002335
28	Irving St & Georgia Ave, NW	E	1002019
29	New Hampshire Ave & Georgia Ave, NW	E	1003081
30	Riggs Rd & North Capitol St, NE	W	1002584

Table 15. Locations of Midblock Bus Stops

#	Location	Direction	Bus Stop ID
1	14th & Fairmont St, NW	S	1001861
2	14th St & Columbia Rd, NW	W	1001964
3	14th St & Irving St, NW	S	1003087
4	14th St & Irving St, NW	N	1001996
5	14th St & U St, NW	N	1001702
6	14th St & Oak St, NW	N	1002166
7	Florida Ave & 5th St, NW	E	1001619
8	14th St & Otis St, NW	S	1002214
9	14th St & Rhode Island Ave, NW	N	1001393
10	14th St & W St, NW	N	1003475
11	16th St & Euclid St, NW	S	1002874
12	16th St & Harvard St, NW	S	1002873
13	16th St & Park Rd, NW	S	1002870
14	16th St & Sheridan St, NW	N	1002924
15	16th St & U St, NW	S	1002877
16	7th St & Pennsylvania Ave, NW	W	1003398
17	7th St & H St, NW	W	1001121
18	7th Georgia Ave & Florida Ave, NW	N	1003615
19	First Pl & Riggs Rd, NE	N	1002588
20	Florida Ave & North Capital St, NW	W	1001513
21	Georgia Ave & Decatur St, NW	N	1003613
22	Georgia Ave & Farragut St, NW	S	1002527
23	Georgia Ave & Lamont St, NW	S	1002076
24	Georgia Ave & Missouri Ave, NW	N	1003786
25	Georgia Ave & Butternut St, NW	S	1002817
26	Georgia Ave & New Hampshire Ave, NW	N	1003419
27	Georgia Ave & Underwood St, NW	N	1002779
28	Pennsylvania Ave & 12th St, NW	W	1000981
29	U St & 13th St, NW	E	1001679
30	16th St & Buchanan St, NW	S	1002862

APPENDIX 2: DATA COLLECTION SHEETS

FIELD DATA COLLECTION SCHEME FOR TBST PROJECT

Data Collection Logistics

Before commencing the data collection, field technicians will be equipped with the following:

- Stop watch
- Data collection form
- Pencil

The following should be noted:

- The entry (front) door is denoted as Y and exit only (back) door as X
- Location of the bus stop
- Time of day

Requirements:

- Work in pairs
- 1 bus stop per day
- Day to be collected
  - AM: 8:30 am – 10:30 am
  - Midday: 1230PM – 2:30 pm
  - PM: 4:00 pm – 6:00 pm
- Collect data for 10 buses

Variables to be Obtained at Bus Stops

The following data will be obtained at the bus stops:

1. **Bus #**
2. $\mathbf{S}_{1:}$ Time Bus arrive at the bus pad
3. **X:** Number of passengers exiting

4. **Y:** Number of passengers entering

5. **D_1:** Time door opens

6. **D_2:** Time door closes

7. **S_2:** Time bus pulls away from the **bus stop or bus pad AFTER the doors are closed**.

Person 1 records Bus #, verbally communicates time bus stops out to the seconds, records it.

Person 2 starts stop watch after **Person 1** calls out Bus stop time, records seconds after for time Door opens, Doors closes and Bus Pulls Away.

****Note:** If the doors open after the initial "closure," record that in D_2, then record time bus pulls away again in S_2.

Data Collection Sheet for TBST Project

madwur

Name: 14 SC + USC NW - Camila
Date: June 10, 2014
Day: Tuesday
Start time: 9:16 am
End Time: 10:01 am
Bus stop ID: 1001072

(7)

	Person 1 Digital Clock (HH:MM:SS)				Person 2 Stop watch in seconds(SS)		
#	Bus #	S_1 Time Bus arrive	X # Exiting	Y # Boarding	D_1 Time Doors Opens	D_2 Time Doors Closes #	S_2 Time Bus pulls away
~	70	8:15:22	2	4	04	10	15
1	52	9:16	9	1	4.35	21.98	7.35
2	54	9:17	5	3	5.81	33.92	5.39
3	53	9:24	6	0	6.20	8.80	19.35
4	52	9:28	4	2	8.90	19.20	7.80
5	52	9:35	0	6	6.69	15.22	9.74
6	woodley	9:39	0	3	7.48	16.33	11.48
7	53	9:45	0	8	10.04	49.02	12.03
8	woodley	9:47	1	1	6.18	11.35	6.80
9	54	9:58	2	6	6.26	25.50	5.31
10	52	10:01	1	1	7.51	6.83	11.91
11							
12							
13							
14							
15							

Figure 9. Data Collection Sheet for TBST Project

APPENDIX 3: DESCRIPTIVE STATISTICS

Table 16. Descriptive Statistics for Variables Collected at Intersections – AM

Descriptive Statistics	Dwell Time	P. Boarding	P. Alighting	TBST	# Lanes	BP Length
Mean	22.70	3.57	2.92	42.36	2.33	1161.44
Standard Error	1.18	0.23	0.22	1.47	0.04	41.37
Median	16.25	2	2	34.715	2	1052
Mode	9.05	1	0	19.38	2	1098
Standard Deviation	20.43	4.03	3.81	25.30	0.70	714.16
Sample Variance	417.24	16.21	14.55	640.26	0.49	510022.91
Kurtosis	20.30	4.58	4.96	10.04	0.31	11.97
Skewness	3.51	2.02	2.11	2.45	0.61	3.40
Range	177.09	22	19	187.75	3	3765
Minimum	3.04	0	0	11.85	1	609
Maximum	180.13	22	19	199.6	4	4374
Sum	6765.21	1064	870	12623.41	695	346108
Count	298	298	298	298	298	298
Confidence Level (95.0%)	2.33	0.46	0.43	2.88	0.08	81.42

Table 17. Descriptive Statistics for Variables Collected at Intersections – Midday

Descriptive Statistics	Dwell Time	P. Boarding	P. Alighting	TBST	# Lanes	BP Length
Mean	32.45	4.30	2.96	50.68	2.33	1161.27
Standard Error	1.81	0.27	0.22	1.98	0.04	41.38
Median	22.10	3	2	40.49	2	1052.00
Mode	25.13	1	0	66.33	2	1098.00
Standard Deviation	31.31	4.68	3.77	34.25	0.70	714.28
Sample Variance	980.47	21.95	14.19	1172.84	0.49	510195.55
Kurtosis	8.63	10.02	4.38	6.56	0.34	11.97
Skewness	2.41	2.44	2.00	2.09	0.63	3.40
Range	240.17	38	21	251.68	3	3765.02
Minimum	3.11	0	0	11.1	1	609.00
Maximum	243.28	38	21	262.78	4	4374.02
Sum	9669.13	1282	882	15103.49	694	346059.35
Count	298	298	298	298	298	298
Confidence Level (95.0%)	3.57	0.53	0.43	3.90	0.08	81.43

Table 18. Descriptive Statistics for Variables Collected at Intersections – PM

Descriptive Statistics	Dwell Time	P. Boarding	P. Alighting	TBST	# Lanes	BP Length
Mean	31.21	5.17	3.35	49.60	2.33	1159.08
Standard Error	1.77	0.37	0.26	1.93	0.04	41.72
Median	19.85	3	2	39.53	2	994.00
Mode	40.91	0	0	24.86	2	848.00
Standard Deviation	30.39	6.32	4.50	33.25	0.70	717.71
Sample Variance	923.26	39.96	20.23	1105.33	0.49	515102.30
Kurtosis	13.84	7.62	5.18	9.67	0.32	11.83
Skewness	2.82	2.47	2.13	2.29	0.62	3.38
Range	267.05	39	26	271.30	3	3765.02
Minimum	3.18	0	0	14.03	1	609.00
Maximum	270.23	39	26	285.33	4	4374.02
Sum	9236.68	1530	991	14681.56	690	343087.34
Count	296	296	296	296	296	296
Confidence Level (95.0%)	3.48	0.72	0.51	3.80	0.08	82.10

Table 19. Descriptive Statistics for Variables Collected at Midblock – AM

Descriptive Statistics	Dwell Time	P. Boarding	P. Alighting	TBST	# Lanes	BP Length
Mean	20.32	3.25	2.86	33.94	2.21	948.63
Standard Error	0.95	0.24	0.25	1.07	0.04	14.73
Median	14.64	2	1	28.34	2	915
Mode	14.21	1	0	27.33	2	614
Standard Deviation	16.38	4.09	4.29	18.49	0.75	253.43
Sample Variance	268.25	16.72	18.44	341.78	0.56	64228.46
Kurtosis	2.74	14.79	10.02	2.86	0.38	2.19
Skewness	1.72	3.00	2.88	1.73	0.61	1.42
Range	83.66	35	26	104.73	3	1076
Minimum	1.60	0	0	12.16	1	614
Maximum	85.26	35	26	116.89	4	1690
Sum	6013.42	962	846	10046.6	653	280795.036
Count	296	296	296	296	296	296
Confidence Level (95.0%)	1.87	0.47	0.49	2.11	0.09	28.99

Table 20. Descriptive Statistics for Variables Collected at Midblock – Midday

Descriptive Statistics	Dwell Time	P. Boarding	P. Alighting	TBST	# Lanes	BP Length
Mean	22.06	2.82	2.63	36.70	2.21	948.63
Standard Error	1.28	0.25	0.20	1.44	0.04	14.73
Median	14.66	1.5	1.00	28.95	2	915
Mode	18.45	1	1.00	16.4	2	614
Standard Deviation	22.05	4.27	3.45	24.89	0.75	253.43
Sample Variance	486.12	18.22	11.89	619.49	0.56	64228.46
Kurtosis	28.05	51.29	6.00	23.42	0.38	2.19
Skewness	3.93	5.52	2.31	3.63	0.61	1.42
Range	228.14	50	21.00	247.45	3	1076
Minimum	2.98	0	0.00	12.95	1	614
Maximum	231.12	50	21.00	260.40	4	1690
Sum	6572.40	840	783.00	10935.3	653	280795
Count	298	298	298.00	298	296	296
Confidence Level (95.0%)	2.51	0.49	0.39	2.84	0.09	28.99

Table 21. Descriptive Statistics for Variables Collected at Midblock – PM

Descriptive Statistics	Dwell Time	P. Boarding	P. Alighting	TBST	# Lanes	BP Length
Mean	19.70	2.85	3.33	33.26	2.21	948.63
Standard Error	1.01	0.23	0.22	1.15	0.04	14.73
Median	14.35	2	2.00	26.64	2	915
Mode	14.96	0	1.00	21.61	2	614
Standard Deviation	17.24	3.88	3.85	19.78	0.75	253.43
Sample Variance	297.09	15.03	14.86	391.43	0.56	64228.46
Kurtosis	9.04	6.94	4.35	7.79	0.38	2.19
Skewness	2.68	2.49	2.04	2.50	0.61	1.42
Range	106.35	24	21.00	124.34	3	1076
Minimum	3.01	0	0.00	13.82	1	614
Maximum	109.36	24	21.00	138.16	4	1690
Sum	5790.35	838	980.00	9777.81	653	280795
Count	294.00	294	294.00	294	296	296
Confidence Level (95.0%)	1.98	0.44	0.44	2.27	0.09	28.99

APPENDIX 4: REGRESSION ANALYSES

Table 22. Intersections – Regression Analysis TBST – AM

Regression Statistics	
Multiple R	0.81908
R Square	0.67089
Adjusted R Square	0.58503
Standard Error	8.56552
Observations	30

ANOVA

	df	SS	MS	F	Significance F
Regression	6	3439.8408	573.3068	7.81411	0.000116
Residual	23	1687.4677	73.3682		
Total	29	5127.3085			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	14.61219	11.80052	1.23827	0.22811	-9.79904	39.02343	-9.79904	39.02343
Dwell Time	1.40299	0.30874	4.54424	0.00014	0.76431	2.04167	0.76431	2.04167
Pass. Boarding	-1.90465	1.32860	-1.43358	0.16515	-4.65308	0.84377	-4.65308	0.84377
Coded Parking	-1.19137	3.68525	-0.32328	0.74940	-8.81489	6.43215	-8.81489	6.43215
# Lanes	2.45191	2.64297	0.92771	0.36319	-3.01548	7.91930	-3.01548	7.91930
BP Length (In)	-0.00109	0.00280	-0.38824	0.70141	-0.00688	0.00471	-0.00688	0.00471
Pass. Alighting	-0.01825	0.77982	-0.02340	0.98153	-1.63143	1.59493	-1.63143	1.59493

Table 23. Intersections – Regression Analysis TBST – Midday

Regression Statistics	
Multiple R	0.98079
R Square	0.96194
Adjusted R Square	0.95201
Standard Error	5.03410
Observations	30

ANOVA

	df	SS	MS	F	Significance F
Regression	6	14732.203	2455.37	96.8887	3.72E-15
Residual	23	582.869	25.3421		
Total	29	15315.073			

	Coefficients	Std. Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	17.22624	7.28714	2.36392	0.02691	2.15165	32.30083	2.15165	32.30083
Dwell Time	1.12091	0.11047	10.14690	0.00000	0.89239	1.34943	0.89239	1.34943
Pass. Boarding	0.26085	0.67136	0.38855	0.70118	-1.12796	1.64966	-1.12796	1.64966
Park	-1.87268	2.28178	-0.82071	0.42024	-6.59291	2.84754	-6.59291	2.84754
# Lanes	0.51754	1.59214	0.32506	0.74808	-2.77606	3.81114	-2.77606	3.81114
BP Length (In)	-0.00170	0.00142	-1.19539	0.24412	-0.00464	0.00124	-0.00464	0.00124
Pass. Alighting	-0.15176	0.45831	-0.33113	0.74354	-1.09985	0.79633	-1.09985	0.79633

Table 24. Intersections – Regression Analysis TBST – PM

Regression Statistics	
Multiple R	0.97388
R Square	0.94843
Adjusted R Square	0.93498
Standard Error	5.99613
Observations	30

ANOVA

	df	SS	MS	F	Significance F
Regression	6	15209.665	2534.944	70.506	0.000
Residual	23	826.933	35.954		
Total	29	16036.597			

	Coefficients	Std. Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	21.72054	7.89701	2.75048	0.01139	5.38433	38.05675	5.38433	38.05675
Dwell Time	1.17435	0.17278	6.79685	0.00000	0.81693	1.53177	0.81693	1.53177
Pass. Boarding	-0.01566	0.80190	-0.01953	0.98459	-1.67451	1.64319	-1.67451	1.64319
Park	-1.55172	2.58835	-0.59950	0.55470	-6.90612	3.80269	-6.90612	3.80269
# Lanes	-2.06799	1.83959	-1.12416	0.27254	-5.87348	1.73749	-5.87348	1.73749
BP Length (In)	0.00021	0.00186	0.11157	0.91213	-0.00364	0.00406	-0.00364	0.00406
Pass. Alighting	-0.41507	0.63373	-0.65496	0.51899	-1.72603	0.89590	-1.72603	0.89590

Table 25. Intersections – Regression Analysis DT – AM

Regression Statistics	
Multiple R	0.85302
R Square	0.72765
Adjusted R Square	0.67091
Standard Error	5.66309
Observations	30

ANOVA

	df	SS	MS	F	Significance F
Regression	5	2056.386	411.277	12.824	0.000
Residual	24	769.695	32.071		
Total	29	2826.080			

	Coefficients	Std. Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	14.12869	7.24930	1.94897	0.06308	-0.83313	29.09050	-0.83313	29.09050
Pass. Boarding	3.41498	0.53449	6.38926	0.00000	2.31185	4.51810	2.31185	4.51810
Coded Parking	-2.04977	2.40031	-0.85396	0.40157	-7.00376	2.90422	-7.00376	2.90422
# Lanes	-1.33794	1.72592	-0.77520	0.44579	-4.90006	2.22419	-4.90006	2.22419
BP Length (In)	-0.00045	0.00185	-0.24519	0.80839	-0.00427	0.00336	-0.00427	0.00336
Pass. Alighting	1.11263	0.46286	2.40382	0.02431	0.15733	2.06793	0.15733	2.06793

Table 26. Intersections – Regression Analysis DT – Midday

Regression Statistics	
Multiple R	0.90428
R Square	0.81771
Adjusted R Square	0.77974
Standard Error	9.30207
Observations	30

ANOVA

	df	SS	MS	F	Significance F
Regression	5	9315.75	1863.15	21.53	0.00
Residual	24	2076.69	86.53		
Total	29	11392.43			

	Coefficients	Std. Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-20.69753	12.78530	-1.61885	0.11855	-47.08509	5.69004	-47.08509	5.69004
Pass. Boarding	5.36835	0.58151	9.23178	0.00000	4.16818	6.56852	4.16818	6.56852
Park	7.01081	3.96601	1.76772	0.08982	-1.17463	15.19625	-1.17463	15.19625
# Lanes	4.51542	2.79387	1.61619	0.11912	-1.25085	10.28169	-1.25085	10.28169
BP Length (In)	0.00162	0.00261	0.62019	0.54098	-0.00376	0.00700	-0.00376	0.00700
Pass. Alighting	2.25611	0.71071	3.17443	0.00409	0.78927	3.72295	0.78927	3.72295

Table 27. Intersections – Regression Analysis DT – PM

Regression Statistics	
Multiple R	0.94743
R Square	0.89763
Adjusted R Square	0.87630
Standard Error	7.08396
Observations	30

ANOVA

	df	SS	MS	F	Significance F
Regression	5	10560.21	2112.04	42.09	0.00
Residual	24	1204.38	50.18		
Total	29	11764.59			

	Coefficients	Std. Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	4.49918	9.28438	0.48460	0.63236	-14.66284	23.66121	-14.66284	23.66121
Pass. Boarding	4.31161	0.35063	12.29664	0.00000	3.58794	5.03528	3.58794	5.03528
Park	-1.85663	3.03435	-0.61187	0.54638	-8.11923	4.40596	-8.11923	4.40596
# Lanes	0.29243	2.17251	0.13461	0.89405	-4.19142	4.77628	-4.19142	4.77628
BP Length (In)	-0.00286	0.00212	-1.35084	0.18935	-0.00724	0.00151	-0.00724	0.00151
Pass. Alighting	2.87808	0.46412	6.20116	0.00000	1.92019	3.83598	1.92019	3.83598

Table 28. Midblock – Regression Analysis TBST – AM

Regression Statistics	
Multiple R	0.85216
R Square	0.72618
Adjusted R Square	0.65475
Standard Error	9.59570
Observations	30

ANOVA

	df	SS	MS	F	Significance F
Regression	6	5616.475	936.079	10.166	0.000
Residual	23	2117.780	92.077		
Total	29	7734.255			

	Coefficients	Std. Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-0.00090	11.19272	-0.00008	0.99994	-23.15480	23.15300	-23.15480	23.15300
Dwell Time	1.73329	0.46205	3.75134	0.00104	0.77748	2.68911	0.77748	2.68911
Pass. Boarding	-2.19407	1.55036	-1.41520	0.17041	-5.40123	1.01310	-5.40123	1.01310
Park	3.91301	4.68187	0.83578	0.41188	-5.77217	13.59819	-5.77217	13.59819
# Lanes	-0.14751	2.58913	-0.05697	0.95506	-5.50354	5.20852	-5.50354	5.20852
BP Length (in)	0.00199	0.00840	0.23757	0.81432	-0.01538	0.01937	-0.01538	0.01937
Pass. Alighting	-1.20521	0.96989	-1.24263	0.22653	-3.21157	0.80115	-3.21157	0.80115

Table 29. Midblock – Regression Analysis TBST – Midday

Regression Statistics	
Multiple R	0.98853
R Square	0.97718
Adjusted R Square	0.97123
Standard Error	2.59321
Observations	30

ANOVA

	df	SS	MS	F	Significance F
Regression	6	6623.764	1103.961	164.165	0.000
Residual	23	154.669	6.725		
Total	29	6778.433			

	Coefficients	Std. Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	8.70709	3.11499	2.79522	0.01028	2.26323	15.15094	2.26323	15.15094
Dwell Time	1.11624	0.06903	16.17007	0.00000	0.97344	1.25904	0.97344	1.25904
Pass. Boarding	0.04025	0.40782	0.09870	0.92223	-0.80340	0.88390	-0.80340	0.88390
Park	-0.85971	1.23246	-0.69755	0.49245	-3.40925	1.68983	-3.40925	1.68983
# Lanes	0.50409	0.70474	0.71529	0.48163	-0.95378	1.96196	-0.95378	1.96196
BP Length (in)	0.00451	0.00208	2.17061	0.04053	0.00021	0.00880	0.00021	0.00880
Pass. Alighting	-0.27402	0.22159	-1.23660	0.22871	-0.73242	0.18438	-0.73242	0.18438

Table 30. Midblock – Regression Analysis TBST – PM

Regression Statistics	
Multiple R	0.99472
R Square	0.98947
Adjusted R Square	0.98673
Standard Error	1.73428
Observations	30

ANOVA

	df	SS	MS	F	Significance F
Regression	6	6501.574	1083.596	360.272	0.000
Residual	23	69.177	3.008		
Total	29	6570.751			

	Coefficients	Std. Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	7.94187	2.06945	3.83767	0.00084	3.66088	12.22285	3.66088	12.22285
Dwell Time	1.11850	0.08942	12.50854	0.00000	0.93353	1.30348	0.93353	1.30348
Pass. Boarding	0.18518	0.31388	0.58996	0.56097	-0.46414	0.83450	-0.46414	0.83450
Park	-0.49448	0.78154	-0.63270	0.53317	-2.11121	1.12225	-2.11121	1.12225
# Lanes	-0.18671	0.46637	-0.40035	0.69260	-1.15146	0.77804	-1.15146	0.77804
Bus Pad Length (in)	0.00444	0.00143	3.10844	0.00495	0.00149	0.00740	0.00149	0.00740
Pass. Alighting	-0.07302	0.18091	-0.40361	0.69023	-0.44725	0.30122	-0.44725	0.30122

Table 31. Midblock – Regression Analysis DT – AM

Regression Statistics	
Multiple R	0.94096
R Square	0.88541
Adjusted R Square	0.86154
Standard Error	4.23921
Observations	30

ANOVA

	df	SS	MS	F	Significance F
Regression	5	3332.663	666.533	37.089	0.000
Residual	24	431.303	17.971		
Total	29	3763.965			

	Coefficients	Std. Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-1.31	4.93754	-0.26493	0.79333	-11.49867	8.88248	-11.49867	8.88248
Pass. Boarding	3.00	0.30705	9.76819	0.00000	2.36562	3.63308	2.36562	3.63308
Park	4.52	1.85077	2.44446	0.02223	0.70433	8.34391	0.70433	8.34391
# Lanes	1.43	1.10593	1.29351	0.20815	-0.85200	3.71307	-0.85200	3.71307
BP Length (in)	-0.004	0.00363	-1.01005	0.32255	-0.01117	0.00383	-0.01117	0.00383
Pass. Alighting	1.69	0.25436	6.64108	0.00000	1.16425	2.21420	1.16425	2.21420

Table 32. Midblock – Regression Analysis DT – Midday

Regression Statistics	
Multiple R	0.85459
R Square	0.73033
Adjusted R Square	0.67415
Standard Error	7.66809
Observations	30

ANOVA

	df	SS	MS	F	Significance F
Regression	5	3821.7808	764.3562	12.9994	0.0000
Residual	24	1411.1892	58.7995		
Total	29	5232.9699			

	Coefficients	Std. Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	8.15135	9.05948	0.89976	0.37719	-10.54649	26.84919	-10.54649	26.84919
Pass. Boarding	4.75417	0.71590	6.64084	0.00000	3.27663	6.23172	3.27663	6.23172
Park	-4.60800	3.52090	-1.30876	0.20301	-11.87479	2.65879	-11.87479	2.65879
# Lanes	2.20222	2.03486	1.08225	0.28990	-1.99752	6.40195	-1.99752	6.40195
BP Length (in)	0.00051	0.00614	0.08333	0.93428	-0.01215	0.01318	-0.01215	0.01318
Pass. Alighting	1.04873	0.61929	1.69343	0.10332	-0.22943	2.32689	-0.22943	2.32689

Table 33. Midblock – Regression Analysis DT – PM

Regression Statistics	
Multiple R	0.95848
R Square	0.91868
Adjusted R Square	0.90173
Standard Error	3.95896
Observations	30

ANOVA

	df	SS	MS	F	Significance F
Regression	5	4249.320	849.864	54.223	0.000
Residual	24	376.161	15.673		
Total	29	4625.482			

	Coefficients	Std. Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0.86664	4.72078	0.18358	0.85588	-8.87656	10.60985	-8.87656	10.60985
Pass. Boarding	3.25749	0.26698	12.20148	0.00000	2.70648	3.80850	2.70648	3.80850
Park	1.50919	1.75727	0.85883	0.39893	-2.11764	5.13602	-2.11764	5.13602
# Lanes	0.16028	1.06411	0.15063	0.88153	-2.03592	2.35649	-2.03592	2.35649
Bus Pad Length (in)	0.00137	0.00325	0.42075	0.67768	-0.00534	0.00807	-0.00534	0.00807
Pass. Alighting	1.62940	0.24479	6.65629	0.00000	1.12417	2.13462	1.12417	2.13462

APPENDIX 5: MODEL VALIDATION

Residual and Normal Probability Plots
Kolmogorov-Smirnov Test

BUS STOPS LOCATED AT INTERSECTIONS

Total Bus Stop Time by Time of Day

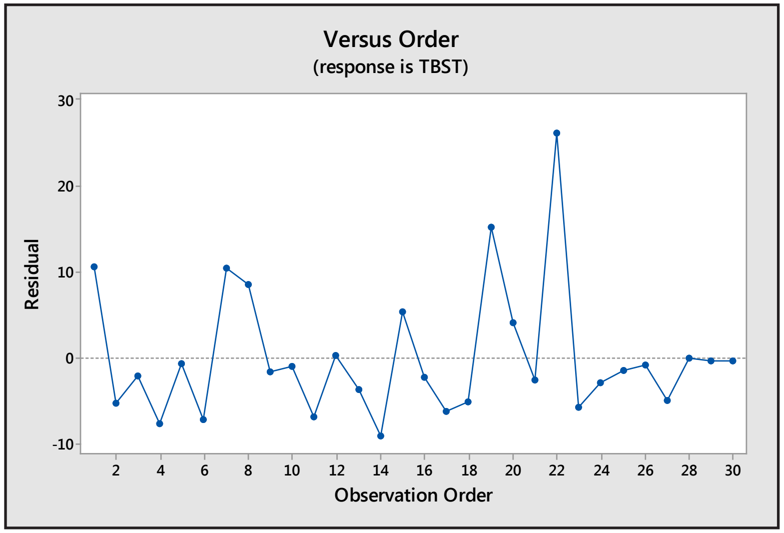

Figure 10. Intersections - TBST AM vs. Order

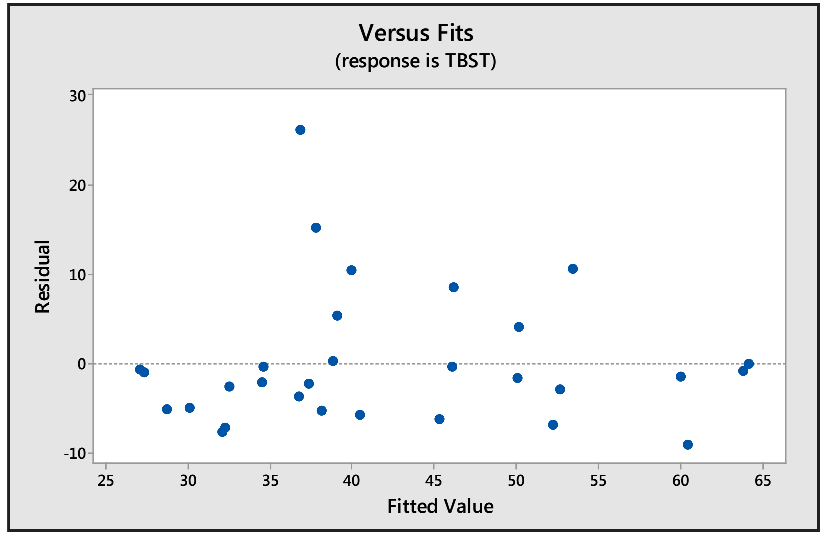

Figure 11. Intersections - TBST AM vs. Fits

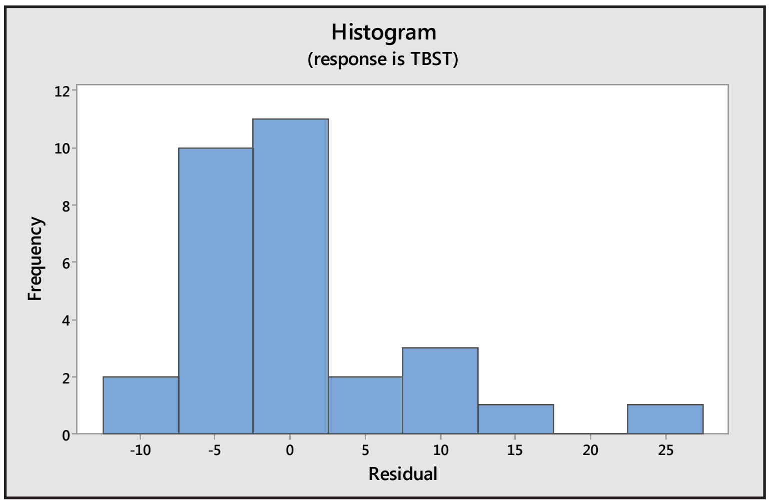

Figure 12. Intersections - TBST AM Histogram

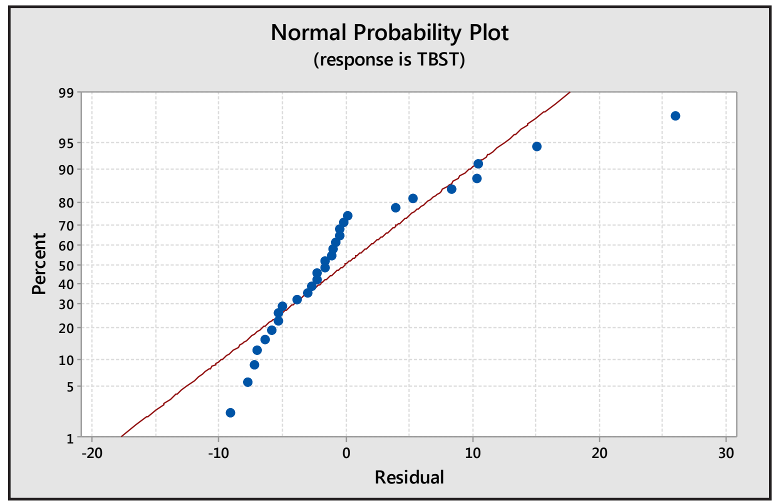

Figure 13. Intersections - TBST AM Normal Probability Plot

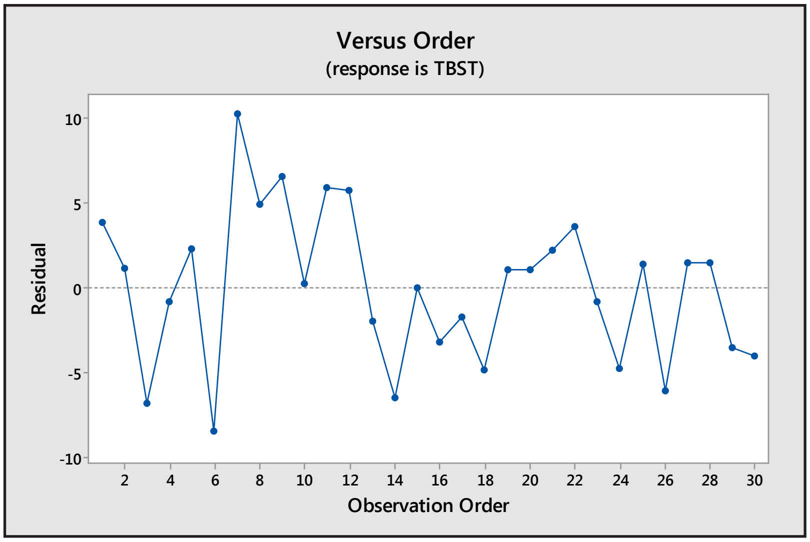

Figure 14. Intersections - TBST Midday vs. Order

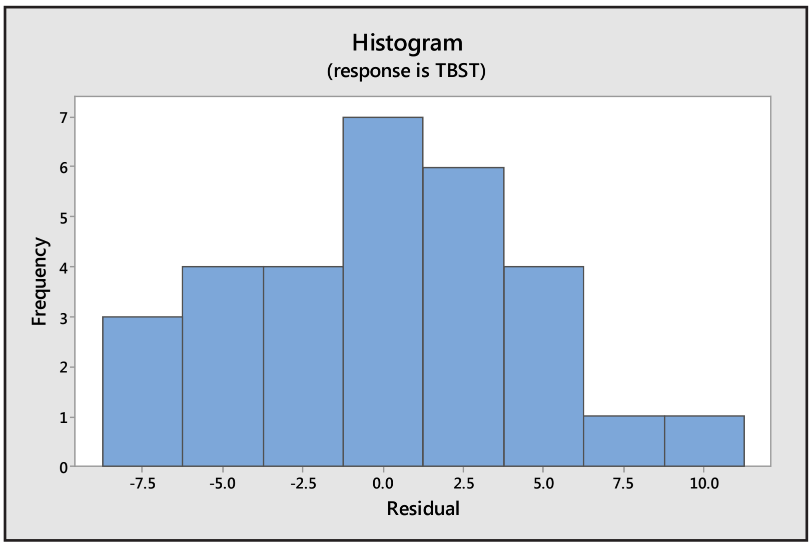

Figure 15. Intersections - TBST Midday Histogram

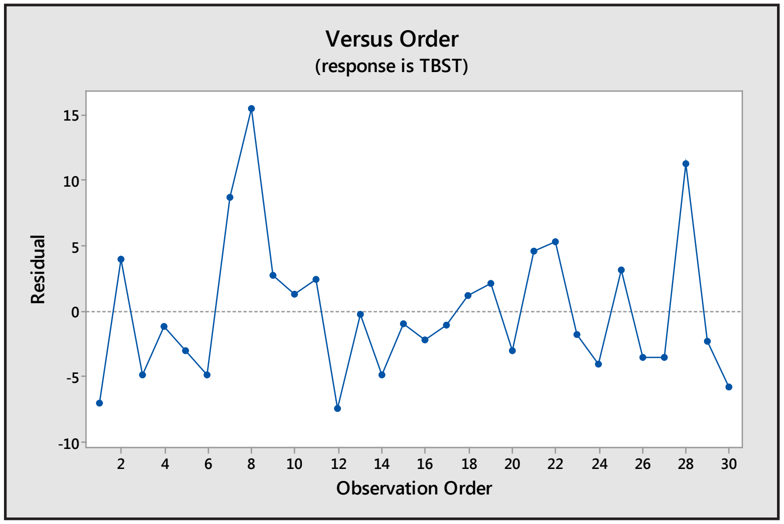

Figure 16. Intersections - TBST PM vs. Order

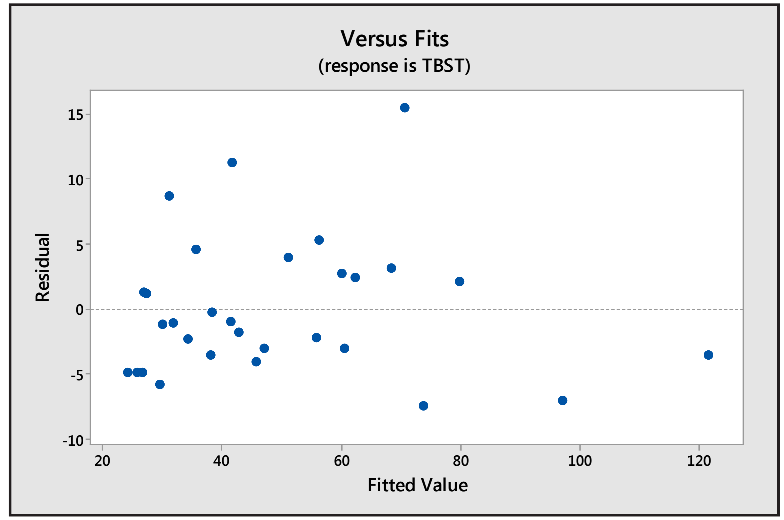

Figure 17. Intersections - TBST PM vs. Fits

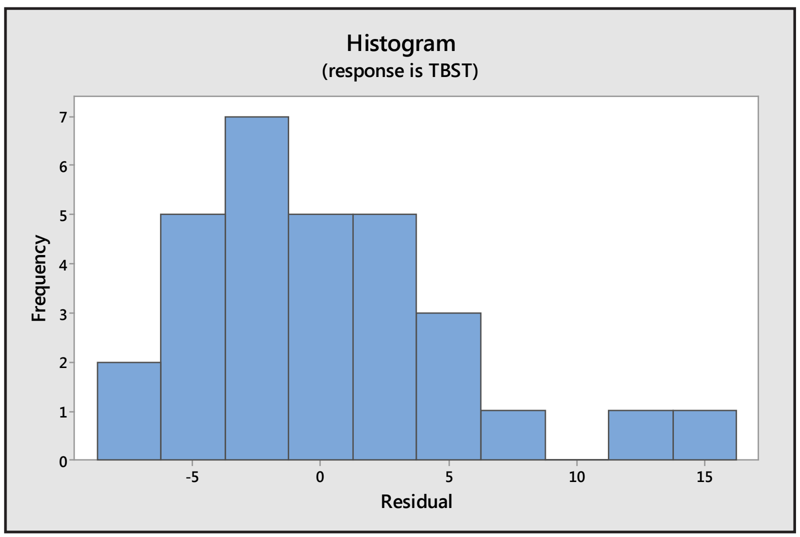

Figure 18. Intersections - TBST PM Histogram

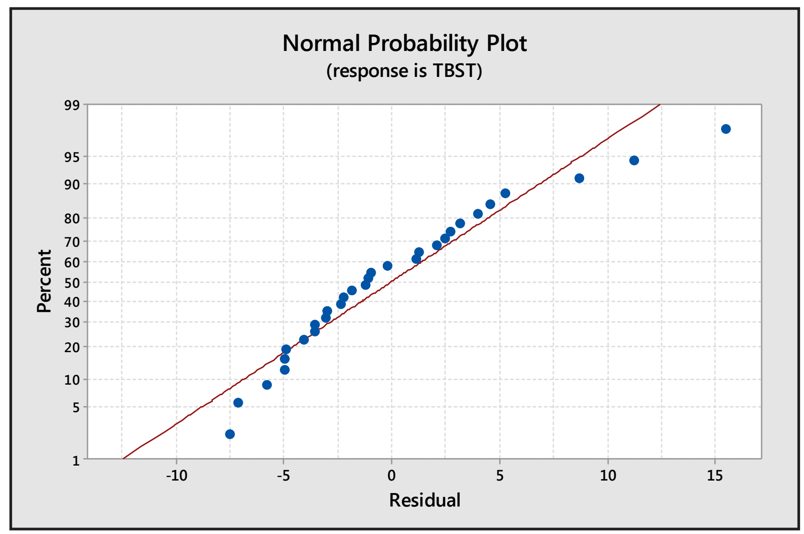

Figure 19. Intersections - TBST PM Normal Probability Plots

Dwell Time by Time of Day

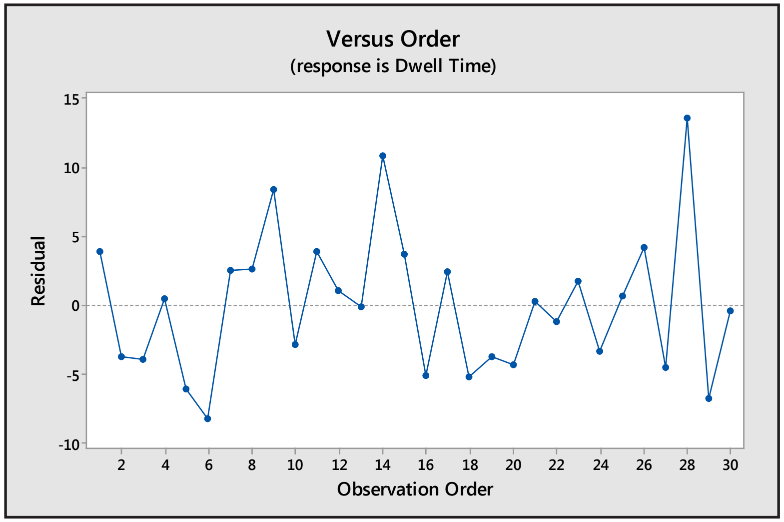

Figure 20. Intersections - DT AM vs. Order

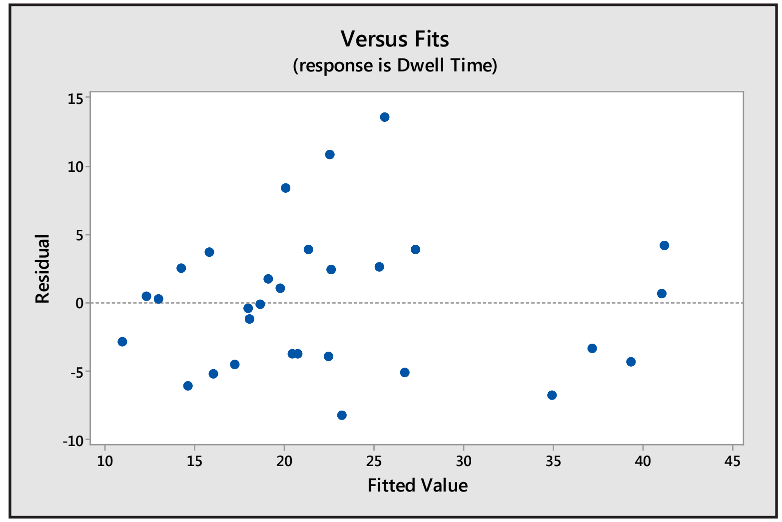

Figure 21. Intersections - DT AM vs. Fits

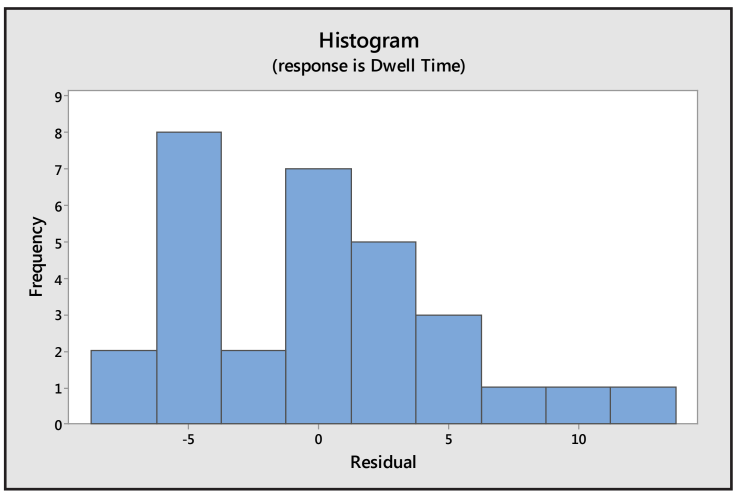

Figure 22. Intersections - DT AM Histogram

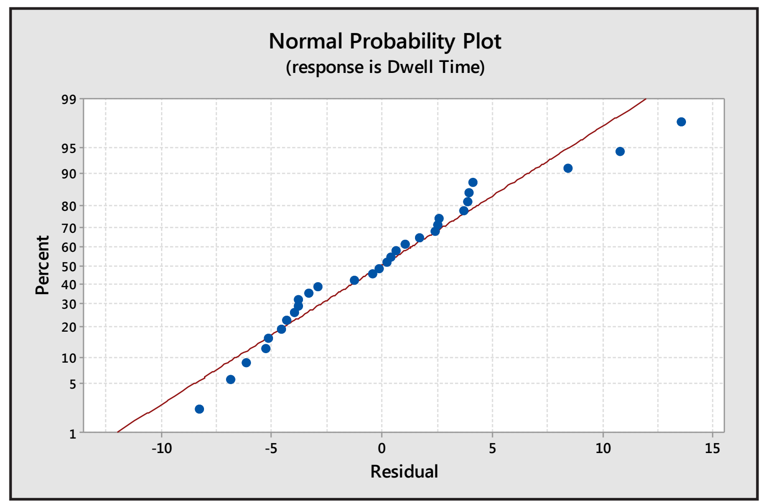

Figure 23. Intersections - DT AM Normal Probability Plot

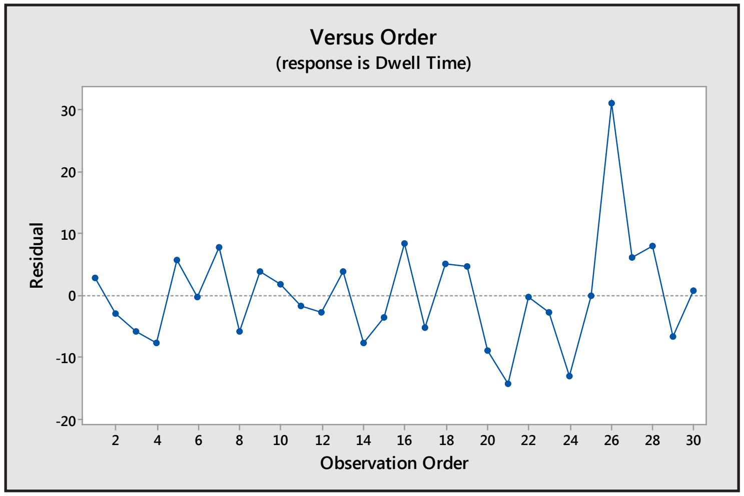

Figure 24. Intersections - DT Midday vs. Order

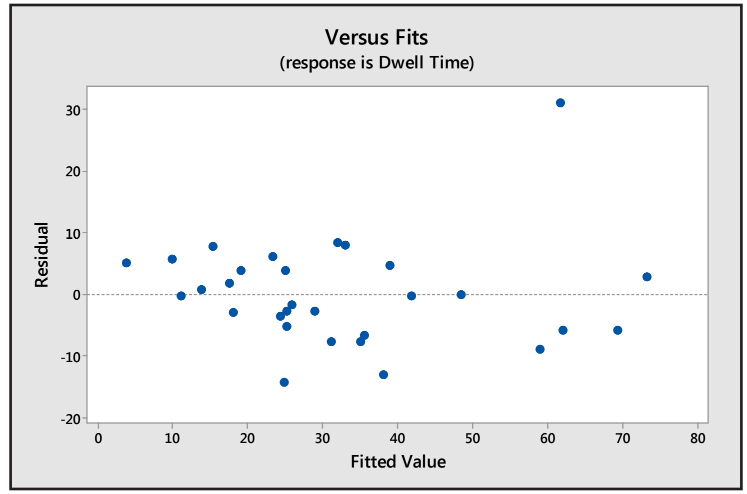

Figure 25. Intersections - DT Midday vs. Fits

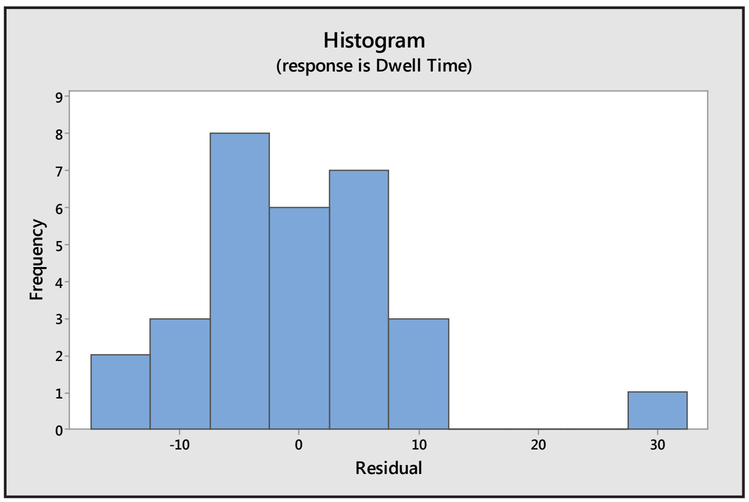

Figure 26. Intersections - DT Midday Histogram

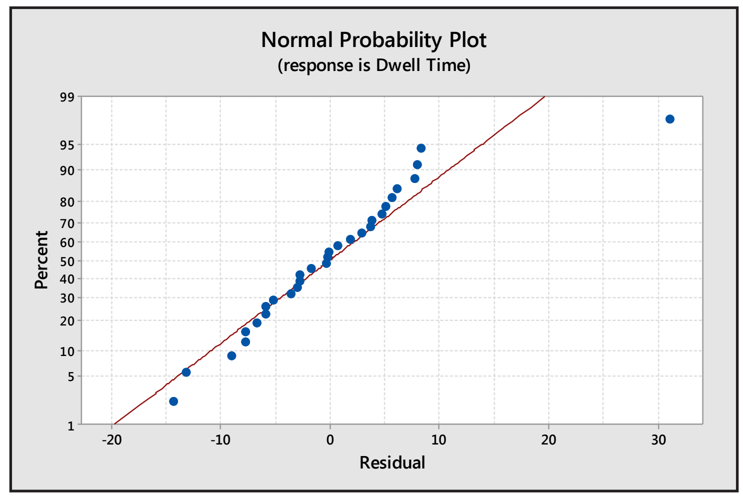

Figure 27. Intersections - DT Midday Normal Probability Plot

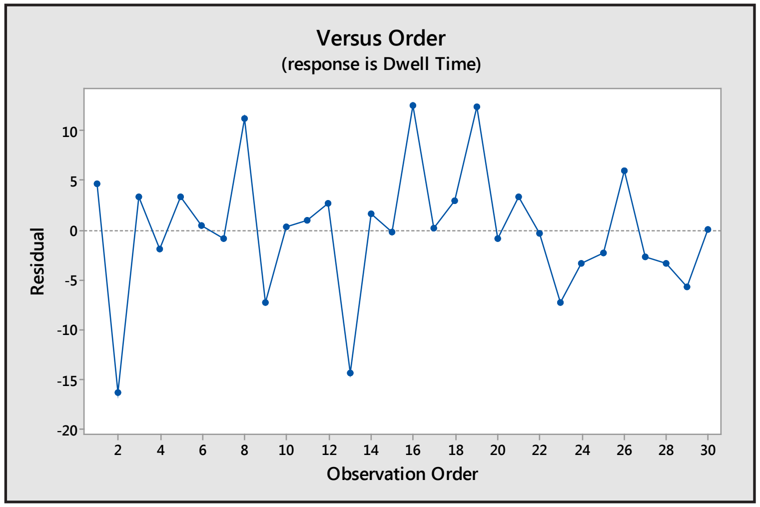

Figure 28. Intersections - DT PM vs. Order

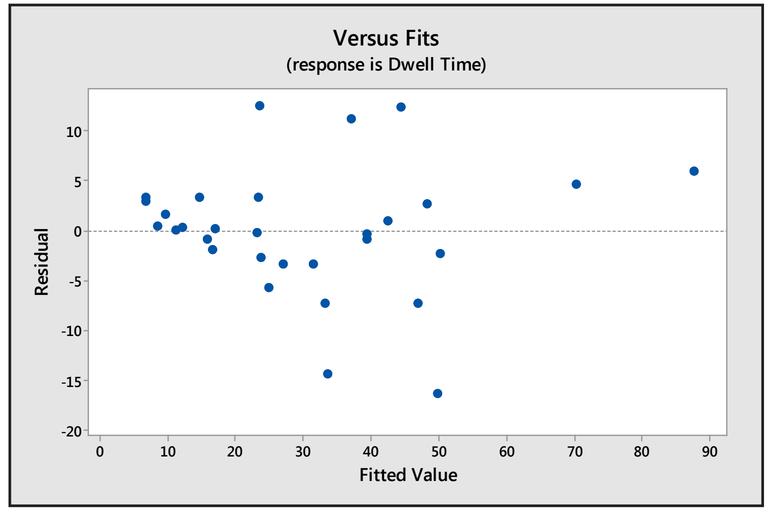

Figure 29. Intersections - DT PM vs. Fits

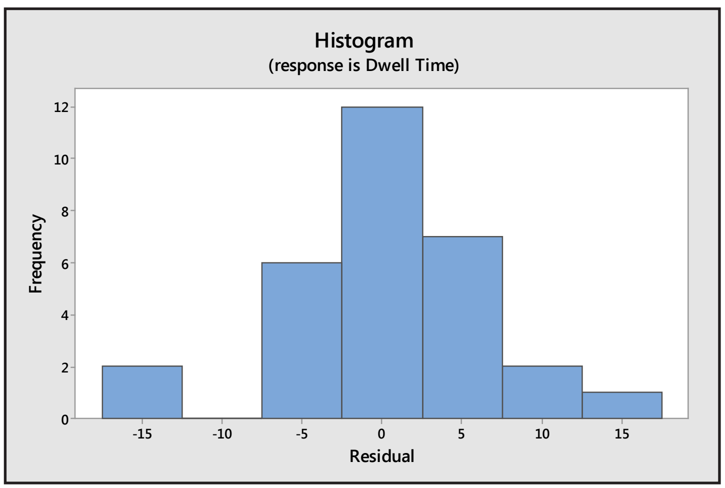

Figure 30. Intersections - DT PM Histogram

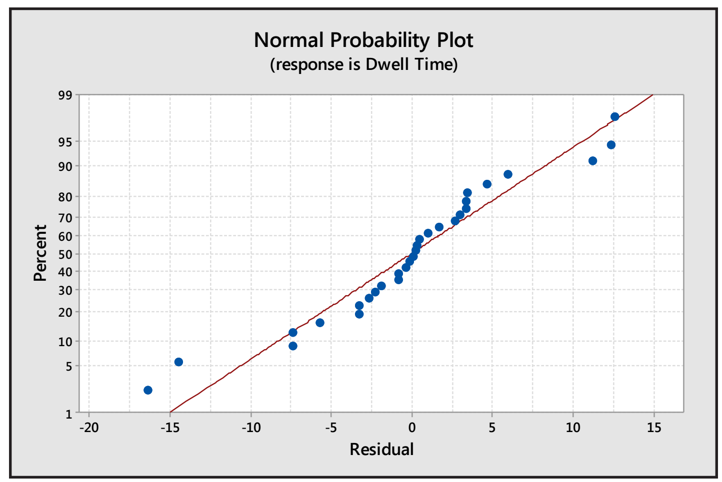

Figure 31. Intersections - DT PM Normal Probability Plot

MIDBLOCK BUS STOPS

Total Bus Stop Time by Time of Day

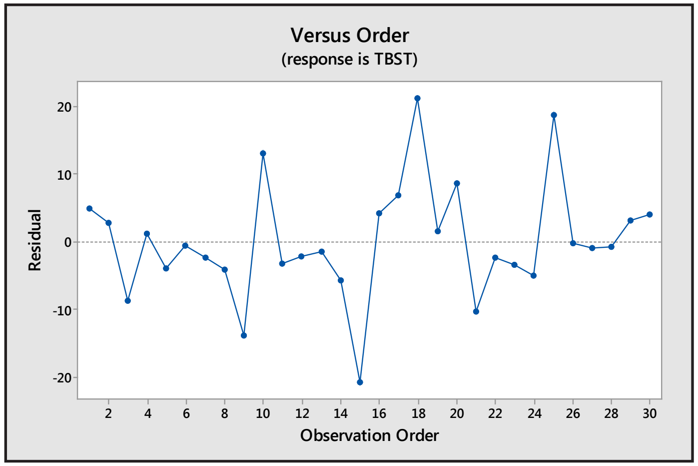

Figure 32. Midblock - TBST AM vs. Order

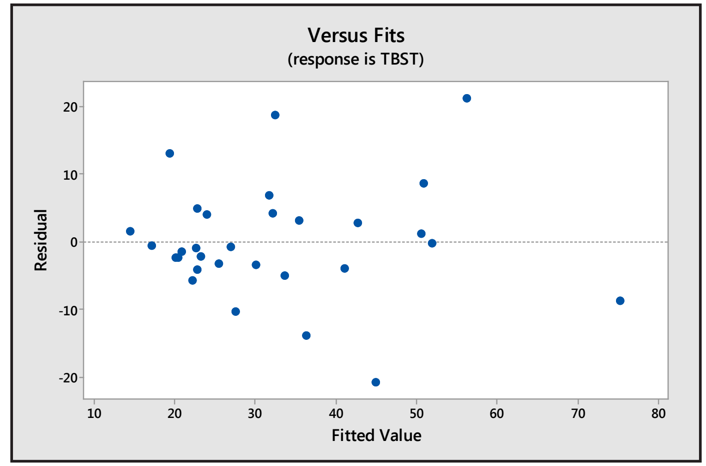

Figure 33. Midblock - TBST AM vs. Fits

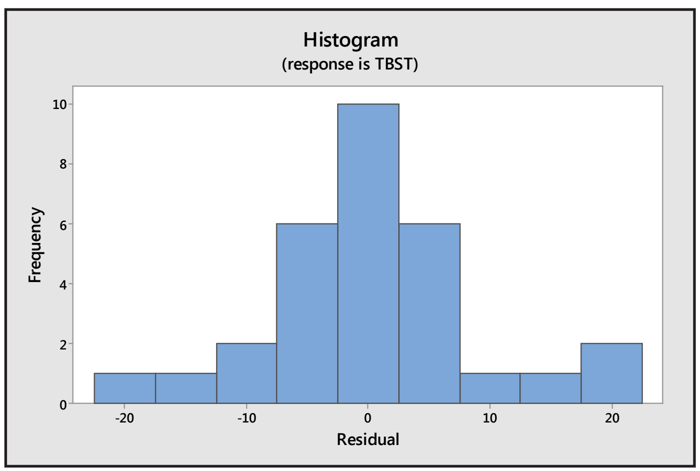

Figure 34. Midblock - TBST AM Histogram

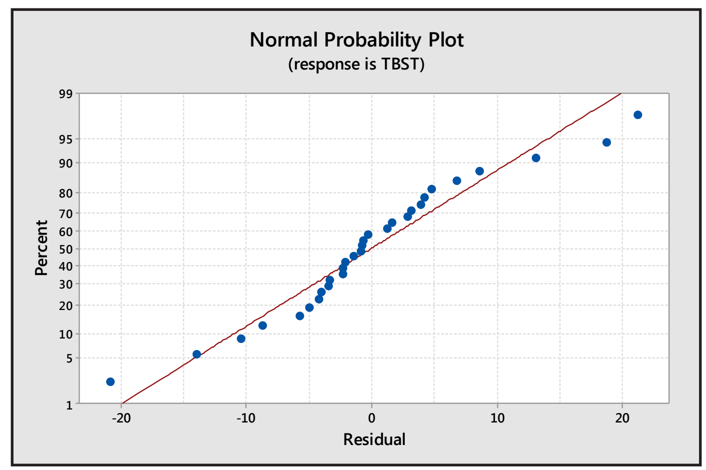

Figure 35. Midblock - TBST AM Normal Probability Plots

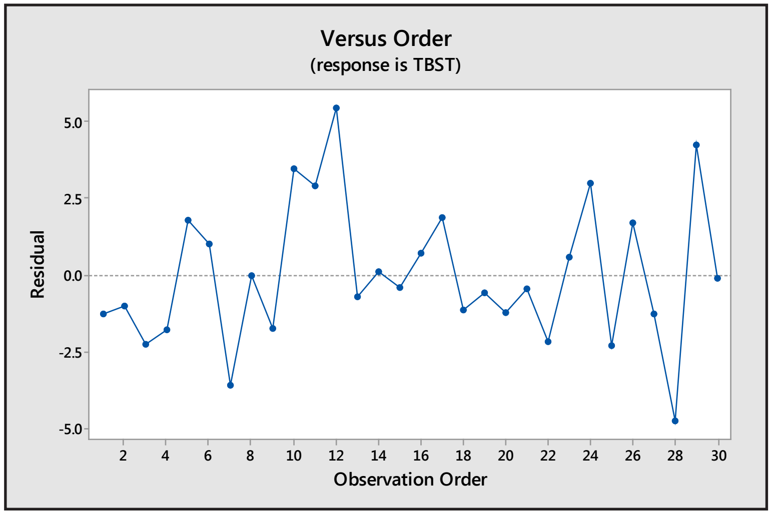

Figure 36. Midblock - TBST Midday vs. Order

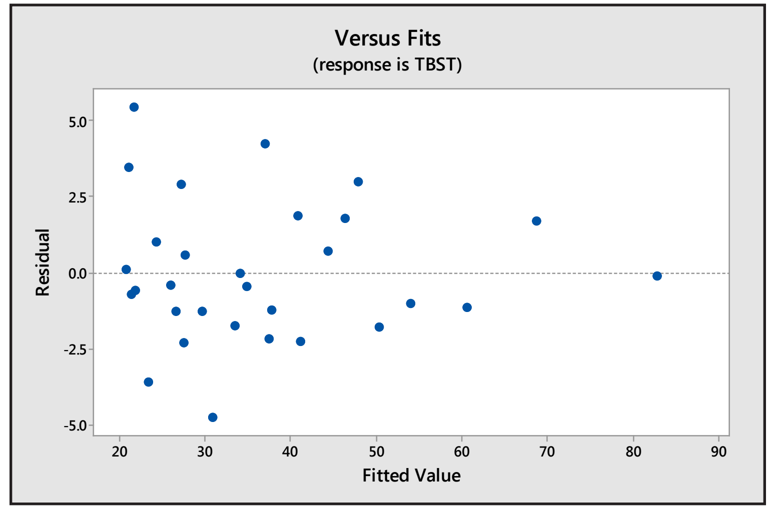

Figure 37. Midblock - TBST MID vs. Fits

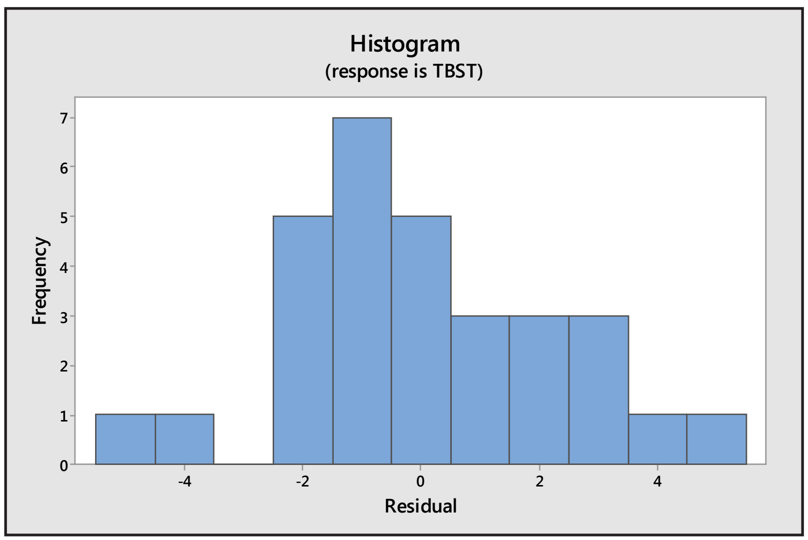

Figure 38. Midblock - TBST Midday Histogram

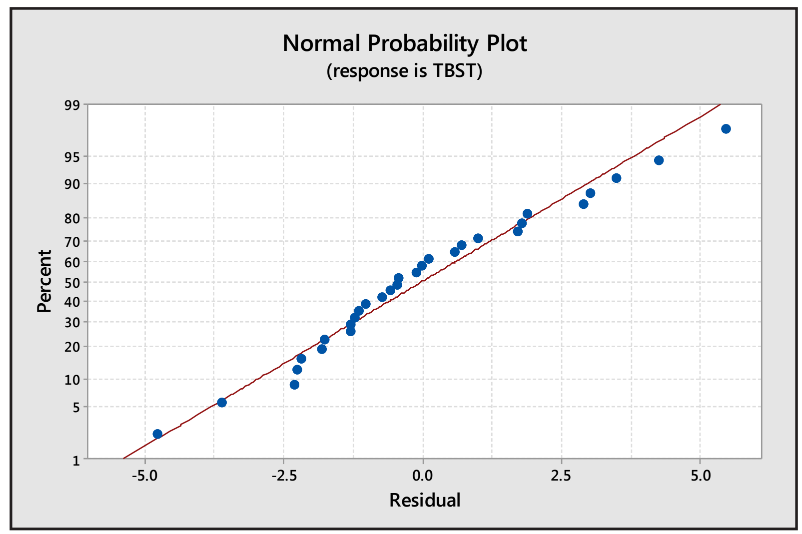

Figure 39. Midblock - TBST Midday Normal Probability Plot

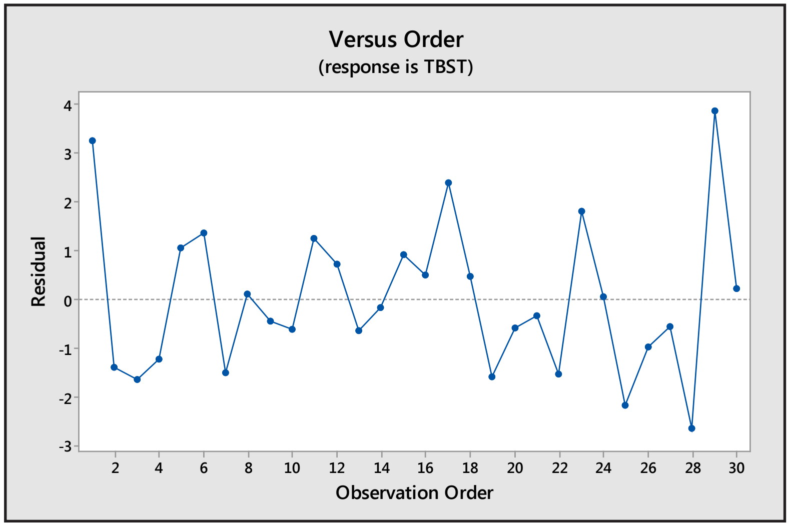

Figure 40. Midblock - TBST PM vs. Order

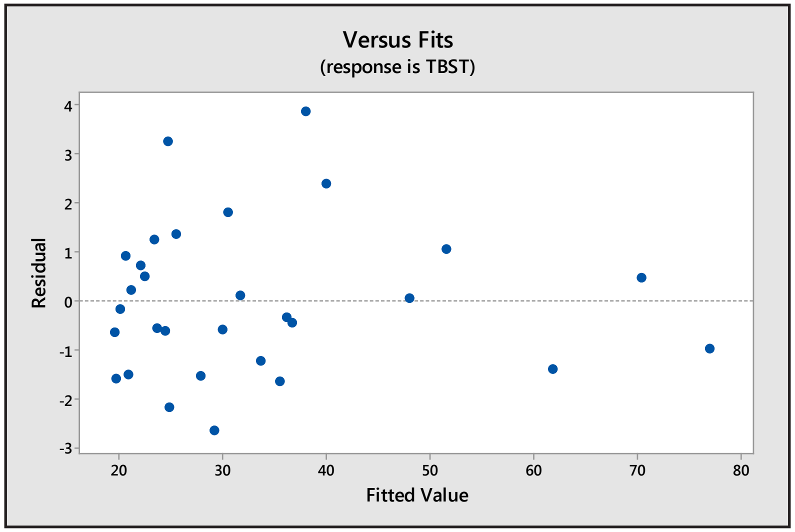

Figure 41. Midblock - TBST PM vs. Fits

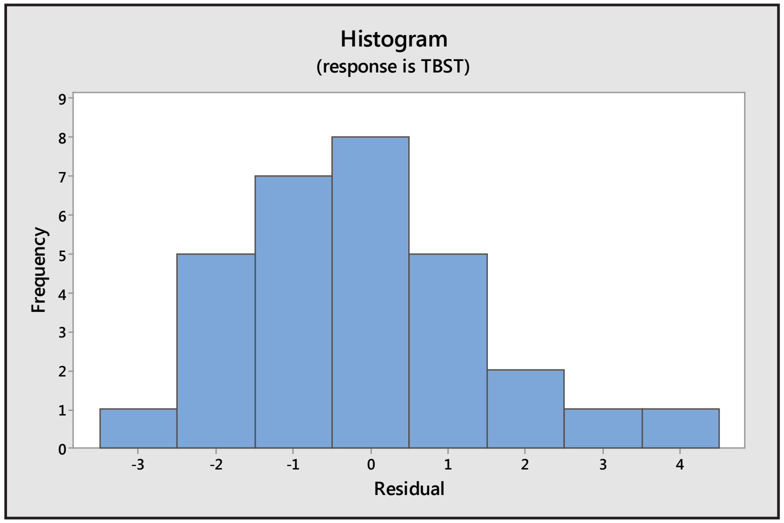

Figure 42. Midblock - TBST PM Histogram

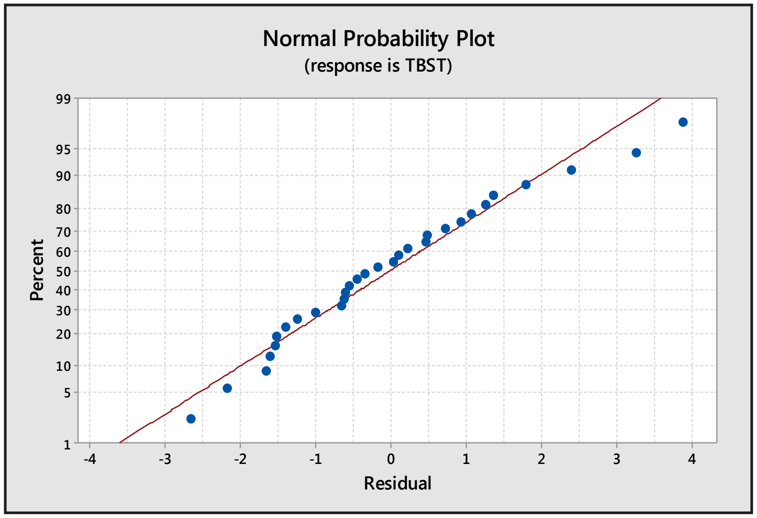

Figure 43. Midblock - TBST PM Normal Probability Plot

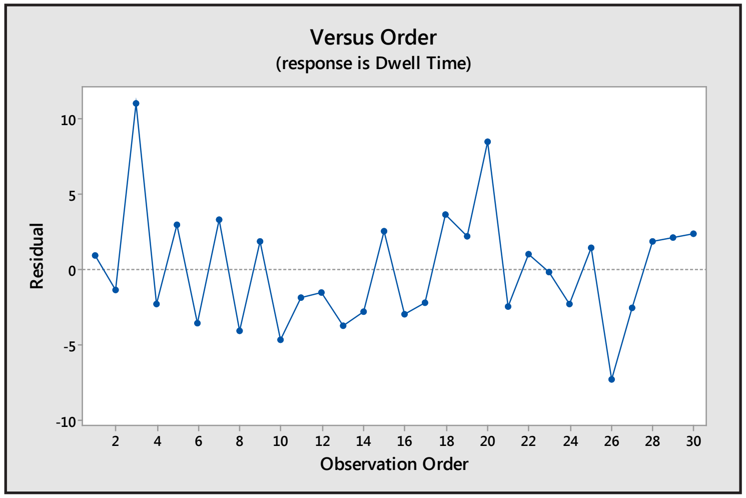

Figure 44. Midblock - DT AM vs. Order

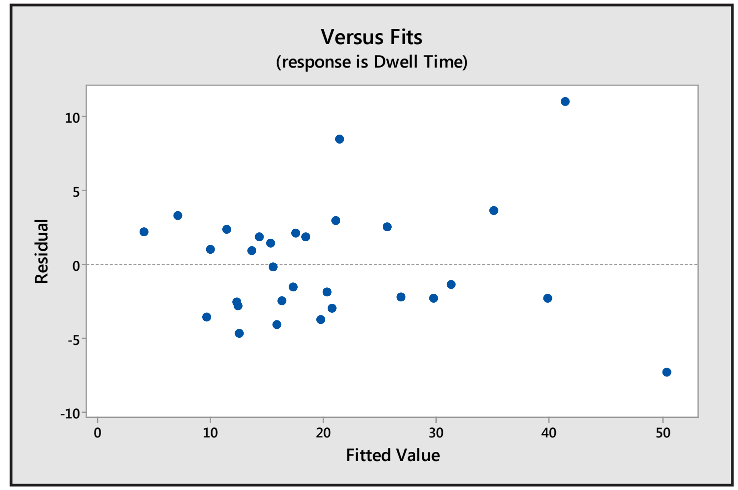

Figure 45. Midblock - DT AM vs. Fits

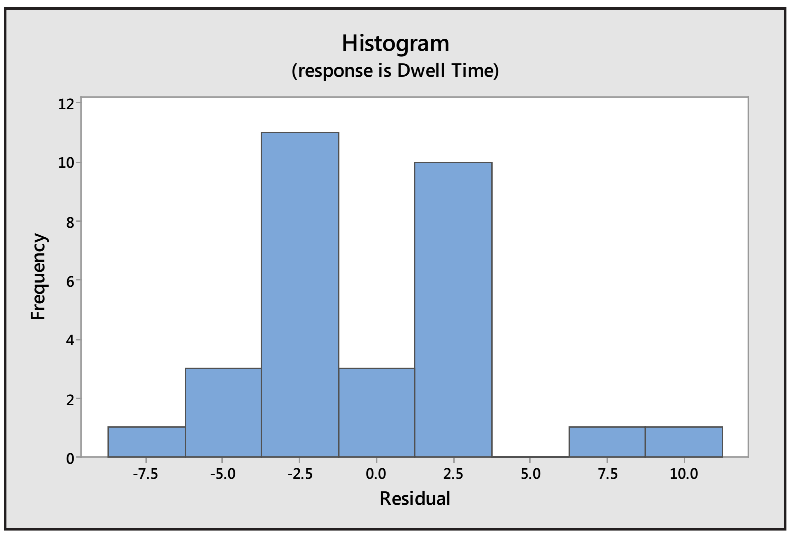

Figure 46. Midblock - DT AM Histogram

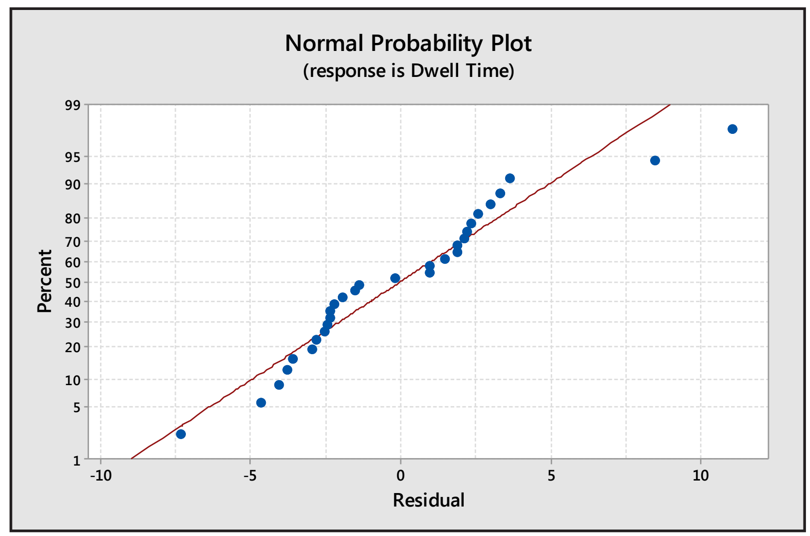

Figure 47. Midblock - DT AM Normal Probability Plot

Dwell Time by Time of Day

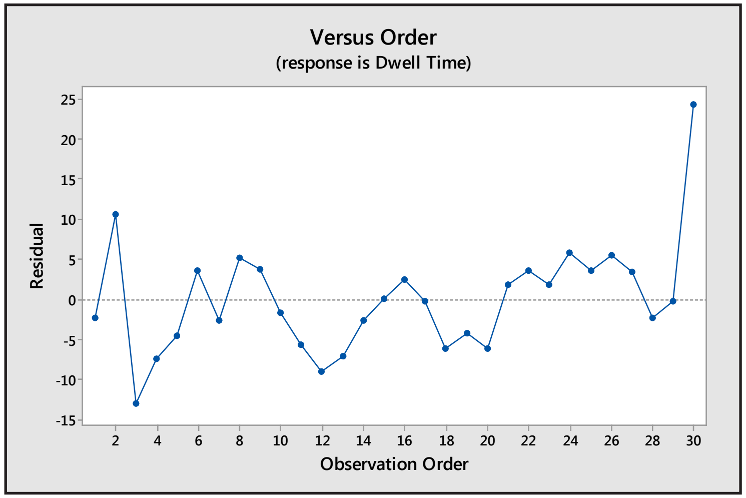

Figure 48. Midblock - DT Midday vs. Order

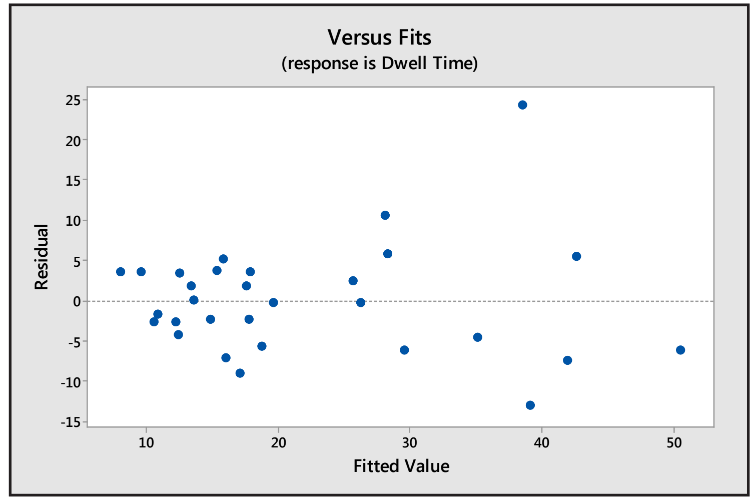

Figure 49. Midblock - DT Midday vs. Fits

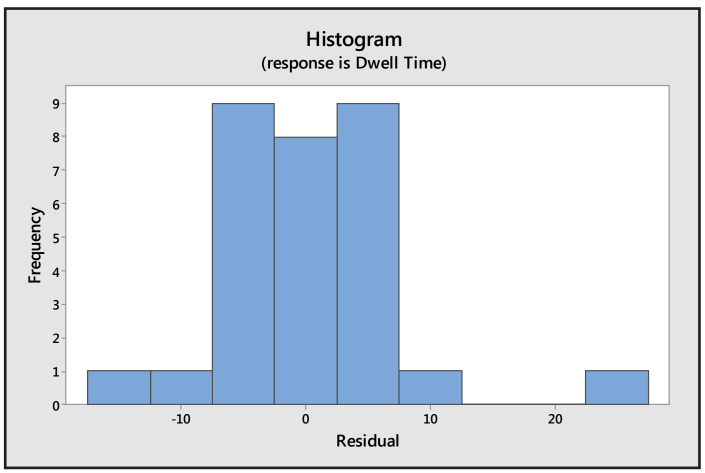

Figure 50. Midblock - DT MID Histogram

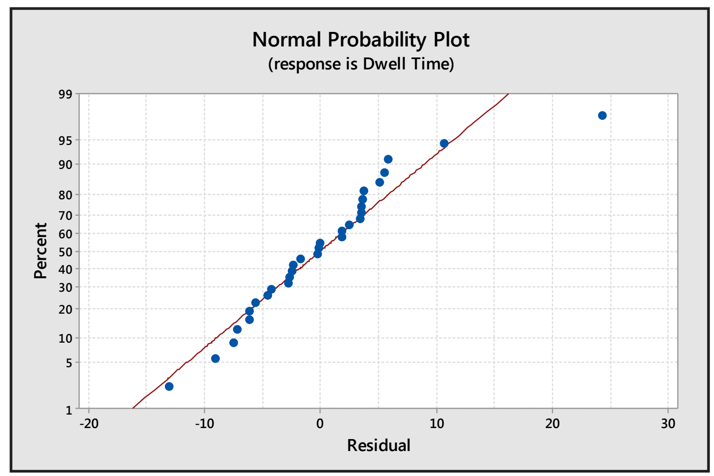

Figure 51. Midblock - DT MID Normal Probability Plot

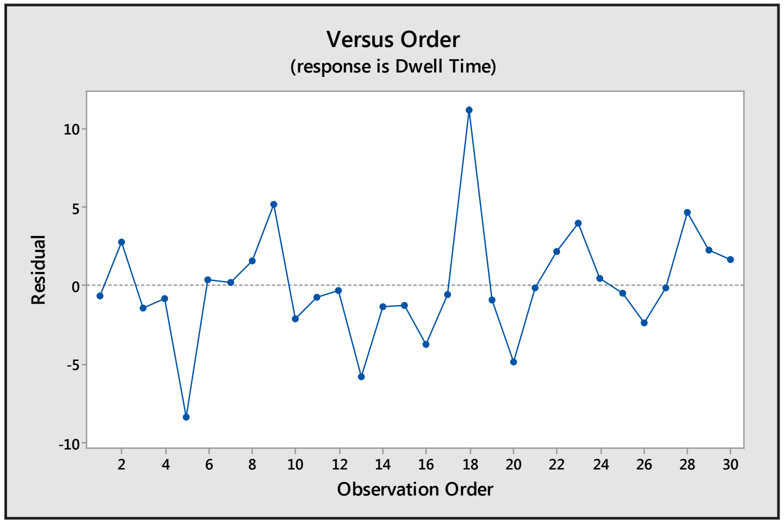

Figure 52. Midblock - DT PM vs. Order

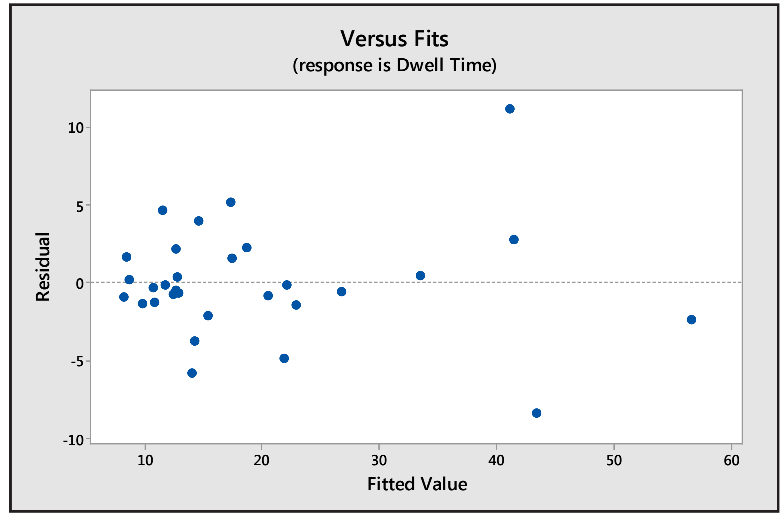

Figure 53. Midblock - DT PM vs. Fits

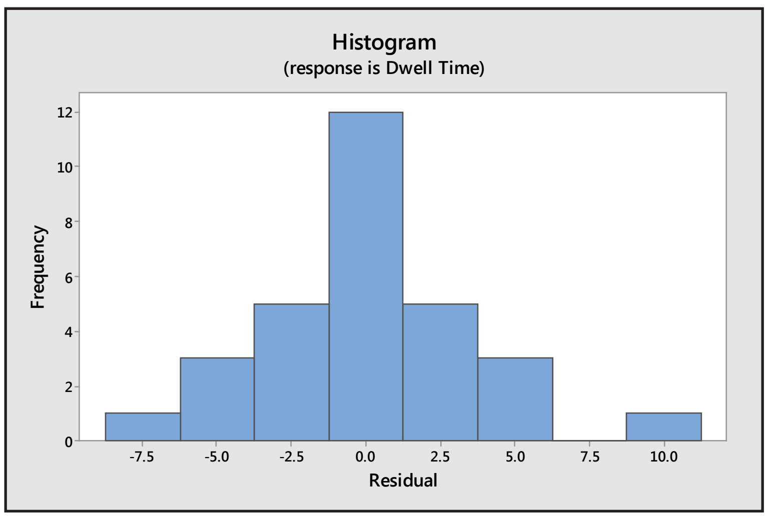

Figure 54. Midblock - DT PM Histogram

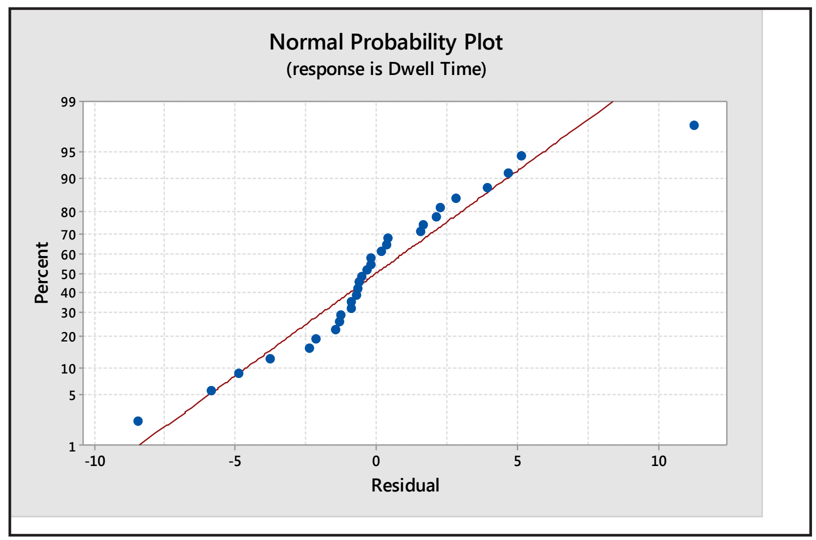

Figure 55. Midblock - DT PM Normal Plot

OPTIMIZATION

Bus Stops Located at Intersections

TBST by Time of Day

TBST AM

Parameters

```
Response Goal Lower Target Upper Weight Importance
TBST Minimum 23.468 64.102 1 1
```

Variable Ranges

```
Variable Values
Dwell Time (20.37, 25.03)
Pass. Boarding (0.9, 9.5)
Coded Parking (1, 2)
Lanes (1, 4)
BP Length (In) (609.002, 4374.02)
Pass. Alighting (0, 11.3)
```

Solution

```
 Dwell Pass. Coded BP Length Pass. TBST Composite
Solution Time Boarding Parking Lanes (In) Alighting Fit Desirability
1 20.37 9.5 2 1 4374.02 11.3 20.2028 1
```

Multiple Response Prediction

```
Variable Setting
Dwell Time 20.37
Pass. Boarding 9.5
Coded Parking 2
Lanes 1
BP Length (In) 4374.02
Pass. Alighting 11.3
```

```
 95% Upper 95% Upper
 Confidence Prediction
Response Fit SE Fit Bound Bound
TBST 20.2 13.0 42.5 46.9
```

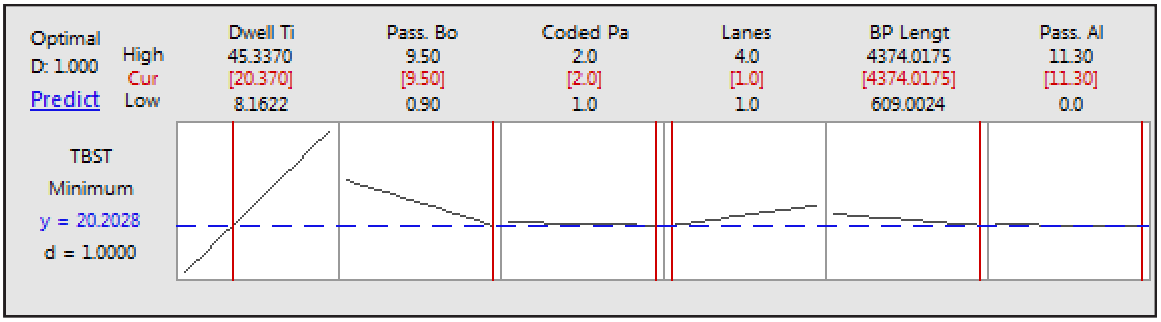

Figure 56. Intersections - TBST AM Optimization Output

TBST Midday

Parameters

```
Response Goal Lower Target Upper Weight Importance
TBST Minimum 19.498 112.895 1 1
```

Variable Ranges

```
Variable Values
Dwell Time (28.88, 36.02)
Pass. Boarding (0.9, 12)
Park (1, 2)
Lanes (1, 4)
BP Length (In) (609.002, 4374.02)
Pass. Alighting (0, 10.9)
```

Solution

```
 Dwell Pass. BP Length Pass. TBST Composite
Solution Time Boarding Park Lanes (In) Alighting Fit Desirability
1 28.88 0.9 2 1 4374.02 10.9 37.5142 0.807101
```

Multiple Response Prediction

```
Variable Setting
Dwell Time 28.88
Pass. Boarding 0.9
Park 2
Lanes 1
BP Length (In) 4374.02
Pass. Alighting 10.9
```

```
 95% Upper 95% Upper
 Confidence Prediction
Response Fit SE Fit Bound Bound
TBST 37.51 5.56 47.05 50.37
```

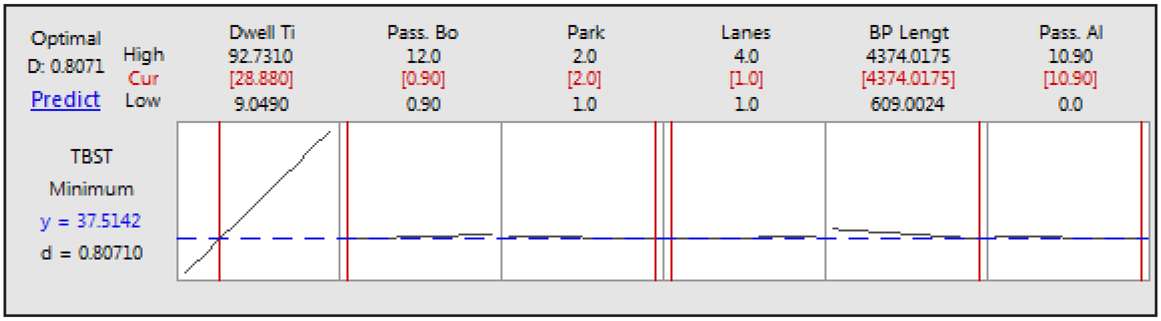

Figure 57. Intersections - TBST MID Optimization Output

TBST PM

Parameters

Response Goal Lower Target Upper Weight Importance
TBST Minimum 19.47 117.971 1 1

Variable Ranges

Variable Values
Dwell Time (27.75, 34.69)
Pass. Boarding (0.7, 19.4)
Park (1, 2)
Lanes (1, 4)
BP Length (In) (609.002, 4374.02)
Pass. Alighting (0.2, 12.2)

Solution

Dwell Pass. BP Length Pass. TBST Composite
Solution Time Boarding Park Lanes (In) Alighting Fit Desirability
1 27.75 19.4 2 4 609.002 12.2 37.6921 0.815006

Multiple Response Prediction

Variable Setting
Dwell Time 27.75
Pass. Boarding 19.4
Park 2
Lanes 4
BP Length (In) 609.002
Pass. Alighting 12.2

95% Upper 95% Upper
Confidence Prediction
Response Fit SE Fit Bound Bound
TBST 37.7 17.0 **66.8** 68.6

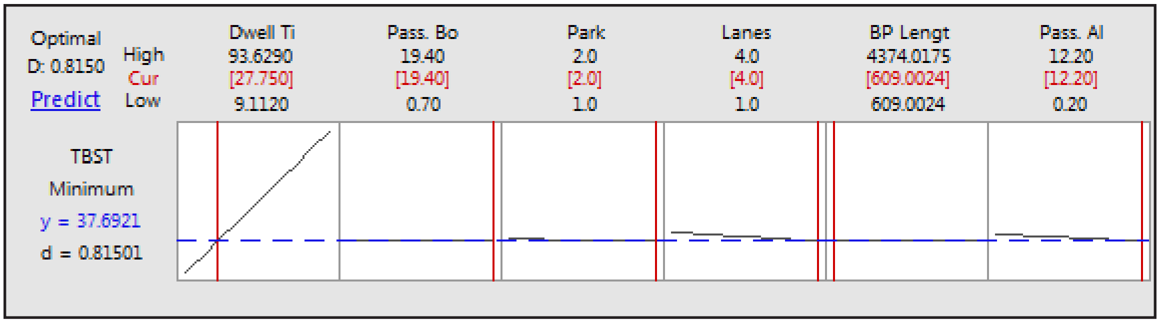

Figure 58. Intersections - TBST PM Optimization Output

Midblock Bus Stops

TBST by Time of Day

TBST AM

Parameters

```
Response Goal Lower Target Upper Weight Importance
TBST Minimum 16.16 77.5 1 1
```

Variable Ranges

```
Variable Values
Dwell Time (18.45, 22.19)
Pass. Boarding (0.1, 13.9)
Park (1, 2)
Lanes (1, 4)
BP Length (in) (614, 1690)
Pass. Alighting (0.1, 12.4)
```

Solution

```
 BP
 Dwell Pass. Length Pass. TBST Composite
Solution Time Boarding Park Lanes (in) Alighting Fit Desirability
1 18.45 13.9 1 4 614 12.4 -8.91587 1
```

Multiple Response Prediction

```
Variable Setting
Dwell Time 18.45
Pass. Boarding 13.9
Park 1
Lanes 4
BP Length (in) 614
Pass. Alighting 12.4
```

```
 95% Upper 95% Upper
 Confidence Prediction
Response Fit SE Fit Bound Bound
TBST -8.9 26.2 36.0 38.9
```

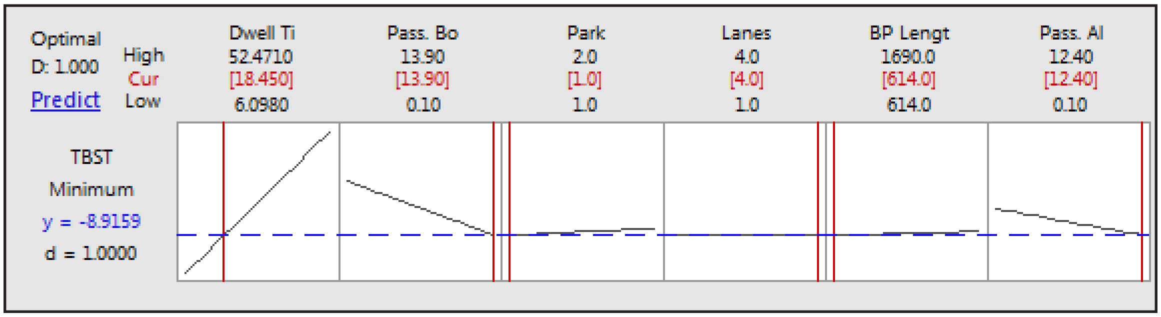

Figure 59. Midblock - TBST AM Optimization Output

TBST Midday

Parameters

```
Response Goal Lower Target Upper Weight Importance
TBST Minimum 19.66 82.706 1 1
```

Variable Ranges

```
Variable Values
Dwell Time (19.55, 24.57)
Pass. Boarding (0.5, 9)
Park (1, 2)
Lanes (1, 4)
BP Length (in) (614, 1690)
Pass. Alighting (0.5, 9.1)
```

Solution

```
 BP
 Dwell Pass. Length Pass. TBST Composite
Solution Time Boarding Park Lanes (in) Alighting Fit Desirability
1 19.55 0.5 2 1 614 9.1 29.6071 0.842225
```

Multiple Response Prediction

```
Variable Setting
Dwell Time 19.55
Pass. Boarding 0.5
Park 2
Lanes 1
BP Length (in) 614
Pass. Alighting 9.1
```

```
 95% Upper 95% Upper
 Confidence Prediction
Response Fit SE Fit Bound Bound
TBST 29.61 2.09 33.19 35.32
```

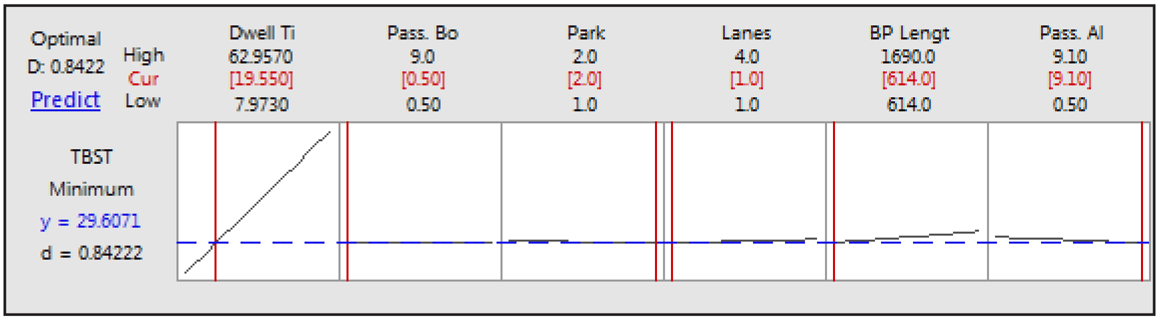

Figure 60. Midblock - TBST MID Optimization Output

TBST PM

Parameters

```
Response Goal Lower Target Upper Weight Importance
TBST Minimum 18.1988 75.91 1 1
```

Variable Ranges

```
Variable Values
Dwell Time (17.72, 21.68)
Pass. Boarding (0.4, 13.4)
Park (1, 2)
Lane (1, 4)
Bus Pad Length (in) (614, 1690)
Pass. Alighting (0.5, 11.7)
```

Solution

```
 Bus Pad
 Dwell Pass. Length Pass. TBST Composite
Solution Time Boarding Park Lane (in) Alighting Fit Desirability
1 17.72 0.4 2 4 614 11.7 27.9722 0.830649
```

Multiple Response Prediction

```
Variable Setting
Dwell Time 17.72
Pass. Boarding 0.4
Park 2
Lane 4
Bus Pad Length (in) 614
Pass. Alighting 11.7
```

```
 95% Upper 95% Upper
 Confidence Prediction
Response Fit SE Fit Bound Bound
TBST 27.97 1.87 31.17 32.34
```

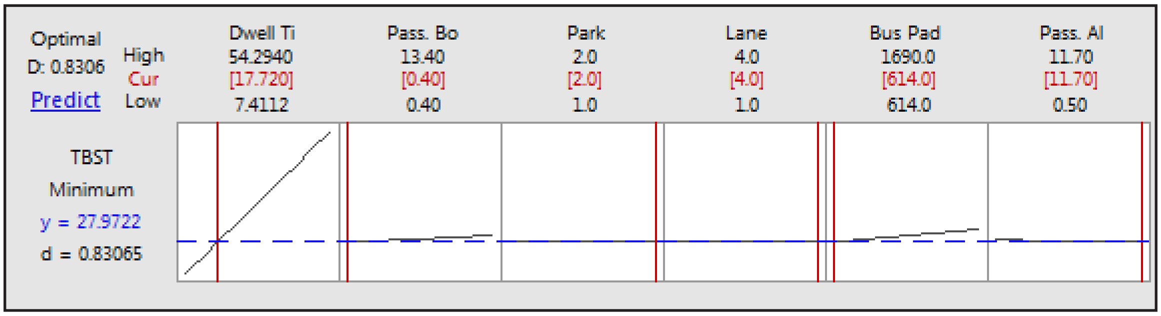

Figure 61. Midblock - TBST PM Optimization Output

KOLMOGOROV-SMIRNOV TEST

Table 34. Summary of TBST K-S Test Results

	Intersection		Midblock	
Time	**D**	**p-value**	**D**	**p-value**
AM	0.20	0.54	0.17	0.76
MID	0.1	0.997	0.1	0.997
PM	0.1034	0.996	0.1	0.997

Table 35. Summary of DT K-S Test Results

	Intersection		Midblock	
Time	**D**	**p-value**	**D**	**p-value**
AM	0.1667	0.76	0.1	0.997
MID	0.1667	0.76	0.1667	0.76
PM	0.1333	0.936	0.1333	0.936

Bus Stops Located at Intersections

Total Bus Stop Time by Time of Day

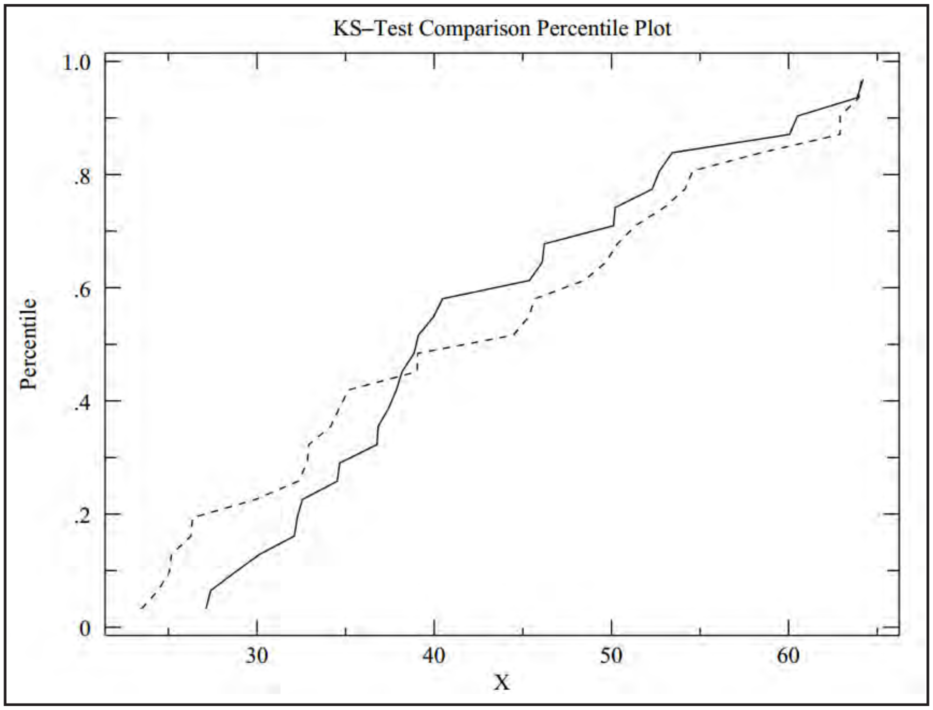

Figure 62. Intersections - TBST AM K-S Test Comparison Percentile Plot

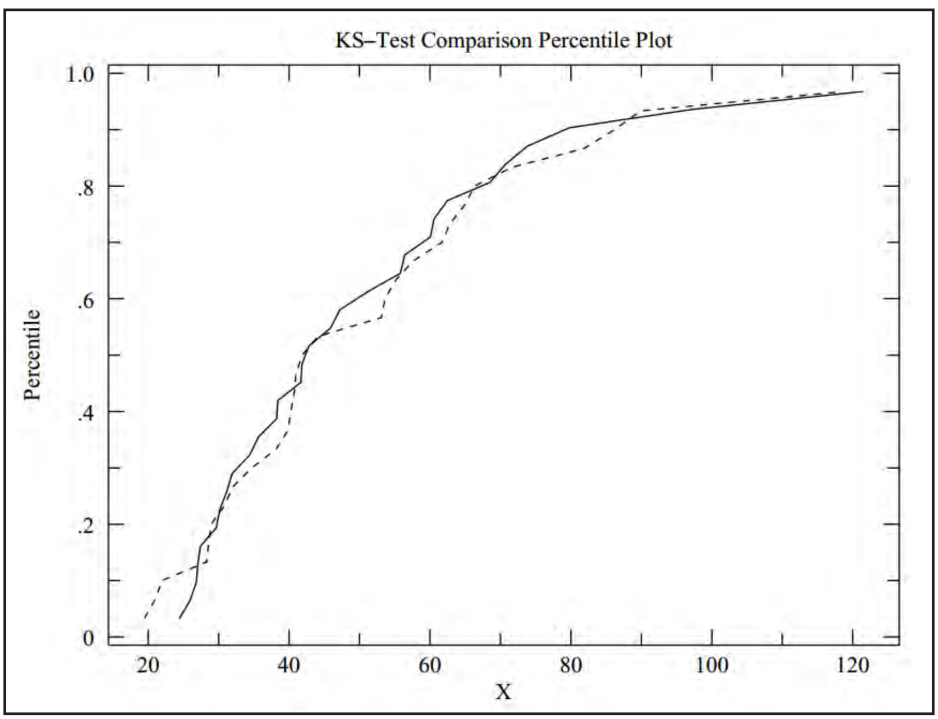

Figure 63. Intersections - TBST PM K-S Test Comparison Percentile Plot

Dwell Time by Time of Day

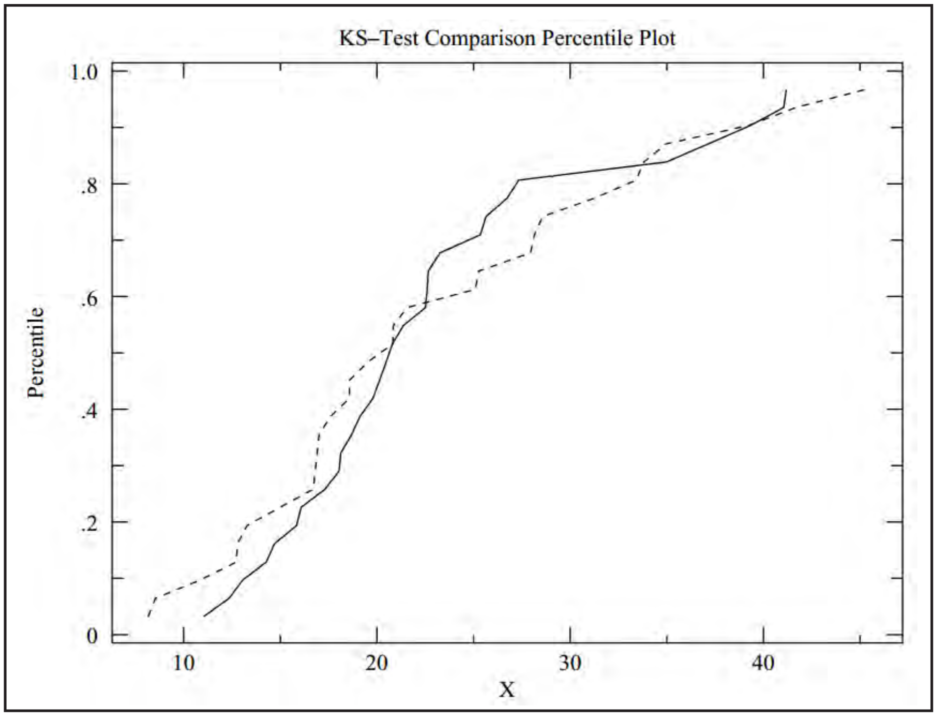

Figure 64. Intersections - DT AM K-S Test Comparison Percentile Plot

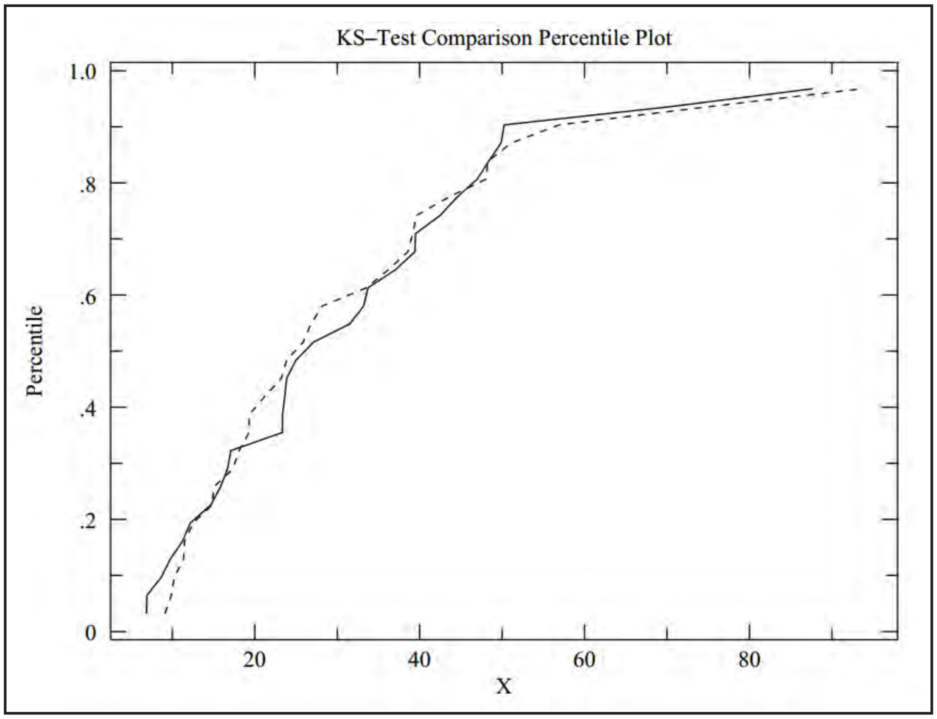

Figure 65. Intersections - DT PM K-S Test Comparison Percentile Plot

Midblock Bus Stops

TBST by Time of Day

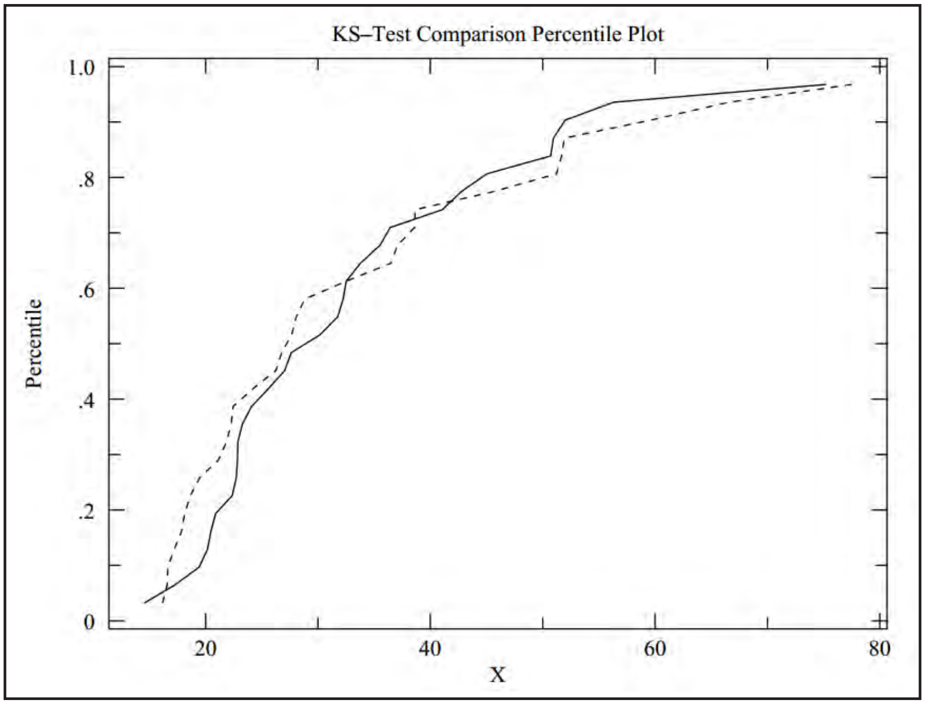

Figure 66. Midblock - TBST AM K-S Test Comparison Percentile Plot

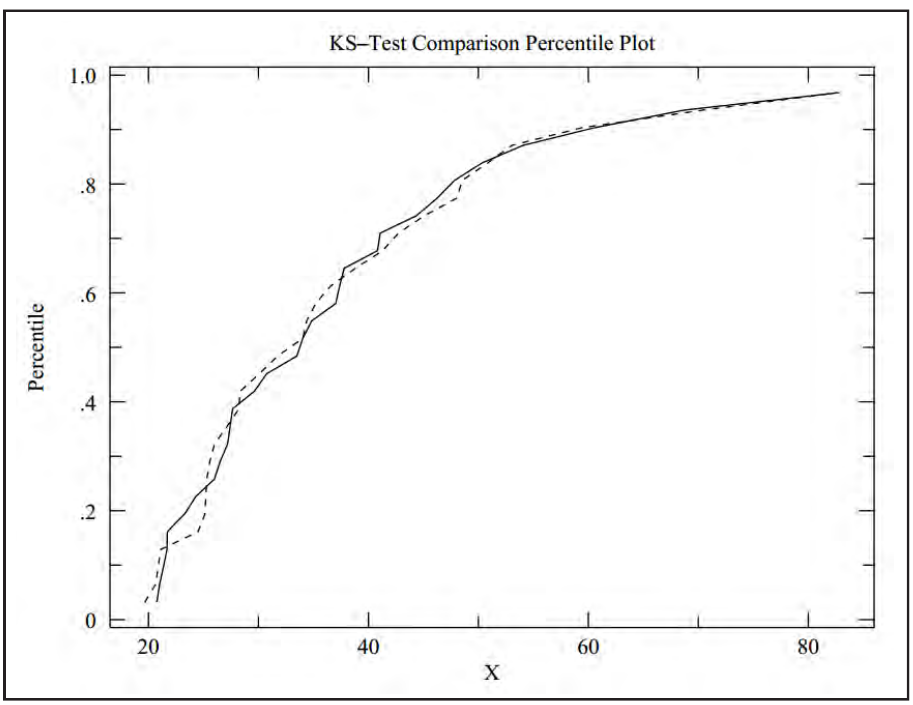

Figure 67. Midblock - TBST MID K-S Test Comparison Percentile Plot

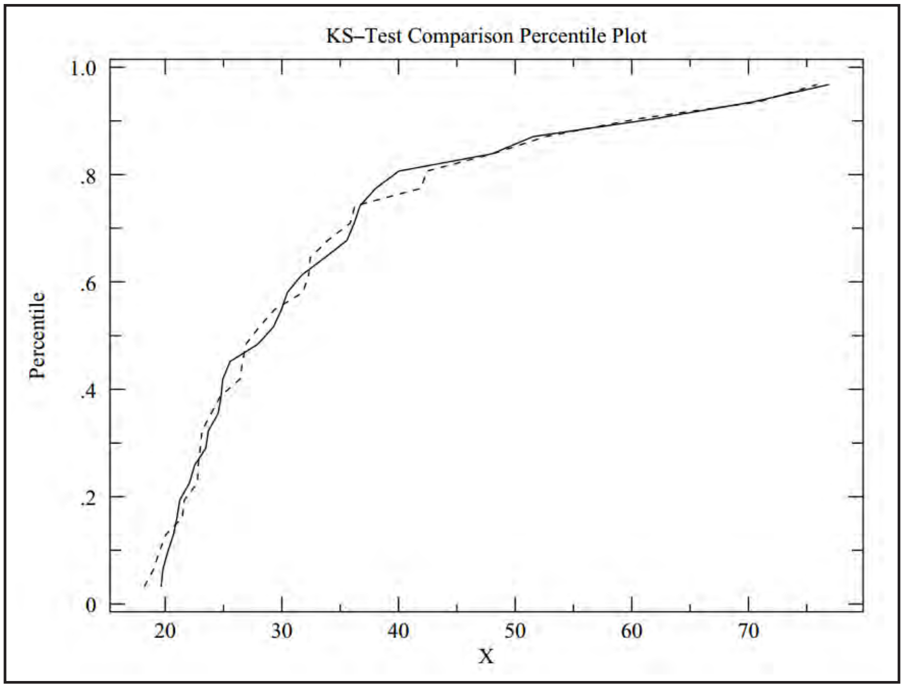

Figure 68. Midblock - TBST PM K-S Test Comparison Percentile Plot

DT by Time of Day

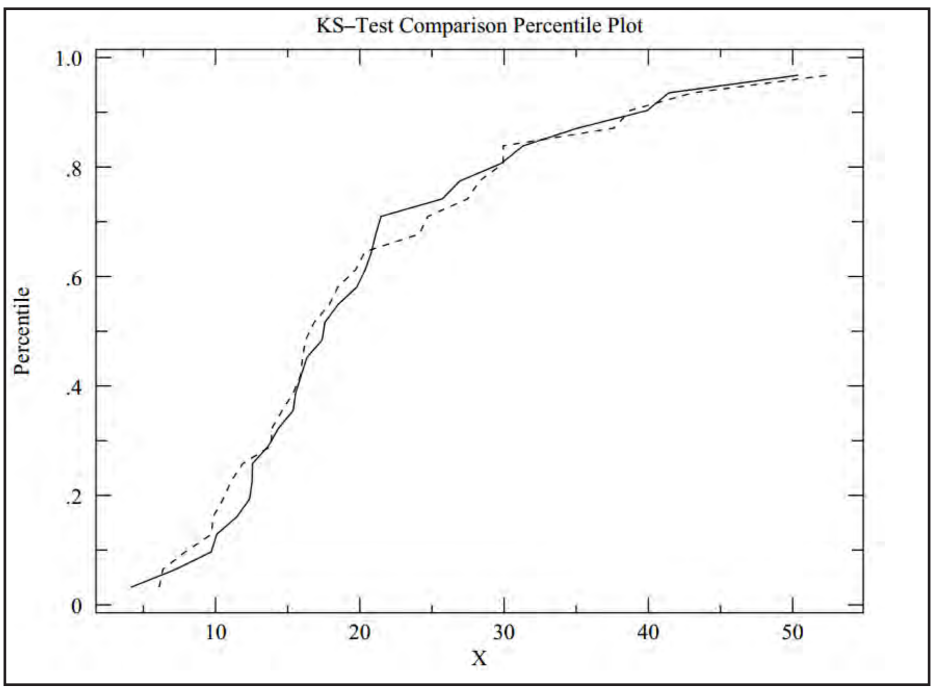

Figure 69. Midblock - DT AM K-S Test Comparison Percentile Plot

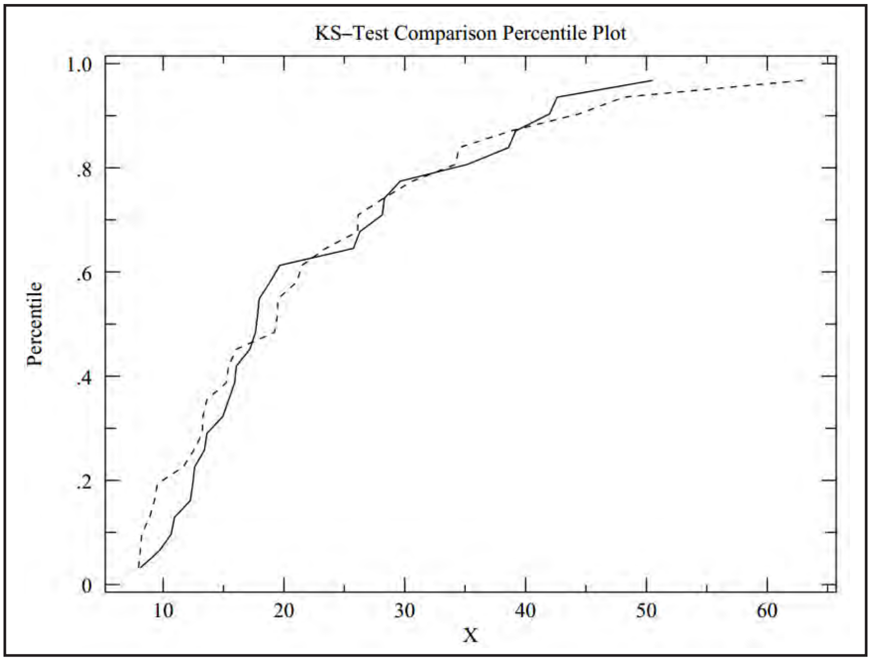

Figure 70. Midblock - DT MID K-S Test Comparison Percentile Plot

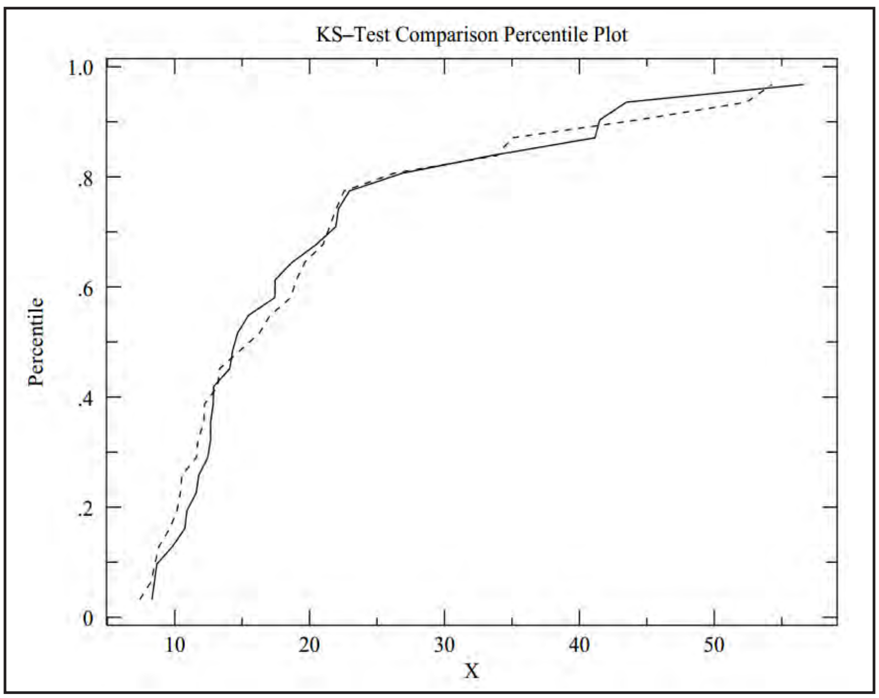

Figure 71. Midblock - DT PM K-S Test Comparison Percentile Plot

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