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Data-Driven Support Tools for Transit Data Analysis, Scheduling and Planning

Final Report

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16. Abstract (Limit: 250 words)

Many transit agencies in the U.S. have instrumented their fleet with Automatic Data Collection Systems (ADCS) to monitor the performance of transit vehicles, support schedule planning and improve quality of services. The objective of this study is to use an urban local route (Metro Transit Route 10 in Twin Cities) as a case study and develop a route-based trip time model to support scheduling and planning while applying different transit strategies. Usually, timepoints (TP) are virtually placed on a transit route to monitor its schedule adherence and system performance. Empirical TP time and inter-TP link travel time models are developed. The TP-based models consider key parameters such as number of passengers boarding and alighting, fare payment type, bus type, bus load (seat availability), stop location (nearside or far side), traffic signal and volume that affect bus travel time. TP time and inter-TP link travel time of bus route 10 along Central Avenue between downtown Minneapolis and Northtown were analyzed to describe the relationship between trip travel time and primary independent variables. Regression models were calibrated and validated by comparing the simulation results with existing schedule using adjusted travel time derived from data analyses. The route-based transit simulation model can support Metro Transit in evaluating different schedule plans, stop consolidations, and other strategies. The transit model provides an opportunity to predict and evaluate potential impact of different transit strategies prior to deployment.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADCS	Automatic Data Collection System
AFC	Automatic Fare Collection
APC	Automatic Passenger Counter
AVL	Automatic Vehicle Location
BRT	Bus Rapid Transit
CBD	Central Business District
COV	Covariance
CTA	Chicago Transit Authority
CTS	Center for Transportation Studies
DT	Dwell Time
DTC	Digital Technology Center
DTI	Digital Technology Initiative
Est.	Estimated
FS	Farside Bus Stop
ft	Feet
GIS	Geographic Information System
GPS	Global Positioning System
GUI	Graphical Users Interface
HCM	Highway Capacity Manual
IQR	Inter-Quartile Range
ITS	Intelligent Transportation Systems
km/h	Kilometers per hour
LOS	Level Of Service
LT	Left Turn
MAPE	Mean Absolute Percentage Error
MBTA	Massachusetts Bay Transportation Authority
min	Minute
Mn/DOT	Minnesota Depart of Transportation
mph	Miles per hour
MT	Metro Transit
MUTCD	Manual on Uniform Traffic Control Devices
N_a	Number of Passengers Alighting
N_{a_d}	Number of Passengers Alighting per Door
N_{a_f}	Number of Passengers Alighting by the Front Door
N_{a_r}	Number of Passengers Alighting by the Rear Door
N_b	Number of Passenger Boarding
N_{b_d}	Number of Passengers Boarding per Door
N_s	Number of Standing Passengers
N_{s_d}	Number of Departing Standees

NB	Northbound
NS	Nearside Bus Stop
NYCT	New York City Transit
Obs.	Observed
OD	Origin to Destination
OTP	On-Time Performance
RMSE	Root Mean Square Error
RT	Right Turn
RTE	Route
SB	Southbound
SD	Standard Deviation
sec	Second
SMART-Signals	Systematic Monitoring of Arterial Road Traffic and Signals
Stdev	Standard Deviation
SQL	Structured Query Language
TCQSM	Transit Capacity and Quality of Service Manual
TCRP	Transit Cooperative Research Program
TOD	Time of Day
TP	Timepoint
TT	Travel Time
TriTAPT	TRIp Time Analysis in Public Transport
TSP	Transit Signal Priority
UMN	University of Minnesota
UPA	Urban Partnership Agreement
VOC	Volume to Capacity Ratio

EXECUTIVE SUMMARY

Many transit agencies in the U.S. have instrumented their fleet with Automatic Data Collection Systems (ADCS) to monitor the performance of transit vehicles, support schedule planning and improve quality of services. Metro Transit currently serves over 200 routes daily, including 100 express routes that connect the suburban communities to the Central Business Districts (CBD) in downtown Minneapolis and St. Paul. The massive ADCS data, including vehicle location, passenger counts and electronic fare payment transactions, are typically analyzed on an as-needed basis due to limited resources. The ADCS data can be fused to gain better insight on improving transit performance and productivity using data mining and fusion techniques.

A data analysis framework (Liao & Liu, 2010), previously developed through a seed grant under the Digital Technology Initiative (DTI) sponsored by the Digital Technology Center (DTC) at the University of Minnesota, enables data mining and fusion of massive transit data including vehicle location, passenger count and electronic fare transactions (GoTo card). Performance measures can thereafter be derived to transform data into information for decision making support.

The objective of this study is to use an urban local route (Route 10) as a case study and develop a route-based trip time model to support scheduling and planning while applying different transit strategies. Usually, timepoints are virtually placed on a transit route to monitor its schedule adherence and system performance. Time Point (TP) time is defined as the time duration from bus check-in to check-out boundary around a TP zone. The check-in and check-out boundaries, as practiced by Metro Transit, are typically placed about 60 m (200 ft) before and after a stop. Inter-TP link travel time is the trip time from departing the current TP check-out boundary to the arrival of the downstream TP check-in boundary.

Empirical TP time and inter-TP link travel time models are developed. The TP-based models consider key parameters such as number of passengers boarding and alighting, fare payment type, bus type, bus load (seat availability), stop location (nearside or far side), traffic signal and volume that affect bus travel time. TP time and inter-TP link travel time of bus route 10 along Central Avenue between downtown Minneapolis and Northtown were analyzed to describe the relationship between trip travel time and primary independent variables. Regression models were calibrated and validated by comparing the simulation results with the existing schedule using adjusted travel time derived from data analyses. The route-based transit simulation model can support Metro Transit in evaluating different schedule plans, stop consolidations, and other strategies. The transit model provides an opportunity to predict and evaluate potential impact of different transit strategies prior to deployment.

1 INTRODUCTION

Many transit agencies in the U.S. have instrumented Automatic Data Collection Systems (ADCS) on their transit vehicles to monitor vehicle location and gather system performance information in order to improve quality of services. The ADCS includes: (1) Automatic Vehicle Location (AVL) system which monitors vehicle location using Global Positioning System (GPS); (2) Automatic Passenger Counter (APC) which collects number of passengers boarding and alighting at each stop; and (3) Automatic Fare Collection (AFC) system that uses contactless smartcard to automatically collect fare payment and reduce boarding time. Significant amount of transit data are collected as results of the ADCS deployment. The massive ADCS data are largely underutilized due to substantial amount of resources and effort required to transform them into information.

A methodological data analysis framework, as shown in Figure 1-1, was previously developed to process massive transit data including vehicle location, passenger count and electronic fare transactions (Liao & Liu, 2010). The developed data analysis framework can assist a number of research and applications such as transit route performance measurement and decision making support for transit planning and operation. As part of the ongoing collaboration with Metro Transit, a transit performance analyst tool, as illustrated in Figure 1-2, was developed to analyze and visualize transit data at node, link segment, and route levels. This study takes advantage of the developed data process framework to model bus dwell and trip time at Time Point (TP) level. A TP node is a control point for evaluating schedule adherence as illustrated in Figure 1-3. A TP is a zone defined virtually around a bus stop, for example, 60 meter (200 ft) upstream and downstream from a bus stop. TPs are placed throughout the entire transit network to systematically monitor schedule adherence and running time performance using the AVL system. In urban area, the spacing between TPs is typically around 4 km (2.5 miles). There are over 660 timepoints in the Twin Cities metro transit network.

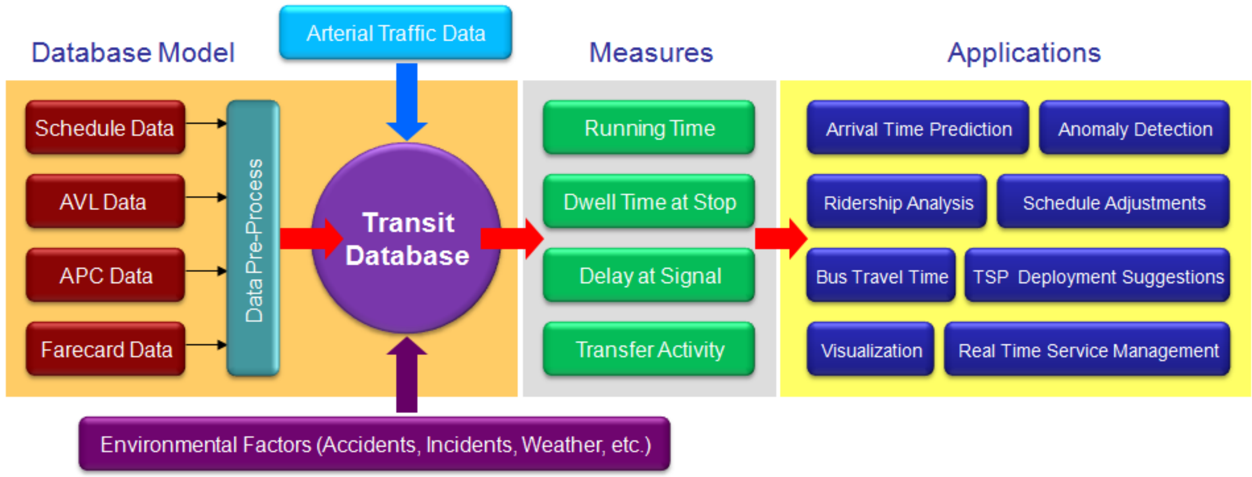


Figure 1-1 Transit Performance Data Processing Framework

According to Highway Capacity Manual (HCM2000), transit dwell time is defined as the duration of transit vehicle stopped for serving passengers. However, current ADCS used Metro Transit (MT) does not record door open and close events on APC equipped buses. APC sensors are triggered by the door opening/closing event and the combined passenger boarding alighting counts are recorded. In order to distinguish from the dwell time, we defined the TP time as the time duration of a transit vehicle enters check-in and leaves check-out boundaries of a TP zone.

This study focuses on the development of TP-based model and route-based simulation tool for analyzing route productivity, scheduling and reliability. Metro Transit has been using the AVL/APC data to improve the schedule reliability regularly. Recently, Metro Transit is evaluating eleven urban routes and planning to convert some of those routes into potential Bus Rapid Transit (BRT) equivalent services. Development of a TP-based trip model and simulation tool can support Metro Transit's current practice to better determine appropriate schedule and running time therefore improve route productivity and reliability.

Minnesota is one of five communities nationwide to receive funding through the U.S. Department of Transportation's Urban Partnership Agreement (UPA) program to develop strategies and to implement and deploy applications that will reduce traffic congestions in the Twin Cities. As part of the UPA program, Twin Cities Metropolitan Council (Met Council) and the City of Minneapolis have instrumented Metro Transit buses and 27 signalized intersections with Transit Signal Priority (TSP) along Central Avenue (Route 10 – local service and Route 829/59 – limited stop service) running in parallel with I-35W. The wireless-based TSP approach allows late buses to request for green signal while approaching a signalized intersection. This study will use route 10 as a case study to analyze transit performance and develop TP-based transit model for scheduling and planning support.

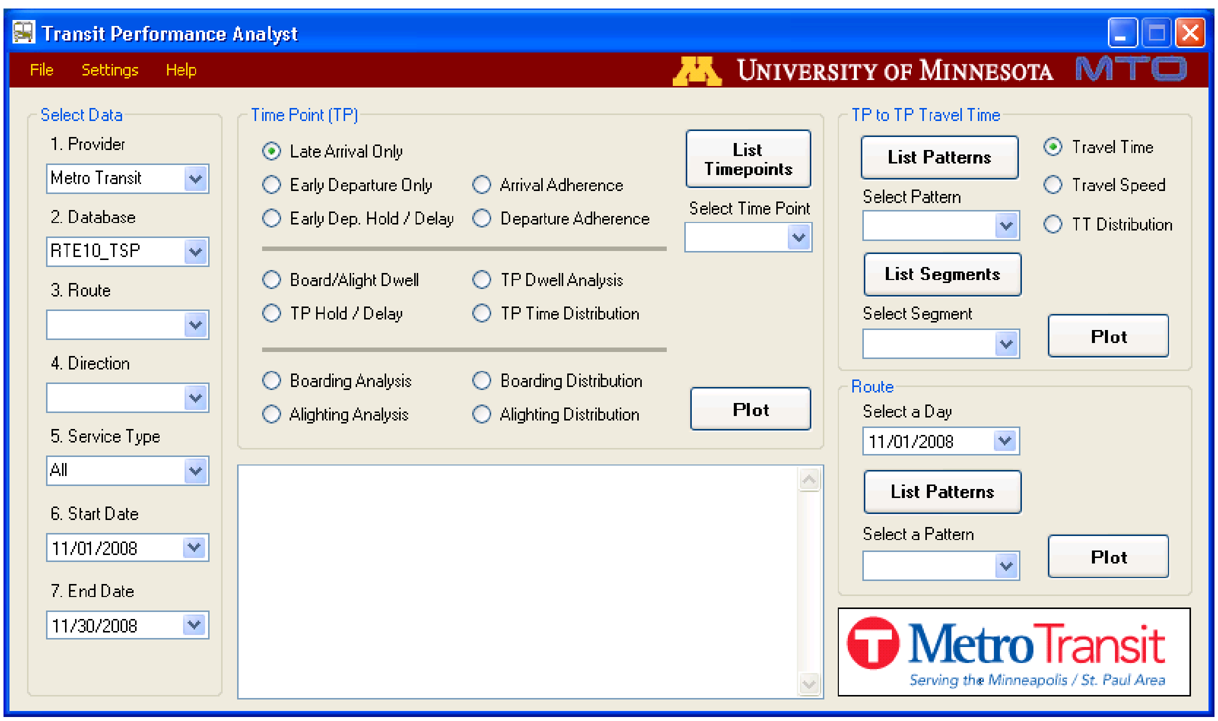


Figure 1-2 Transit Performance Analysis Tool

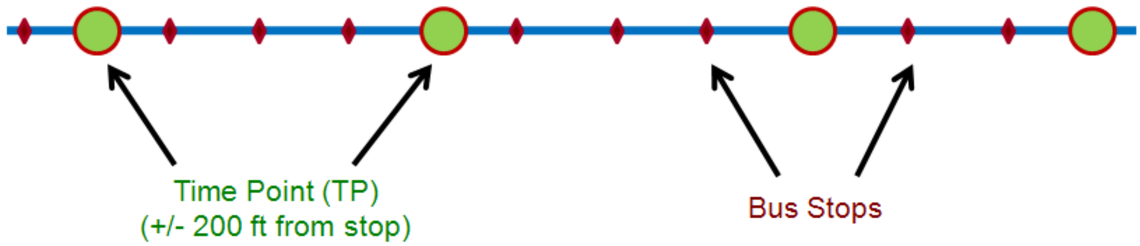


Figure 1-3 Time Point and Bus Stop

1.1 Background

Metro Transit currently provides over 200 routes daily, including 100 express routes that connect suburban communities in the metro Twin Cities area to downtown Minneapolis and St. Paul. Transit performance is typically analyzed and evaluated on an as-needed basis due to limited resources. Our previous study focuses on running time analysis or travel pattern analysis individually. Raw AVL/APC and electronic fare collection data (GoTo card transactions) are processed using Geographic Information System (GIS) tools to exclude outliers. Because of the AVL system polling rate and the nature of GPS data inaccuracy, a data filter is designed to improve transit data quality during pre-processing. Pre-processed data are cross-validated among available data sources through the data matching processes. The data processing system will then integrate the massaged data to generate performance measures such as bus running time variations, schedule adherence, delays, boarding/alighting activities, and dwell time. The analysis methodology improves transit data quality though data mining and fusion processes. It presents opportunities to study transit travel patterns that could identify problems with transit service delivery. The eventual goal is to predict potential transit service problems based on archived or real-time transit data.

1.2 Research Objectives

Massive transit data, including vehicle location, passenger count and electronic fare payment, can be fused and analyzed to gain better insight on improving transit route performance and productivity using data mining and fusion techniques. These data present opportunities to diagnose unusual or irregular pattern that deteriorates performance. The goal is to develop a TP-based route trip model to support scheduling and planning though the simulation of trip model while applying different transit strategies such as stop consolidation, pay payment type, BRT, or signal priority.

1.3 Literature Review

Automatic transit data collection system has been demonstrated as an effective tool to support transit operation, management and improve transit services. For example, TriMet uses ITS data to trace the reliability problems on late departure buses and investigate the connection between improving departure times and improving customer satisfaction (Strathman et al., 2008). As described in TCRP Report 113 (Furth et al., 2006), the AVL/ APC system facilitates data collection with the accuracy and detail needed for off-line data analysis. The TCRP Report 88 (Kittelson & Associates, 2003) provides procedural guidelines to help transit agencies develop transit performance measurement program, using the continuous data stream from AVL/APC.

TCRP Synthesis 34 (Furth, 2000) suggested that network-level and geographic analysis methods are needed for transit performance analysis.

Real-time transit arrival time estimation and advanced trip planning tools (for example, Google Transit, http://www.google.com/transit) rely upon the AVL/APC data from transit agencies to provide riders with near real-time online transit information. Providing real-time traveler information is recommended as one of the effective strategies to improve quality of services (Schweiger, 2003).

1.3.1 Boarding, Alighting and Dwell Time

Transit dwell time at stop influences the running time and route performance significantly (HCM2000). Lin and Wilson (1992) used number of passengers and standees as key independent variables to model dwell time estimation for light rail transit operated by Massachusetts Bay Transportation Authority (MBTA). They found that number of standees could affect dwell time by 'up to a half minute, or more'. Levine and Torng (1994) investigated the dwell time effects of low-floor bus design. Seneviratne (1998) modeled the dwell time by using a weighted mean of boarding and alighting to produce better fit. Puong (2000) developed a dwell time model that includes linear effects (from number of passenger boarding and alighting) and nonlinear effects (from on-vehicle crowding) based on observation data collected at stations on MBTA Red Line. Fricker (2011) used on-board video data to develop dwell time model and compared with other models in the literature.

Wiggenraad (2001) reported that more than 60% of the dwell time of Dutch railroad vehicles was used for passenger boarding and alighting. Rajbhandari et al. (2003) utilized automatic passenger count data to analyze bus dwell time influenced by time of day, number of boarding, alighting and standees in the vehicle. Four simple linear and non-linear regression models were evaluated and compared. They concluded that the number of passengers served is the key variables on bus dwell time at stops. However, due to the data availability, the AFC data and bus type were not considered in the model. Li et al. (2006) developed a bus dwell time model using manually collected data along three routes in Florida. The model includes a binary door choice model to predict the portion of riders alighting from the rear door. Fare collection type and bus type were not explicitly considered.

Daamen et al. (2008) recently studied the boarding and alighting behavior on railroad vehicles by performing lab experiments using video camera. They tested the effects of physical environment, population, flow composition, and passenger crowding. Milkovits (2008) developed a bus dwell time estimation model using the AVL/APC and Automatic Fare Collection (AFC) data from Chicago Transit Authority (CTA) to analyze the impact of dwell time caused by number of boarding, alighting, crowding, fare type and bus design. Navick and Furth (2002, 1996) integrated electronic fare box with bus location system to provide location-stamped records of passenger boarding for study of passenger travel patterns. Reddy et al. (2009) from New York City Transit (NYCT) developed AFC-based methodologies to infer ridership, rider destinations, and passenger miles for route performance monitoring. El-Geneidy et al. (2011) investigated the dwell time of articulated buses in Montreal, Canada. The dwell time savings of articulate buses do not reflect on overall running time since the articulated buses require more time to accelerate, decelerate and merge with traffic.

1.3.2 Trip Travel Time

The general guideline for establishing optimal running times that is recommended by the Transit Capacity and Quality of Service Manual (Kittelson & Associates, 2003) and is supported by several transit planning software packages is to set running time between time points equal to the mean observed running time (Kittelson & Associates, 2003). Median travel time, often used by transit agencies, is less sensitive to extreme running time which might be caused by traffic, ridership, lift use, driver experience and so on. AVL/APC data provides opportunities to study transit performance and reliability issues (El-Geneidy et al., 2007), limited stop services (Tétreault and El-Geneidy, 2010), and impact of reserved bus lane on running time and on-time performance (Surprenant-Legault and El-Geneidy, 2011).

Bertini and El-Geneidy (2004) incorporated parameters such number of dwells, total numbers of passenger boarding and alighting to estimate trip travel time for a bus route in Portland, Oregon. Muller and Furth (2001) developed a trip time analyzer to analyze the running time by link, schedule and headway deviation TP and delay by segment. Furth and Muller (2006, 2007) suggested a new approach for quantifying the user costs associated with unreliability. Researchers at the Delft University of Technology in the Netherlands have developed an application called TriTAPT (2008). TriTAPT uses a semi-automated analysis of “homogenous periods” to examine the feasibility of current running times and to suggest optimal running times and running time periods (Muller and Furth, 2000). Cevallos and Wang (2008) developed a SQL-based data archiving and mining system to help improve operational efficiencies and quality of service. Barry et al. (2009) used entry-only AFC data to estimate trip travel time in New York City where no AVL and GPS information were available for their buses.

1.3.3 Transit Origin and Destination (OD) Inference

In addition to utilizing the AVL/APC data for transit performance analysis, electronic fare collection data provide rich information on bus dwell time and rider behavior. Bagchi and White (2004) examined the impact of smart-card data in relation to the data collection process and travel behavior analysis. Barry et al. (2002) used AFC data to estimate the Origin and Destination (OD) information of transit riders. Zhao et al. (2007) analyzed collected transit data to estimate the origin-destination matrix for rail passenger trips. Wang et al. (2011) utilized ADCS data to infer transit route level OD and travel behavior in London.

Metro Transit outbound express buses collect fare at leave. All local bus services collect fare at boarding. Lack of tap-off transaction records at alighting presents some challenges for trip chaining study. Destination arrival time can be inferred by assuming that the rider will get off at the nearest stop in connection to the transfer location. For example, Nassir et al. (2011) developed a model to infer boarding and alighting stops using schedule and ADCS data in the Twin Cities area.

1.3.4 Bus Arrival Time and Signal Priority

As transit agencies are more actively seeking solutions to traffic congestion, such as signal priority and various traffic management schemes, they need tools to monitor whether countermeasures are effective. For example, a Portland State University study conducted for Tri-Met using archived AVL/APC data found that while signal priority reduced running time on some routes, it had no positive effect on others (Kimpel et al., 2005). Altun and Furth (2009) proposed a methodology to adjust bus schedules to take advantage of transit signal priority in a simulation study. Bus schedules can potentially be adjusted to take advantage of TSP strategy through proposed data analysis. In addition, arterial traffic information, intersection signal timing, and weather condition (Hofmann and O'Mahony, 2005) can also be included in the transit processing framework to gain a holistic view of transit performance network-wide.

Transit performance analysis can also include other data that may significantly affect the bus travel time, such as latest traffic information and/or historical traffic patterns. The authors recently developed a SMART-SIGNAL (Systematic Monitoring of Arterial Road Traffic and Signals) system to evaluate arterial travel time on 11 consecutive intersections (Liu et al., 2009). The transit database model can later be integrated with the arterial travel time model to develop robust and effective operation plans and to support other intelligent transit applications. For example, Cathey and Dailey (2003) developed a model using Kalman filter and AVL data to predict transit vehicle arrival and departure time. Travel time estimation on arterial streets has been a challenging task for traffic engineers because of the interrupted nature of urban traffic flows. Many research efforts have been devoted on this topic, but their successes are limited due to the availability of traffic data from signalized intersections. Berkow et al. (2008) developed a model to estimate arterial travel time by combining the loop detector data and bus AVL data. Additional features to include arterial traffic data (for example, signal timing/phasing, arterial traffic volume, speed, delay, and travel time) can be incorporated for transit applications as shown in Figure 1. These applications include real-time bus arrival time prediction, running time estimation, schedule adjustments, recommendations for Transit Signal Priority (TSP) deployment, and real-time service management in the future. Data visualization based on system performance can also be used as an effective tool to support transit planning, scheduling and decision making.

1.4 RTE10 Signal and Service Timeline

One month (Nov. 2008) of AVL/APC and GoTo card transaction data were initially acquired from Metro Transit for analysis and modeling. However, due to traffic signal and bus service changes in 2009 and 2010 as part of the UPA TSP implementation, three months (Apr. 09, Oct. 09, and Oct. 10) of transit data were analyzed for comparison and model verification. Timeline of traffic signal changes and bus service changes due to TSP implementation on RTE10 is listed in Table 1-1.

According to the City of Minneapolis traffic engineer, all intersections on Central Avenue between 2^{nd} & 27^{th} Street are semi-actuated, except Broadway and Lowry. Broadway has actuated left-turn phases. Lowry is pre-timed, including the left-turn arrows. Semi-actuation controllers were installed around July 2009. The semi-actuated signal controllers along Central Avenue in Minneapolis has the following cycle settings; off-peak = 70 seconds, AM peak = 100 seconds, PM peak = 110 seconds, and Midday = 90 seconds. Prior to semi-actuation installation, fixed-time signals were configured with the following cycle time; AM/PM peak = 90 seconds and off-peak = 70 seconds. Intersections north of 27^{th} Street, managed by Mn/DOT, are already semi-actuated prior to TSP implementation.

Table 1-1 Timeline of Signal Changes and Transit Services

Description of Changes Related to Route 10	Signals	Service
Signals changed from pre-timed to semi-actuated in Minneapolis. (between 2nd and 27th)	7/1/2009	
Traffic signal timings implemented in Minneapolis (for general traffic)	10/1/2009	
Traffic signal timings implemented by Mn/DOT and Ramsey County (for general traffic)	12/1/2009	
TSP Signal Timing Parameters installed on all signals	12/1/2009	
Running time reduction of about 2 minutes on all trips and service types along corridor. Weekday peak route 10 adjusted to coordinate with NorthStar commuter rail schedule.		12/12/2009
Initial date when TSP was active for Route 10 (and at Roseville intersections)	1/1/2010	
10 min. headway limitation for TSP activation in Minneapolis. (2nd St. to 37th Ave.)	2/25/2010	
Nicollet Mall changed to two-block spacing. Rerouted past Convention Center. Route 829 renumbered to 59. Beginning of 10/59 coordination - 8 trips added to 59		3/20/2010
Peak 10 and 59 schedules coordinated - 6 Rte 10 trips converted to Rte 59		5/15/2010
Change to 5 min. late threshold for all signals	6/1/2010	
Running time increased downtown and beyond 53rd. 3 School trips added to the weekday 10		9/11/2010
Change to 3 min late & 8-min headway threshold for all signals	11/26/2010	

1.5 Report Organization

This report is organized as follows. In Chapter 2, timepoint time, inter-timepoint link travel time and trip travel time of bus route #10 are analyzed. Empirical models of bus service at timepoint and link level are formulated and discussed in Chapter 3. Model verification and performance comparisons using different set of ADCS data are presented in Chapter 4. In Chapter 5, a numerical simulation tool is developed. Results from the timepoint based route model are compared and discussed. Finally, discussion and summary are included in Chapter 6.

Data analysis flowchart and procedures are included in Appendix A. Detail timepoint time and link travel time comparisons are included in Appendix B. Link travel time adjustment and route 10 trip data are included in Appendix C and D, respectively. Appendix E includes R source code for statistical analysis. ADCS data structure and SQL scripts are discussed in Appendix F and G.

The on-time performance comparison between observed and simulation model are presented in Appendix H.

2 DATA ANALYSIS

The AVL system reports bus location information at one minute polling rate. Each AVL record contains message ID, timestamp, lat-long position, heading, odometer and related system information. The APC system automatically collects passenger boarding and alighting counts at stop level between door opening and closing. Combined passenger activities from front and rear doors are aggregated and stored on the on-board system. Additional information about operations can also be collected from the APC system, for example maximum and minimum load points, vehicle timepoint time at each stop, distance traveled, and average travel speed.

In 2004, Metro Transit implemented the GoTo card system, an electronic fare collection system, with the objective to improve transit service quality. The electronic fare collection system helps reduce boarding time and administrative cost. The GoTo card system is integrated with bus AVL system to record the vehicle location when fare transaction occurs. Trip transfer activities and analysis of origin and destination information can be derived by processing the smart card and AVL/APC data to better understand the rider behavior and travel pattern (Wang et al., 2011). However, lack of tap-off transaction records at alighting presents some challenges for trip chaining study. Destination arrival time can be estimated by assuming that the rider will get off at the nearest stop in connection to the transfer location.

As part of the Urban Partnership Agreement (Mn/DOT, 2008), Metro Transit, Mn/DOT, and the City of Minneapolis have implemented Transit Signal Priority (TSP) along Central Avenue (bus route 10) in parallel of I-35W from north of Minneapolis to south of I-694. Transit performance before and after the deployment of TSP strategy can be examined through the data analysis process to evaluate the effectiveness and benefit of TSP strategy. Bus schedules can potentially be adjusted to take advantage of TSP strategy through running time and timepoint time analysis. Therefore, bus route 10, as shown in Figure 2-1, was selected for performance analysis and modeling in this study. The blue segments on Central Avenue are local streets and the red segment (between NOTW and 53UV) on University Avenue is a state highway with posted speed of 89 km/h (55 mph). Complete listings of signalized intersections and bus stops are included in Appendix D.

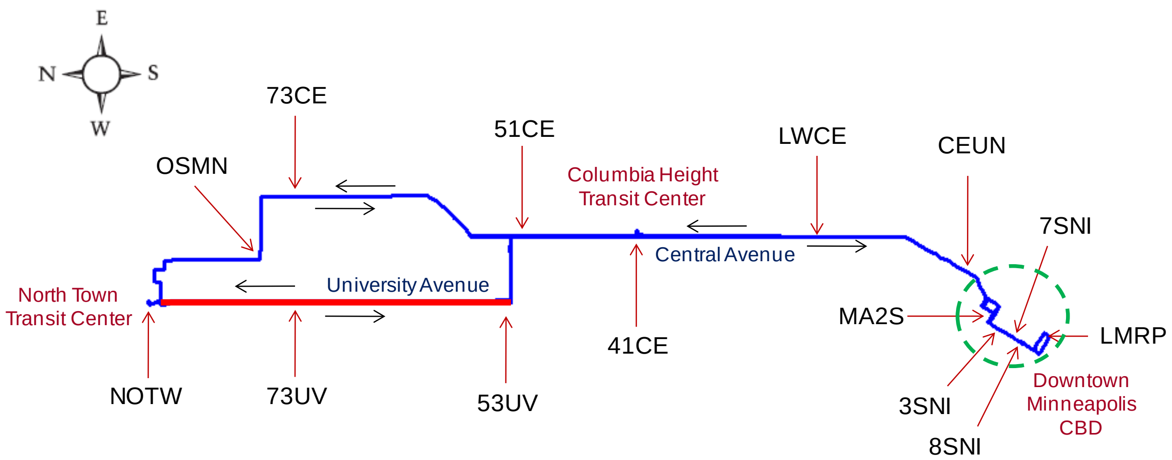


Figure 2-1 Route Map and Timepoints of Metro Transit Bus Route 10

2.1 ADCS Data Summary

Currently, Metro Transit operates over 200 bus routes with 1,600 bidirectional timepoints for monitoring schedule on-time performance. The arrival check-in and departure check-out boundaries around a TP is set typically about 61 m (200 ft) before and after a stop. The configuration of a TP zone mostly includes an intersection for both near and farside scenarios. There are over 15,000 stops in the transit network and two thirds of the stops are nearside bus stops. One month of raw AVL data (4.2 million records), APC data (3.4 million records), and GoTo card transaction data (2.1 million records) collected in November 2008 were obtained from Metro Transit for initial data analysis and modeling. Additional three months of data in 2009 and 2010 were also obtained for model verification and comparison. All data were loaded to a Microsoft® SQL database server for data pre-processing and mining. APC equipped buses are used for collecting ridership information (boarding and alighting counts) at stop level.

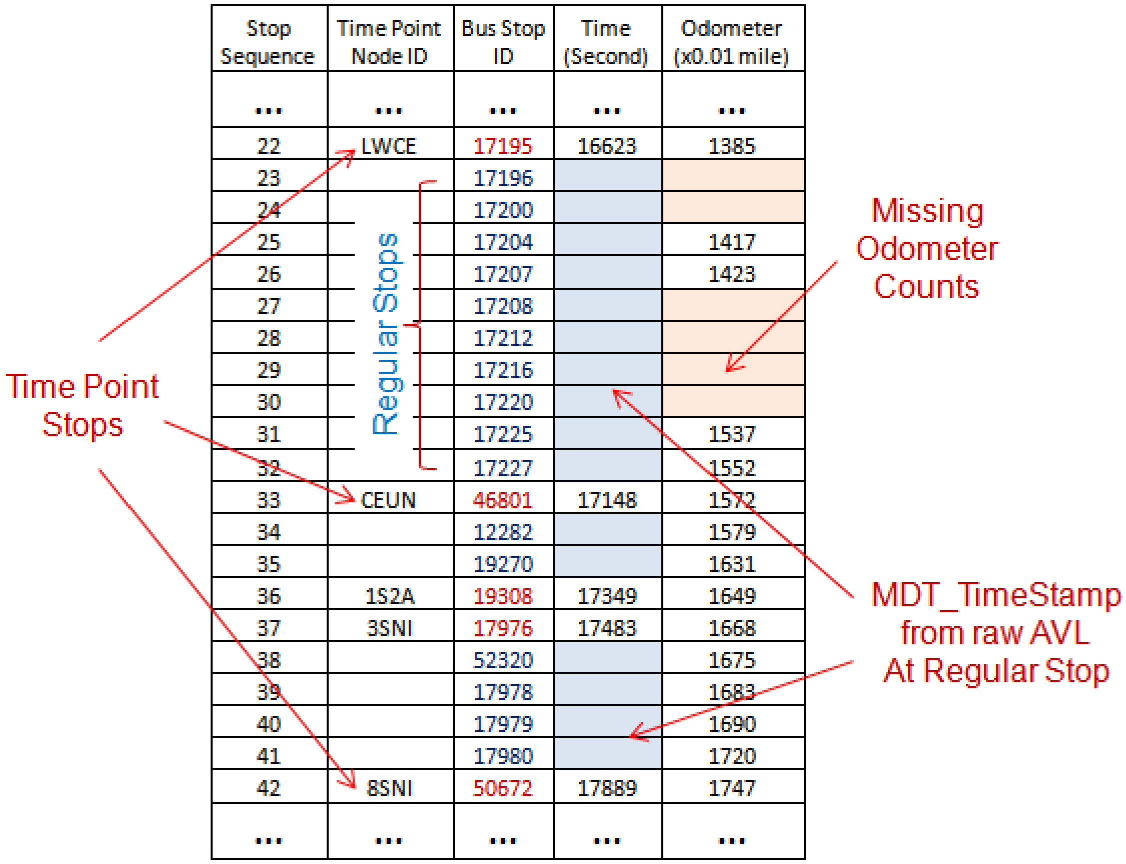
2.1.1 Automatic Vehicle Location (AVL) and Automatic Passenger Count (APC)

An Automatic Vehicle Location (AVL) system was installed on each bus in the Metro Transit fleet to monitor vehicle location and track its schedule adherence. In addition to improving the efficiency of transit operations, AVL data can also be used to provide real-time transit travel time information or schedule planning. About 30% of buses are equipped with Automatic Passenger Count (APC) system to collect ridership data for route planning, schedule frequency analysis and quality of service evaluation. Significant amounts of AVL and APC data are collected by Metro Transit daily. A sample of APC data, including Time, stop sequence, TP, stop ID and odometer counts, is illustrated in Figure 2-2.

2.1.2 Automatic Fare Collection (AFC)

The GoTo card system was introduced by Metro Transit in 2004. The GoTo card is a contactless smart card used to pay fares for bus and light rail line operated by Metro Transit and other providers in the Twin Cities area. The AFC system can help reduce boarding time (Milkovits, 2008) and administrative cost. The GoTo card system is integrated with bus AVL system to record the vehicle location when fare transaction occurs. The AFC data contains location (latitude-longitude) information from AVL system. Matching GoTo card transaction events to APC data is needed in order to determine number of GoTo card users at stop level.

Currently, there are over 30% of transit riders using the GoTo card for fare payment. Tremendous amount of fare transaction data collected through the AFC system presents rich information of riders' travel pattern and transfer activities. With the additional AFC data, analysis of trip frequency and consistency by individual rider or transfer pattern at route and time point level can be performed to infer origin to destination, to examine bus load/crowding, and to study traveler behavior or preference.



Stop Sequence	Time Point Node ID	Bus Stop ID	Time (Second)	Odometer (x0.01 mile)
...	...	...	...	...
22	LWCE	17195	16623	1385
23		17196		
24		17200		
25		17204		1417
26		17207		1423
27		17208		
28		17212		
29		17216		
30		17220		
31		17225		1537
32		17227		1552
33	CEUN	46801	17148	1572
34		12282		1579
35		19270		1631
36	1S2A	19308	17349	1649
37	3SNI	17976	17483	1668
38		52320		1675
39		17978		1683
40		17979		1690
41		17980		1720
42	8SNI	50672	17889	1747
...	...	...	...	...

Figure 2-2 Sample APC Data

2.2 Timepoint (TP) Time Analysis

Analyzing data across bus routes and stop type (nearside or far side), TP time and stop dwell time estimations can be modeled for different bus type, payment type, and ridership activity. The TP time model can then be developed together with inter-TP link model to simulate and evaluate the impact of schedule modification, mixes of vehicle types (for example, standard vs. articulated, and low vs. high floor buses) and mixes of fare media type at route level. A bus is arriving late at a time point when the arrival check-in time is later than the schedule time. When a bus is considered as early arrival, it is possible that it may be late when it is ready to leave TP depending on the dwell time at stop and possible delay at signalized intersection.

Bus arrival adherence can be calculated as described in equation (2-1). Metro transit currently uses a 1-minute early and 5-minute late window for On-Time Performance (OTP) measures. Bus departure adherence is defined as equation (2-2). In average, the transit network has 90% of on-time performance when considering all TPs, as shown in Figure 2-3. The on-time window was introduced before the AVL/APC deployment. Some transit agencies in the US use a much tighter window (for example, ±1 minute) for on-time performance measure to further improve their operations. The network-wide on-time performance will drop below 46% when using 1-minute on-time performance window.

$$T_{Bus\_arrival\_time\_at\_time\_point} - T_{Bus\_schedule} > 0 \qquad \textit{Late arrival bus at TP} \qquad (2\text{-}1)$$
$$T_{Bus\_schedule} - T_{Bus\_departure\_time\_at\_time\_point} > 0 \qquad \textit{Early departure bus at TP} \qquad (2\text{-}2)$$

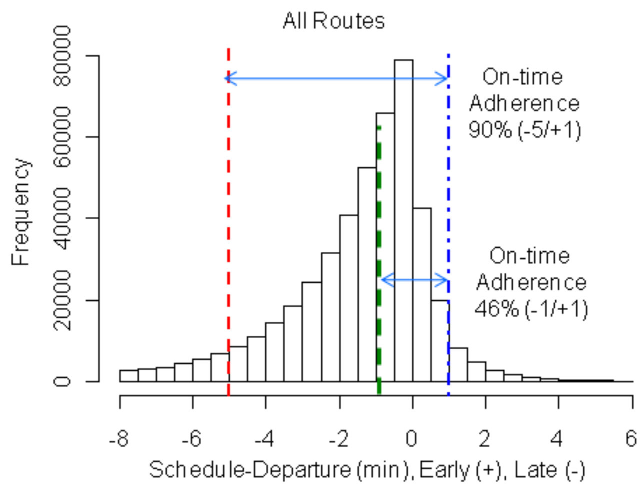


Figure 2-3 On-time Performance Distribution

2.2.1 Marginal TP Time Analysis

Dwell time at a bus stop is defined as the time interval between the first door open and the last door close, as illustrated in Figure 2-4, t_2. Because the AVL/APC data collected by the ADCS do not record the door open or close event, the TP time is used instead to distinguish the time duration from dwell time. TP arrival and departure zones in the Twin Cities transit network are usually set 60 m (200 ft) before and after the bus stop. Bus TP time calculated from AVL/APC system includes, (1) bus travel time from the check-in point to the actual stop location and doors open, labeled as t_1, (2) bus dwell time at stop which is a function of the number of boarding/alighting, bus type, bus floor configuration, payment type, wheelchair deployment and passenger load, labeled as t_2, (3) the time between last bus door close and actual departure time, which consists of possible bus holding time at time point when bus is early or possibly delayed by traffic signal at nearside stop, labeled as t_3, and (4) the time bus departing from a stop to the time point check-out boundary, labeled as t_4. To better understand the TP time affected by number of boarding and alighting, the mobility service (wheelchair lift) events were excluded in initial analysis. Time point dwell time over 5-minute, considered as potential outliers, were also excluded.

The minimum time required for a transit vehicle to stop for service is computed by comparing the time required for single boarding or alighting with the TP travel time having no passenger activity. The minimum single board or alight time is defined in equation (2-3).

Single board/alight time = Minimum{Median(0,1), Median(1,0)} - Median(0, 0) (2-3)

Where,

Median (*b*, *a*) is the median TP time of *b* boarding and *a* alighting.

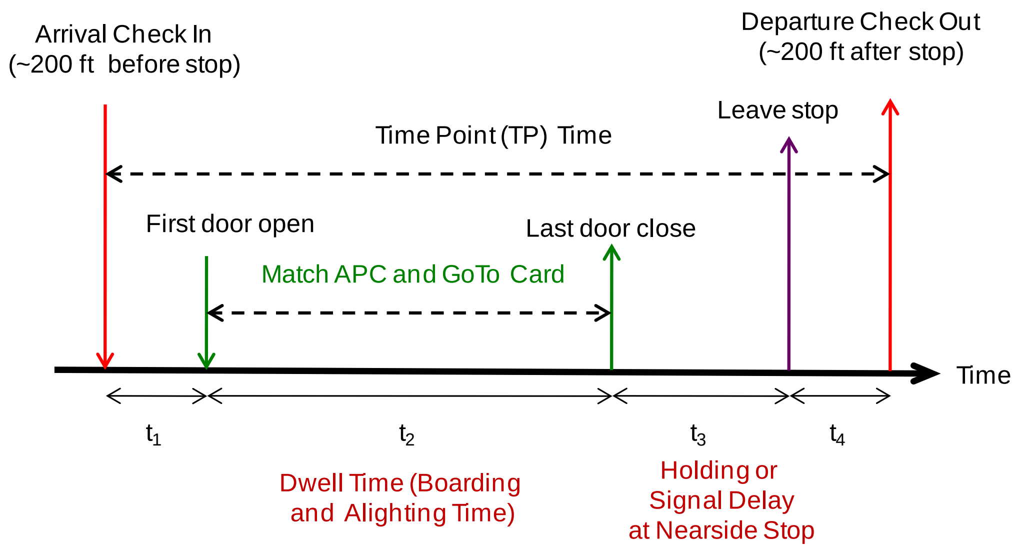


Figure 2-4 Illustration of Time Duration at a Time Point

Generally, the bus schedule time is based on the time when a bus leaving a stop. The on-time/late and early buses at a time point are defined in equation (2-4) using 1-minute buffer.

On-time or late: *TP check-in time - Schedule time > -1 minute* (2-4)
Early: *TP check-in time - Schedule time* $\leq$ *-1 minute*

Results from statistical analysis of single boarding or alighting and no passenger activity for all local buses at time points are listed in Table 2-1. For late or on-time buses, the median time to travel through a near side (NS) TP with no activity is 21 sec and 14 sec for a far side (FS) TP. For early buses with no stop activity, the median time is 63 and 51 sec for NS and FS TP, respectively. When comparing median TP time with no activity, the early buses spend 42 sec (63-21) longer than late/on-time buses at NS stops and 37 sec (51-14) at FS stops. The TP time differences between early and late/on-time buses are consistent when comparing the average TP time for NS (69.8 - 27.8 = 42 sec) and FS (58.5 – 20.8 = 37.7 sec) stops.

Overall, NS stops have longer median TP time than the FS stops for both late/on-time and early buses when there is no service activity and single boarding/alighting. The single board/alight times for late/on-time local buses are 18 sec for both NS and FS stops calculated using equation (2-3). For early buses, the minimum median times required to stop and serve single passenger are 11 and 15 sec for NS and FS stops, respectively. Early buses averagely spend longer time at TP than late buses. This is possibly due to potential holding since there is no need to rush when buses are early.

To further study the dwell time effects by number of passengers boarding and alighting, marginal TP times with pure boarding (no alighting) and pure alighting (no boarding) were analyzed. The mean and median marginal TP times with zero boarding and zero alighting for both late/on-time and early local buses are displayed in Figure 2-5 and 2-6, respectively. The plots on the left column illustrate the marginal alighting time at NS (top left) and FS (bottom left) stops with no boarding activities. The right column illustrated the marginal boarding time at NS (top right) and

FS (bottom right) stops up to 10 passengers with zero alighting. For pure boarding scenario, number of boarding is relatively proportional to the TP time. The relationship between the number of alighting and TP time with zero boarding (pure alighting) is nonlinear, except at late farside stops (bottom left of Figure 2-5) where average alighting per passenger is about **1.97** sec. The resulting average alighting time per passenger (slope) is similar to the dwell time model of alighting only (Alighting_Only_Dwell_Time_sec = 2.25 + **1.81** * N_a, where N_a is number of passengers alighting) published by Guenthner & Hamat (1988). The nonlinear relationship may largely be contributed by the passenger's choice of exiting from either front or rear door as number of alighting increases. The relationship of passengers choosing front vs. rear is more difficult to analyze from current dataset because the aggregate APC data from Metro Transit does not separate front and rear door counts.

Table 2-1 Statistics of Single Board/Alight for All Local Buses

Late/Early	NS/FS	Board	Alight	Median (s)	Mean (s)	SD (s)	Count	SE (s)	Single board / alight (Eq. 2-3)
Late/On-time	NS	0	0	21	27.8	21.6	51275	0.10	18 sec
Late/On-time	NS	1	0	41	47.1	23.0	10407	0.23	
Late/On-time	NS	0	1	39	45.5	22.2	11517	0.21	
Late/On-time	FS	0	0	14	20.8	18.1	20674	0.13	18 sec
Late/On-time	FS	1	0	35	42.4	22.6	3400	0.39	
Late/On-time	FS	0	1	32	37.0	17.5	4668	0.26	
Early	NS	0	0	63	69.8	51.3	8339	0.56	11 sec
Early	NS	1	0	81	88.8	46.6	2123	1.01	
Early	NS	0	1	74	81.4	44.6	2376	0.91	
Early	FS	0	0	51	58.5	45.5	2422	0.92	15 sec
Early	FS	1	0	78	81.3	40.4	573	1.69	
Early	FS	0	1	66	72.6	40.7	754	1.48	

Table 2-2 listed the simple linear regression models for boarding of local buses at NS and FS bus stops. For late/on-time buses, average boarding time per passenger (slope) is about 5.8 and 4.5 sec for NS and FS stops, respectively. The average boarding time per passenger for early buses is 5.4 and 5.1 sec for NS and FS stops. The resulting average boarding time per passenger (slope) is similar to the dwell time model of boarding only (Boarding_Only_Dwell_Time = -0.27 + **5.66** * N_b, where N_b is number of passengers boarding) published by Guenthner & Hamat (1988). The differences of the model intercept parameter reflect the measurement differences of dwell time (t_2) and TP time (t_1+t_2+t_3+t_4) as illustrated in Figure 2-4. As indicated by the models, the FS stops averagely have lower boarding time per passenger as compared to NS stops. Smaller intercept value of the FS TP time model implies less signal delay at FS stops. TP time model of early buses has longer intercept implies late/on-time buses are less likely to hold at TP. More detail TP time analyses by activity for both nearside and farside stop locations are included in Appendix B.

Interaction between boarding and alighting is more complicated, particularly when the APC system does not log passenger count for each door. Fare payment type (GoTo card or magnetic stripe, or cash) and bus floor type (standard vs. low floor) will be included in addition to number of passengers boarding and alighting for TP time modeling in following section.

Table 2-2 Regression Models of Marginal Boarding TP Time (Zero Alighting)

Regression (Mean)	Near Side Stops		Far Side Stops	
	(Intercept, Slope)	R^2	(Intercept, Slope)	R^2
Local Late/On-Time	(42.7, **5.8**)	0.98	(40.8, **4.5**)	0.88
Local Early	(66.1, **5.4**)	0.96	(59.5, **5.1**)	0.92

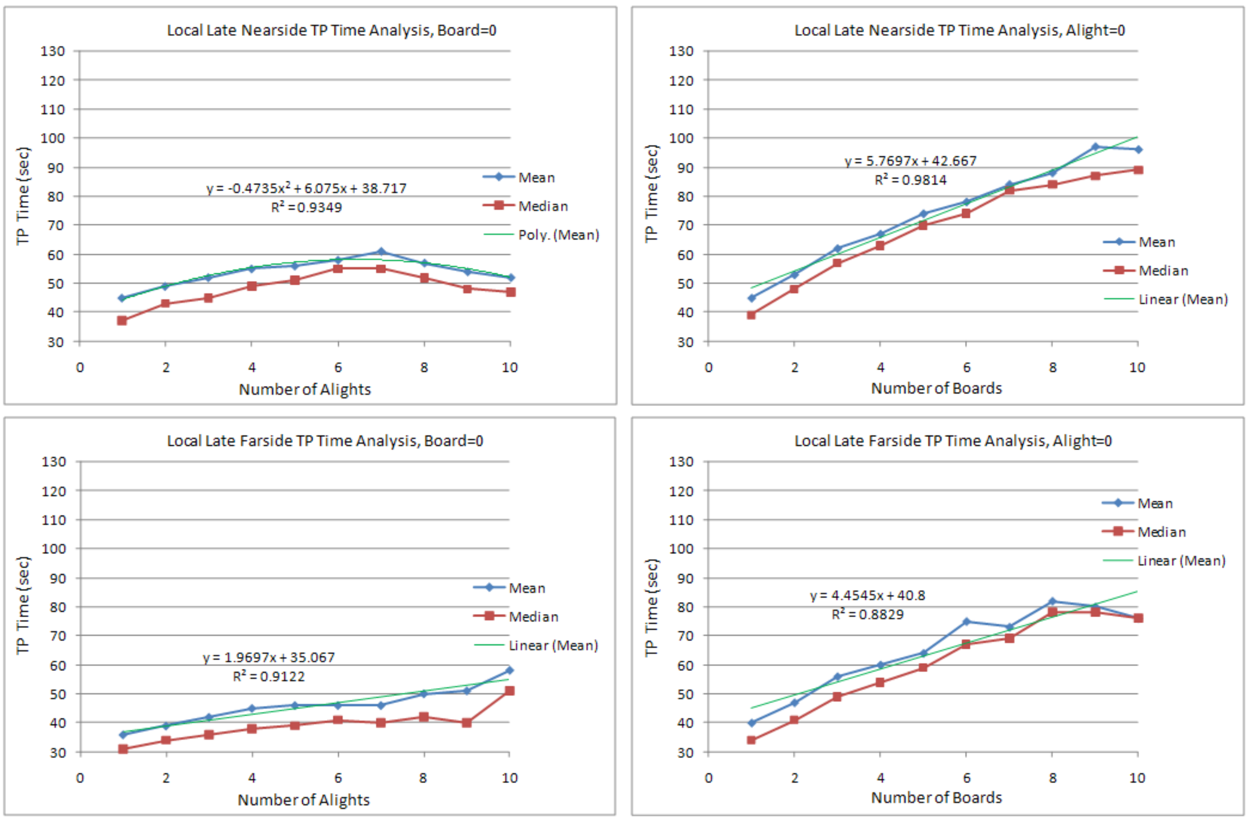


Figure 2-5 Marginal TP Time Analysis for Local Late/On-Time Buses

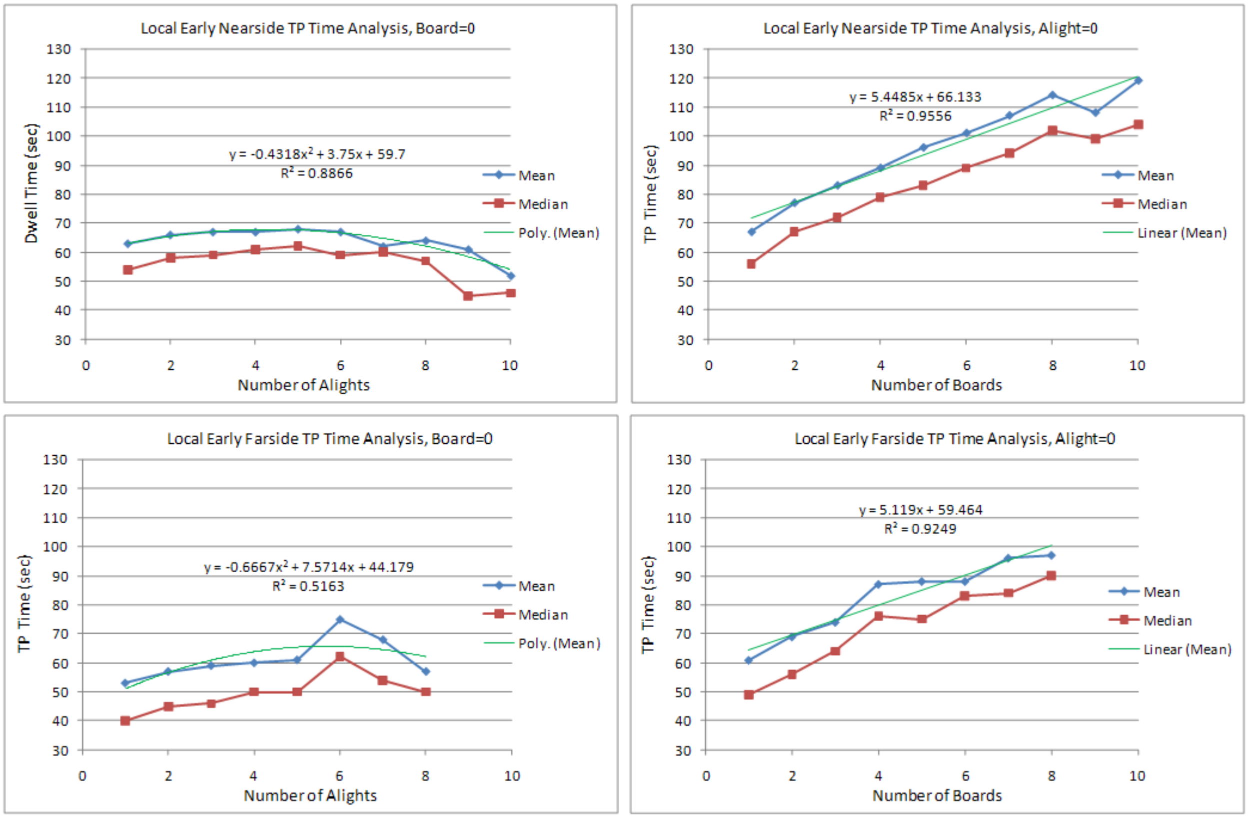


Figure 2-6 Marginal TP Time Analysis for Local Early Buses

In October 2010, Metro Transit conducted a study to investigate the boarding time per passenger for various boarding types, as listed in Table 2-3. In ideal situation with no payment at boarding (Marquette & 2nd and UMN campus shuttle), individual boarding time ranges from 1.4 to 2.4 seconds depending on number of doors. Individual boarding time at park and ride (2.8 sec) is slightly higher than the GoTo card users since there is a small portion of users using magnetic stripes or cash payment at park and ride boardings.

Table 2-3 Average Boarding Time (Data Source: Metro Transit)

Boarding Type	# of Doors	Time per Boarding (sec)
GoTo Only	1	2.1
Marquette & 2nd Ave (Pay at Leave)	1	2.4
	2	1.4
UMN Campus Connector (free)	2	1.9
	3	1.7
	4	1.4
Park & Ride	1	2.8

2.2.2 TP Time Analysis (Route 10)

After analyzing the marginal TP time affected by number of boarding and alighting, bus type, electronic fare payment counts, and number of standees were included through fusing the AVL/APC, and AFC databases. For example, the statistical analysis of TP time on route 10 (Figure 2-1) for late/on-time buses with no boarding or alighting activity was listed in Table 2-4. As highlighted, the median travel time at 73UV (far side) TP is relatively short (7 & 10 sec) for both north and southbound directions. We observed that the check-in boundary at 73UV is relatively close to the intersection stop line. Buses probably enter the check-in point after entering the intersection. i.e., the 73UV TP is configured similar to a mid-block stop. Posted speed limit at node 73UV is 89 km/h (55 mph). The average bus speed with no passenger activity is about 51.5 km/h (32 mph, 400 ft / 8.5 sec ≈ 32 mph) when computed using average median TP time. Near side bus stop at 53UV in southbound involves a left turn at 53rd and University Avenue. The southbound median travel time with no passenger activity is 42 sec, which is 16 sec higher than the time in northbound (NB) direction. One possible reason is that buses have to wait for the left turning signal at 53rd street and University Avenue prior to exiting the check-out point beyond the far side TP. At node CEUN the southbound (SB) median TP time for late/on-time buses with no passenger activity is 11 sec (42%) higher than the TP time in the northbound. It is unclear if the extra TP time is caused by signal delay at the intersection of Central and University Avenue.

TP time medians and distributions of all late/on-time buses at each TP on route 10 in both directions were plotted in Figure B-1 and B-2 in Appendix B, respectively. Time point 7SNI and 8SNI in downtown area indicated bi-modal distributions largely factored by the traffic. Buses traveling on the single-lane (Nicollet Avenue) in these two time points could potentially be held and delayed by preceding buses during peak hours.

Table 2-4 Statistics of Route 10 TP Time of Late/On-Time Buses (No Passenger Activity)

Direction	NS/FS	TP	Median (s)	Mean (s)	SD (s)	Count	SE (s)
NB	NS	CEUN	16	25.50	17.50	269	1.07
NB	NS	LWCE	38	39.30	26.20	124	2.35
NB	FS	53UV	26	32.70	17.40	74	2.02
NB	FS	73UV	**7**	10.60	9.60	109	0.92
NB	NS	73CE	20	20.30	4.10	405	0.20
NB	FS	OSMN	22	23.00	6.30	245	0.40
SB	NS	OSMN	15	17.50	5.90	252	0.37
SB	NS	73CE	17	18.60	6.10	277	0.37
SB	FS	73UV	**10**	18.20	18.30	114	1.71
SB	FS	53UV	42	45.30	27.60	74	3.21
SB	NS	LWCE	39	45.40	19.40	83	2.13
SB	FS	CEUN	27	33.00	16.70	237	1.08

2.2.3 TP Time Comparisons (Route 10)

Three additional months of bus data (Apr. 09', Oct. 09', and Oct. 10') on route 10 were analyzed to compare TP time in each direction. The average NB TP time at each TP is displayed in Figure 2-7. Overall, the TP time at each TP is consostent among the 4 datasets. However, the TP time at node LWCE (Lowry and Central Avenue) is significant lower in Apr. and Oct. 09 (0.2 & 0.23 min) than that in Nov. 08 and Oct. 10.(1.04 & 1.05 min). After further examing the data statistics, as listed in Table 2-5, we found the mean TP time in Apr. and Oct. 09 are not ourliers because the sample size is consistent with the other dataset and and the standard deviation is relative small. The average speed inside the 122 m (400 ft) TP zone was 37 km/h (23 mph) and 32 km/h (19.9 mph) for Apr. and Oct. 09, respectively. The average speed is similar to the average speed when there is no passenger activity as discussed in the marginal TP time section. The mean speed is too high when buses stop for service at a regular stop with possibly additional delay from traffic signal. It is highly possible that NB bus stop at LWCE TP was out of service due to construction that bus did not stop at LWCE during Apr. and Oct. 09 periods.

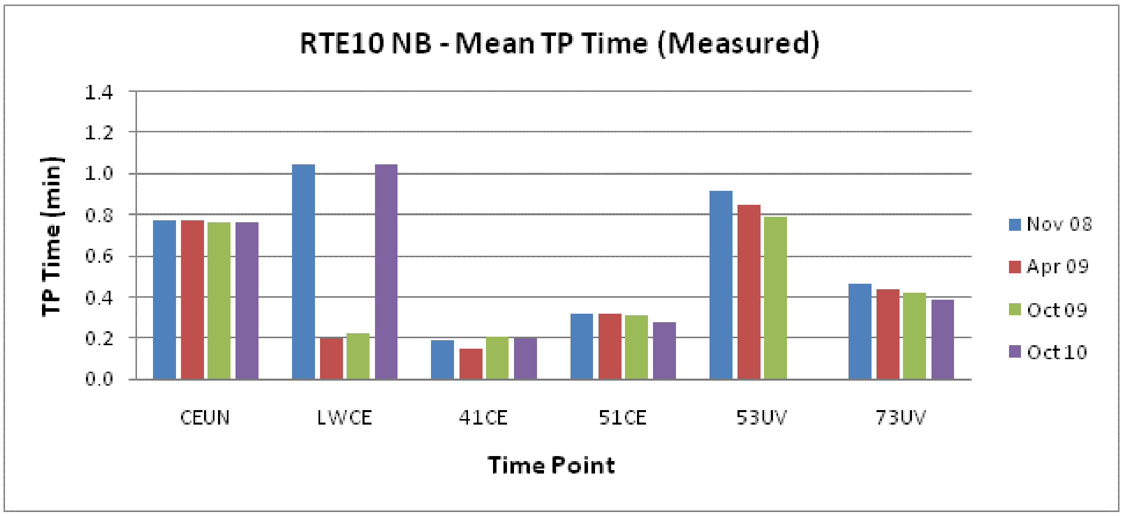


Figure 2-7 NB RTE10 TP Time Comparisons (Note: NB TP time of 53UV is not available for Oct. 10)

Table 2-5 LWCE NB TP Time Statistics

LWCE NB	Mean (s)	Stdev (s)	N	Average Speed, km/h (mph)
Nov 08	1.04	0.38	1314	7.1 (4.4)
Apr 09	0.20	0.05	1638	37.0 (23.0)
Oct 09	0.23	0.15	1536	32.0 (19.9)
Oct 10	1.05	0.39	1232	6.9 (4.3)

The average SB TP time measured from AVL/APC data at each TP is displayed in Figure 2-8. The SB TP time at LWCE drops gradually (1.1 to 0.9 min) from the Nov. 08 to Oct. 09. However, the average TP time at LWCE increases up to 1.2 min in Oct. 10. At 41CE (41st street and Central Avenue) node, the average TP time is around 0.43 min except in Apr. 09 that the TP time reaches up to 0.64 min.

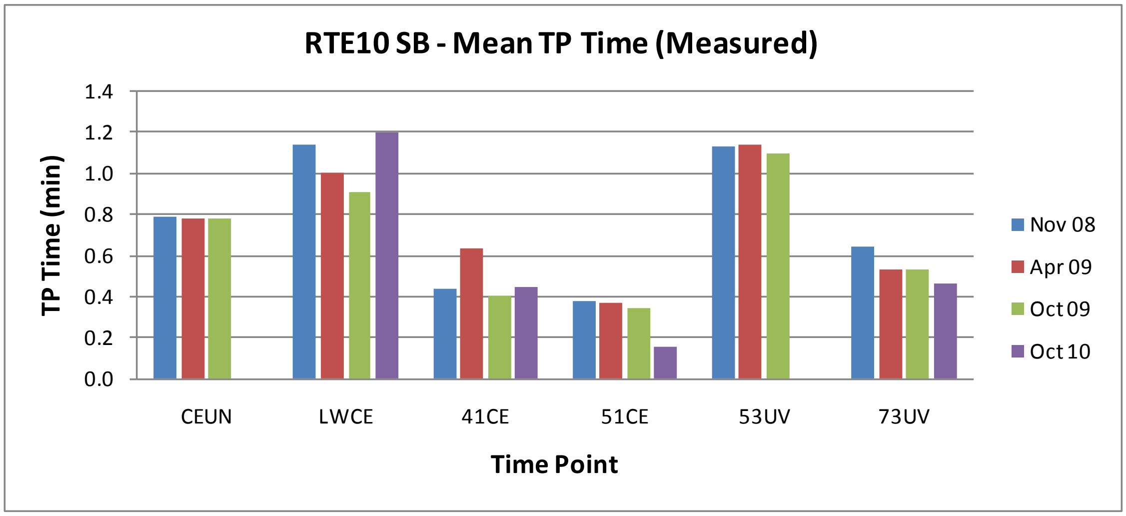


Figure 2-8 SB RTE10 TP Time Comparisons (Note: SB TP time of 53UV is not available for Oct. 10)

2.3 Link Travel Time Analysis

TP to TP, or Inter-TP, link travel time is defined as the time from departing TP check-out time to arriving TP check-in time. Utilizing the data analysis methodology, inter TP link travel time can be analyzed for selected route, direction and service type to study the variations. In order to compare with the schedule link travel, the adjusted link travel time is defined as equation (2-5).

Adjusted Link Travel Time = Mean (Link Travel Time) +
{Mean (TPA_Late_Buses) + Mean (TPB_Late_Buses)}/2 (2-5)

Where,

TPA_Late_Buses is the TP time for late or on-time buses at timepoint A, and
TPB_Late_Buses is the TP time for late or on-time buses at timepoint B

2.3.1 Link Travel Time Analysis (Route 10)

For example, the link travel time of route 10 NB from timepoint LWCE to 41CE is plotted in Figure 2-9. Analyzed data are grouped by hour of day, for example, hour 5 includes all bus trips travel through the two time points between 4:30AM and 5:29AM. Each diamond dot represents one observation. The upper, middle and lower curves represent the 85^{th} percentile, average and 15^{th} percentile of link travel time prior to adjustment, respectively. Data points outside the 15~85 percentile band can potentially be considered as outliers. Scheduled link travel time (from TP check-out to next TP check-out) is plotted in bar chart. The average link travel time from LWCE to 41CE is relatively close to the scheduled travel time as displayed in Figure 2-9, except at AM peak (10 & 11AM), PM peak (2, 3, & 4PM), and evening (8 & 9 PM) where scheduled link travel time is slightly shorter (< 1 min) than the average travel time. Individual link travel time can be visualized and analyzed using the transit performance analyst tool previously developed (as shown in Figure 1-2). The link travel time statistics of route 10 are calculated as listed in Table 2-6. There are two obvious outliers at NB link 3SNI-MA2S with minimum travel time of 1 sec and SB link 8SNI-LMRP with minimum travel time of 2 sec.

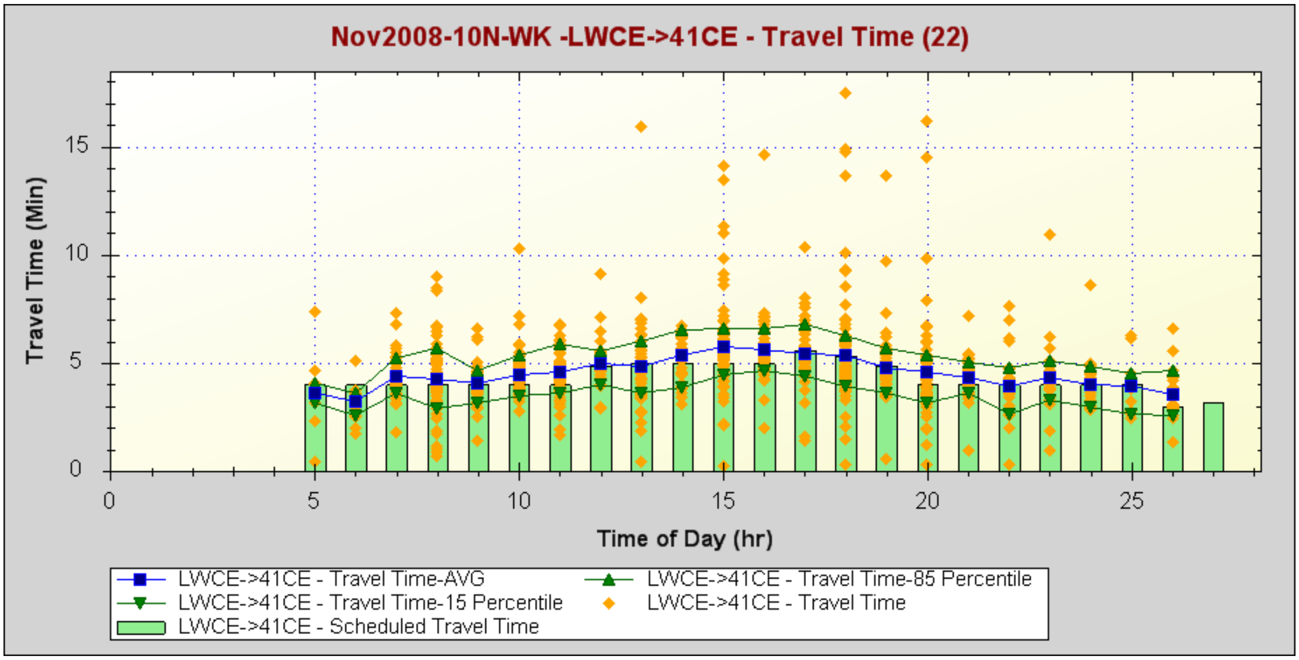


Figure 2-9 Route 10 NB – Link Travel Time from LWCE to 41CE (Nov. 08)

Table 2-6 Route 10 Inter-TP Link Travel Time Statistics (Nov. 08)

Link	Direction	Min. (s)	Median (s)	Mean (s)	Max. (s)	Count N
LMRP-7SNI	NB	132	316.5	340.4	1598	916
7SNI-3SNI	NB	104	223	222.1	1109	907
3SNI-MA2S	NB	1	32	44.89	1079	921
MA2S-CEUN	NB	108	186	192.3	390	922
CEUN-LWCE	NB	335	577	575.5	945	980
LWCE-41CE	NB	173	475	479.7	2081	982
41CE-51CE	NB	135	253	259.3	1161	797
51CE-53UV	NB	121	224	227	486	360
53UV-73UV	NB	203	324	328.6	536	359
51CE-73CE	NB	75	451	453	669	369
73CE-OSMN	NB	102	255	257.1	474	369
73UV-NOTW	NB	142	232	250.6	1437	361
OSMN-NOTW	NB	258	343	349.2	547	359
NOTW-OSMN	SB	290	374.5	510.5	1842	354
OSMN-73CE	SB	141	239	241.1	365	357
73CE-51CE	SB	358	503	509.2	753	355
NOTW-73UV	SB	192	323.5	482.5	1933	326
73UV-53UV	SB	238	370	374.8	664	325
53UV-51CE	SB	108	167	174	354	331
51CE-41CE	SB	141	280	321.6	23520	736
41CE-LWCE	SB	263	434	442.4	2199	939
LWCE-CEUN	SB	300	523	540.7	2129	940
CEUN-1S2A	SB	77	163.5	196.5	24360	946
1S2A-3SNI	SB	28	86	89.84	740	944
3SNI-8SNI	SB	125	281	289.7	801	940
8SNI-LMRP	SB	2	180	189.5	2141	904

From the Nov. 2008 dataset, the average link travel speed is plotted in Figure 2-10 by Time Of Day (TOD). The average travel speed between these two time points drops below 24 km/h (15 mph) from 1PM to 7PM. The lowest average travel speed from LWCE to 41CE occurred around 3PM. The highest link travel speed occurred around mid-night. Statistics of RTE 10 inter-TP link travel speed for both NB & SB is plotted in Figure 2-11 after removing outliers (Table C-1 & C-2). The average link speed is 24 km/h (15 mph) in NB and 23 km/h (14.4 mph) in SB. The median link speed is 23.7 km/h (14.7 mph) and 23.8 km/h (14.8 mph) in NB and SB, respectively.

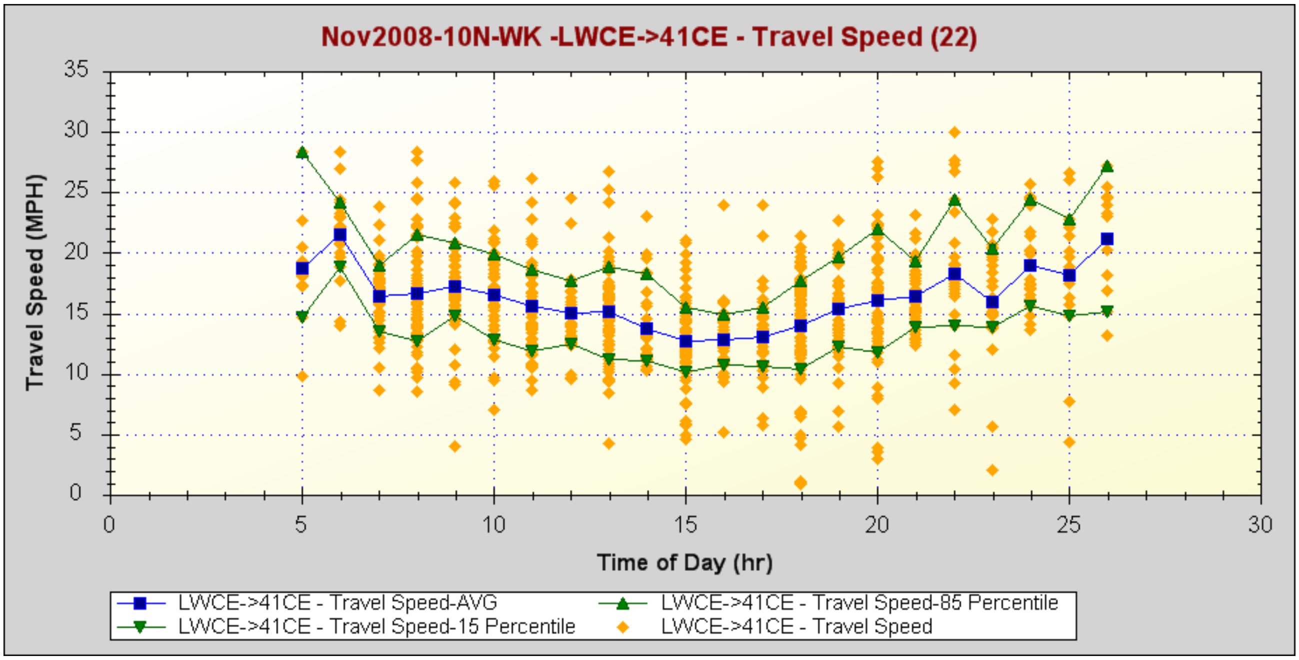
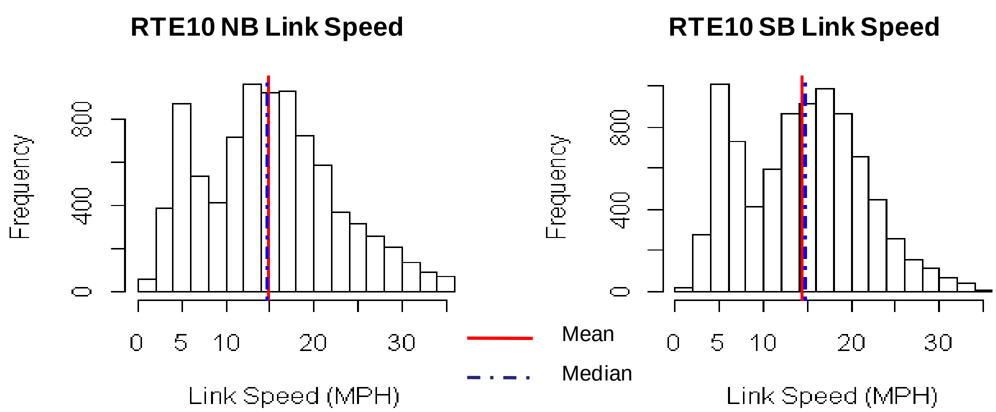


Figure 2-10 Route 10 NB – Link Travel Speed from LWCE to 41CE (Nov. 08)



Speed (MPH)	Min.	1st_Qu.	Median	Mean	3rd_Qu.	Max.	STDEV	Count
NB	0.05	9.32	14.70	14.99	19.71	36.00	7.46	8515
SB	0.10	8.36	14.80	14.40	19.11	35.06	6.77	8397

Figure 2-11 Route 10 – Link Speed Statistics (Nov. 08)

2.3.2 Link Travel Time Comparisons (Route 10)

Inter-TP link travel time outside the downtown Minneapolis Central Business District (CBD) were analyzed. Link travel time is more complicated in CBD, particularly along Nicollet Avenue where buses were held by previous bus (boarding and alighting) in the single bus lane zone. Scheduled link travel time for segments north of timepoint 41CE remains almost the same between Nov. 08 and Oct.10 for both NB and SB directions as shown on the right of Figure 2-12 and 2-13. In average, the scheduled travel time between timepoint CEUN and LWCE was adjusted almost 2 minutes (1.83 min in NB and 1.49 min in SB) shorter in Oct. 10 than the schedule in Nov. 08 in both directions. Similarly, the average scheduled travel time between timepoint LCWE and 41CE was about 1 minute (1.11 min in NB and 1.16 in SB) shorter in Oct. 10 as compared to that in Nov. 2008, as illustrated on the left two groups of bar charts in Figure 2-12 and 2-13, respectively. Detail statistics of observed vs. scheduled link travel are listed in Table B-1 and B-2 in Appendix B. The schedule adjustment of the two southern links is mainly related to the installation of TSP along the Central Avenue.

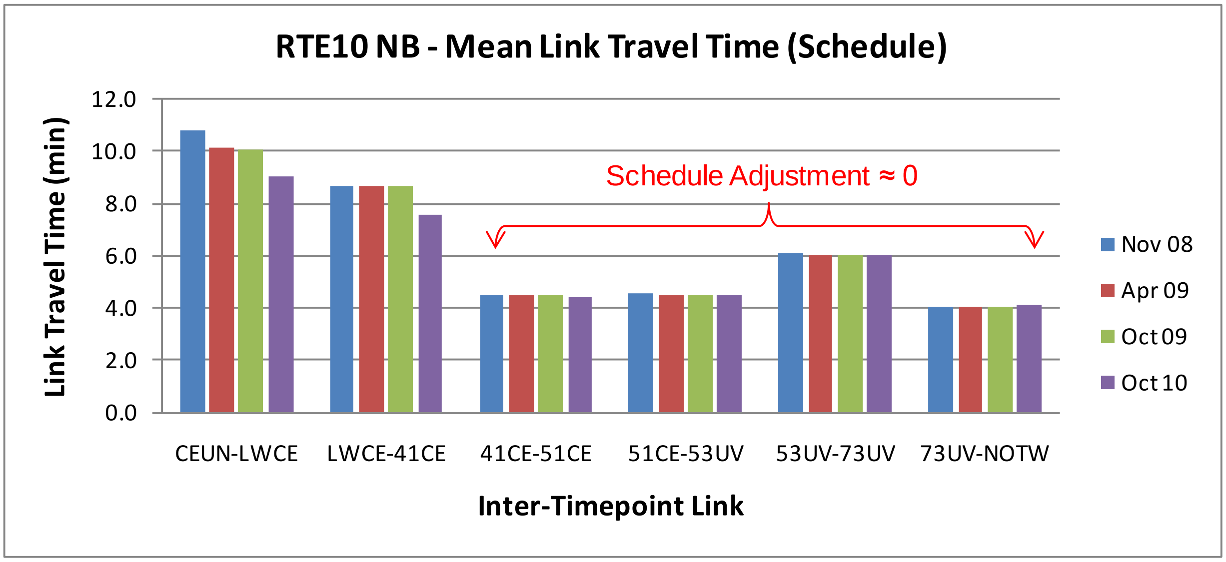


Figure 2-12 Route 10 NB Scheduled Link Travel Time

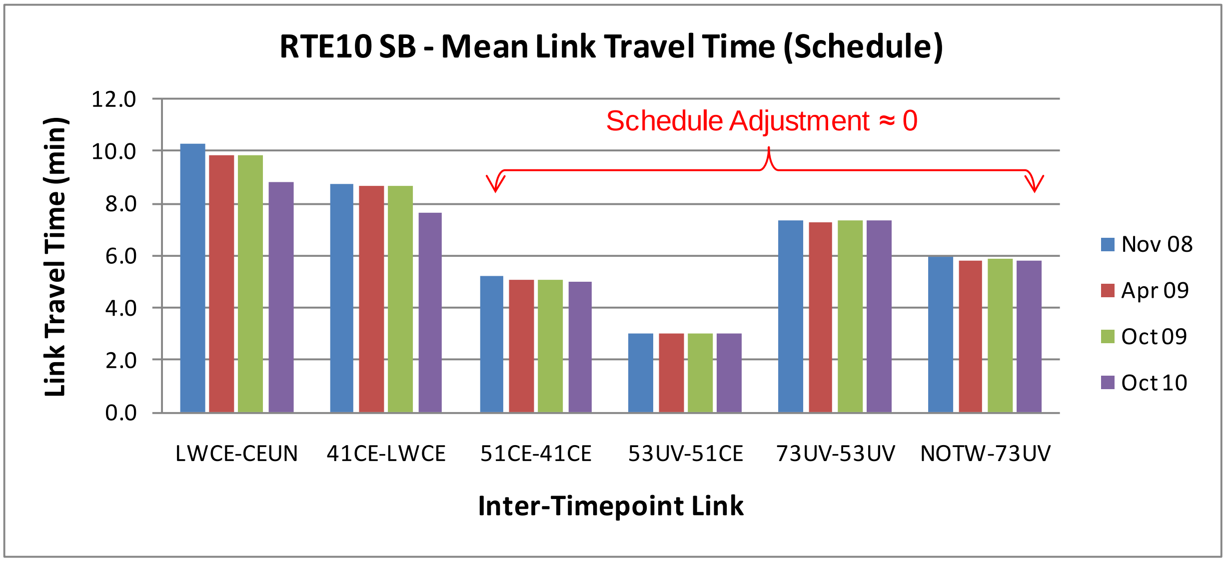


Figure 2-13 Route 10 SB Scheduled Link Travel Time

In Apr. 09, the observed travel time of link CEUN-LWCE and LWCE-41CE in NB direction was higher than the link travel time observed in Nov. 08 (Figure 2-14) even though the scheduled link travel time was adjusted shorter as displayed in Figure 2-12. Link travel time of 53UV-73UV (NB) in Apr. 09 was about 1.5 minutes longer than the mean travel time in Nov. 08 and

Oct. 09 as displayed in Figure 2-14. In southbound, the LWCE-CEUN link travel time measured in Oct. 10 actually increased by about 1 minute as compared to the travel time observed in Oct. 09 as shown in Figure 2-15. Southbound travel time of link 73UV-53UV was about 1-minute longer than that in Nov. 08 and Oct. 09. Since 53UV node data is not available from the Oct. 10 dataset (in Figure 2-14 & 2-15), individual link travel time for 51CE-53UV and 53UV-73UV cannot be derived for comparison. Link travel time impacted by signal priority between CEUN and 51CE is discussed in section 4.6. Detail link travel time statistics and comparisons from the four separate months of dataset are included in Appendix B.4.

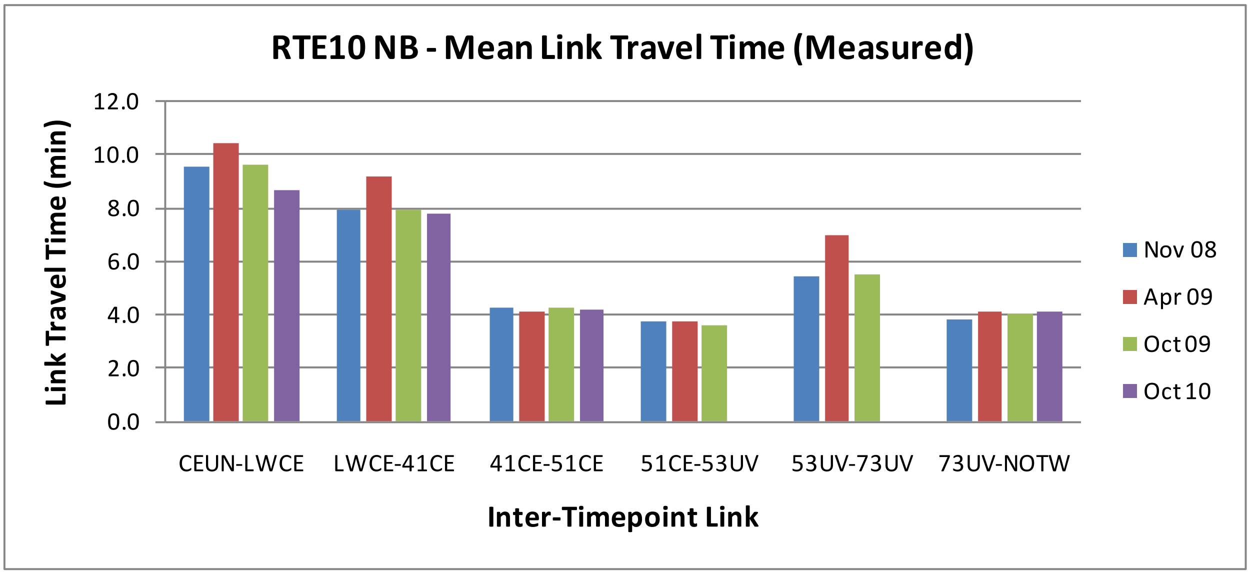


Figure 2-14 Route 10 NB Measured Link Travel Time (Note: NB link 51CE-53UV and 53UV-73UV travel time is not available for Oct. 10)

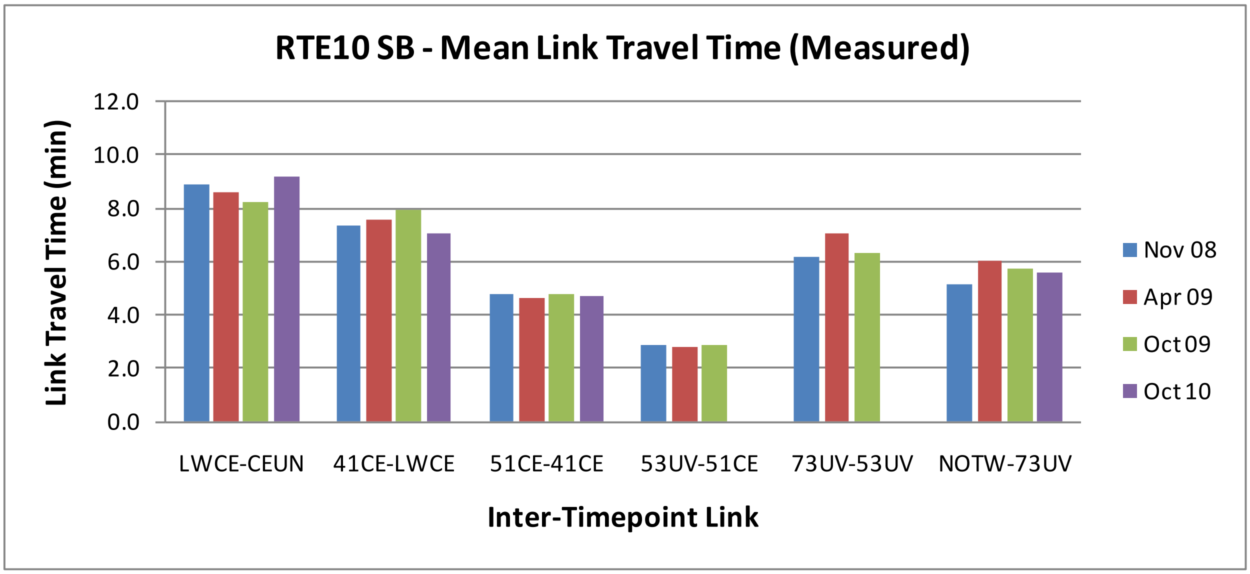


Figure 2-15 Route 10 SB Measured Link Travel Time (Note: SB link 53UV-51CE and 73UV-53UV travel time is not available for Oct. 10)

2.4 Trip Travel Time Comparisons

Trip travel time between CEUN (Central and University Avenue) and NOTW (Northtown Mall transit station) was analyzed for trip travel time evaluation. The average trip travel time observed from 4 separate months is consistent with the schedule adjustment in NB direction, as shown on the left two groups of bar charts in Figure 2-16. However, the average SB trip travel time in Oct. 10 increased as the scheduled travel time reduced. As compared to the individual link travel time previously displayed in Figure 2-15, the main contribution to the travel time increase for Oct. 10 is the SB LWCE-CEUN or the travel between 53UV and 73UV, where individual link travel time cannot be derived from the AVL/APC dataset. Further investigation is needed to understand the increase of SB trip travel time in Oct. 10.

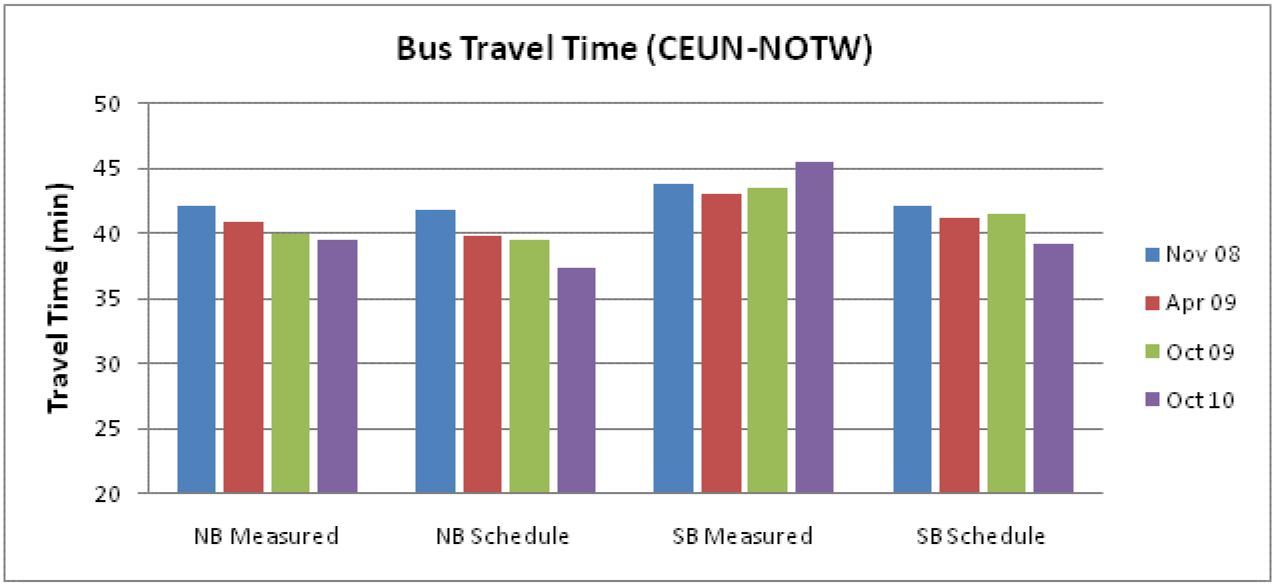


Figure 2-16 RTE10 Mean Travel Time (CEUN-NOTW) Comparisons

Intersections between CEUN and 51CE are equipped with Transit Signal Priority (TSP) capability. Trip travel time within the CEUN-51CE segment is analyzed as shown in Figure 2-17. Travel time of NB segment in Oct. 10 decreases by about 1.4 minutes (6%) while the schedule travel time reduces by about 3 minutes (13%) as compared to that in Nov. 08. Travel time of SB segment in Oct. 10 decreases by about 1 minute (4%) while the schedule travel time reduces by about 1.3 minutes (5%) as compared to that in Nov. 08. Statistics of segment travel time is listed in Table B-3 (Appendix B). More NB and SB trip travel time comparisons and statistics for the four separate months of data are included in Appendix B.5.

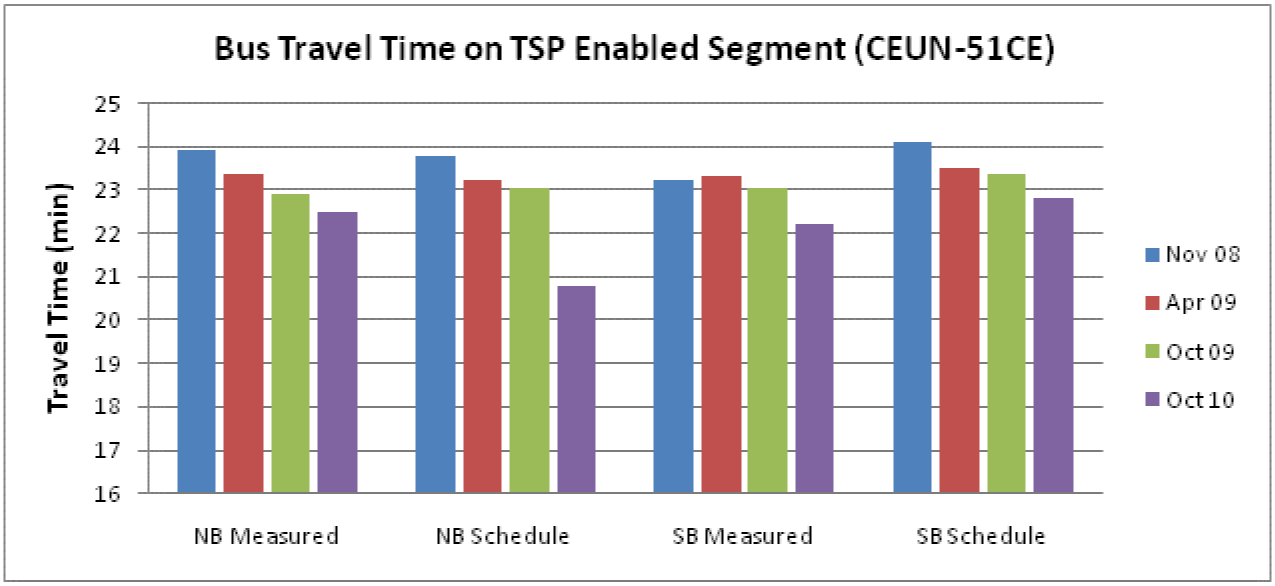


Figure 2-17 RTE10 Travel Time (CEUN-51CE) Comparisons (TSP-Enabled Segment)

3 EMPIRICAL MODELS

Timepoint based bus service regression models are developed using ADCS data from Metro Transit and traffic data from the City of Minneapolis. The route model is developed by integrating the TP-based dwell model and inter-TP link travel time model.

3.1 Timepoint Model

Numbers of passengers boarding, alighting and on-vehicle standees are the primary factors contributing to the dwell time at stops. Several dwell time models can be found in the literature (Fricker 2011) using individual transit route as case study (as listed in Table 3-1). These studies did not include information about stop characteristics, bus type, and fare payment type. In additional to considering primary factors contributing to dwell time model, Milkovits (2008) considered secondary factors such as crowding, fare payment type and bus type in dwell time modeling on Chicago Transit Authority (CTA) buses. He concluded that smartcard fare payment has 1.5 sec shorter transaction time than the magnetic stripe tickets when bus is not crowded.

Table 3-1 Dwell Time Studies Using Primary Factors

Reference	Dwell Time Model	Notes	Location
Feder (1973)	DT = 1.31 + 2.573*(Na + Nb) + ε		
Levinson (1983)	DT = 5.0 + 2.75*(Na + Nb) + ε		Several cities in US
Guenthner & Sinha (1983)	DT = 5.0 - 1.2*ln(Na + Nb) + ε	Negative binomial	Milwaukee, Wisconsin
Guenthner & Hamat (1988)	DT = 2.25 + 1.81*Na, or DT = -0.27 + 5.66*Nb + ε	Separate boarding, alighting model	Southeastern Michigan Transportation Authority (SEMTA)
Bertini & El-Geneidy (2004)	DT = 5.8 + 0.85*Na + 3.6*Nb + ε	R^2 = 0.47	TriMet, Portland, Oregon
Dueker et al. (2004)	DT = 5.136 + 3.481*Nb - 0.04 Nb^2 + 1.701*Na - 0.031*Na^2 - 0.144*Ontime + 1.364*TOD + ε	Ontime: dummy variable TOD: Time of day dwell effects, 1.364 sec	TriMet, Portland, Oregon
Milkovits (2008)	DT = -0.48 + Max(3.66*Nb + 2.26*Na_f, 2.7*Na_r) + 0.0013*Crowding + ε	Na_f: # of alighting by the front door Na_r: # of alighting by the rear door	RTE 63, Chicago Transit Authority (CTA), Chicago, IL
Fricker (2011)	DT = 5.044 + 0.455*Ns + 1.022*Na_f + 2.553*Nb + ε	Ns: # of standing passengers Na_f: # of alighting by the front door	Purdue University campus shuttle

Where, Na: # of alighting passengers, Nb: # of boarding passengers, ε: unmodeled error

A TP model describes the bus dwell and delay time between the check-in and check-out boundaries of a TP zone. TP time model incorporates parameters such as number of passengers boarding and alighting, bus type, fare payment type, and stop location characteristics. TP time can be modeled by analyzing the time distribution for near vs. far-side stops and early vs. late buses. The developed application shown in Figure 1-2 allows users to visualize the histogram of the early arrival bus dwell time at selected TP as discussed in Chapter 2. The late bus TP time distribution should include minimum possible holding assuming a bus operator will be less likely to hold at a TP when the bus is behind schedule. However, bus delay due to traffic light is hidden in the distribution. A bus TP time model can be formulated by including hour of day, number of board and alighting, seat availability, electronic fare transactions, near side or far side bus stop, and bus type parameters as described in equation (3-1).

$$TP\ Time\ Model = \mathcal{F}\{HourOfDay,\ StopAttribute,\ BusAttributes,\ PaymentType\} \tag{3-1}$$

Where,

$StopAttribute = \mathcal{F}\{Near/Far\ Side, Traffic\ Signal\ (Cycle, Split, Phase), Geometry\}$,
$BusAttribute = \mathcal{F}\{SeatAvailability, Board, Alight, LowFloor, Articulate\}$, and
$PaymentType = \mathcal{F}\{GoTo\ Card, Cash, Others\}$.

Most of required parameters can be obtained or indirectly derived from the AVL/APC database except the electronic fare transition records. The automatic fare collection system records the transaction time, type and location. A data mining methodology was developed to match electronic fare transaction data to AVL/APC database and extract the fare transaction counts at stop level for each APC-equipped bus.

3.1.1 Preliminary TP Time Model

Initially, a simplified TP time model was developed as described in equation (3-2). Each TP was individually assigned as a dummy variable in the preliminary model. This preliminary model will allow us to evaluate the level of influence from each independent variable. TP time data of all late/on-time buses without wheelchair lift are included. The total data size (N) is 12,844 from the Nov. 08 dataset.

Preliminary TP time regression model:

tp_time_sec ~ no_activity + board + goto_cnt + alight + low_floor + FS +
bus_no_seat + h10_16 + h17_19 + h20_21 + h22_26 + NLWCE + N41CE +
N51CE + N53UV + N73CE + NOSMN + S73UV + S53UV + S51CE + S41CE +
SLWCE + SCEUN (3-2)

Where,

tp_time_sec:	Timepoint time in seconds
board:	Number of passengers boarding
goto_cnt:	Number of GoTo card users
alight:	Number of passengers alighting
low_floor:	Dummy variable, low-floor bus
FS:	Dummy variable, FS bus stop
bus_no_seat:	Dummy variable, bus load greater than seat capacity

h10_16:	Dummy variable, 10AM-4PM
h17_19:	Dummy variable, 5PM-7PM
h20_21:	Dummy variable, 8PM-9PM
h22_26:	Dummy variable, 10PM-2AM next day
NXXXX:	Dummy variable, northbound TP node
SXXXX:	Dummy variable, southbound TP node

In order to eliminate the effects of holding buses at the time point if they arrive ahead of schedule, the time point models are estimated using only data for buses which are not early. The regression results, generated from R-software, of Route 10 TP time were listed in Table 3-2. There were no articulated buses operating on route 10. The low-floor parameter has a wrong sign and insignificant because most of the RTE 10 buses are operated by hybrid low-floor buses. A GoTo card user will decrease the TP time by 2.5 sec as indicated from the model. The TP time will increase by 6.2 sec when there is no seat available on a bus. A FS stop deducts 2.1 sec from the TP time. Each boarding will add 5.8 sec to the TP time which is similar to the marginal TP time findings listed in Table 2-2. Each alighting will add about 0.7 sec to the TP time. The preliminary time point time model which includes dummy variables for all but one of the time points shows the expected sign for all variables with all being strongly significant, and has an adjusted R-squared value of 0.55 which indicated that 54.8% of the data variability can be explained by the preliminary TP time regression model. Interaction between number of boarding and alighting to account for passenger's choice on alighting through front or rear door requires further information. The preliminary model will be refined later by including intersection signal and geometry related information and eliminating link dummy variables.

Table 3-2 Preliminary TP Time Regression Model (Adjusted R-squared: 0.5484)

Coefficients	Estimate	t value	Coefficients	Estimate	t value
(Intercept)	33.2	36.8	NLWCE	20.1	28.9
no_activity	-13.3	-28	N41CE	-14.4	-20.1
board	5.8	34.6	N51CE	-10	-13.9
goto_cnt	-2.5	-4.8	N53UV	17	16.3
alight	0.7	5.6	N73CE	-3.1	-3.1
low_floor	0.6	0.9	NOSMN	2.1	2.1
FS	-2.1	-3.1	S73UV	1.5	1.4
bus_no_seat	6.2	5.6	S53UV	26.5	24.5
h10_16	3.5	8.2	S51CE	-1.6	-2
h17_19	5.2	10.1	S41CE	-5.5	-7.6
h20_21	3.3	5.1	SLWCE	16.7	20.6
h22_26	1.8	3.2	SCEUN	10.4	12.7

3.1.2 Refined TP Time Model

A refined TP time model was developed as described in equation (3-3). Individual TP dummy variables are replaced by signal and intersection geometry information. These reasonable explanatory variables are necessary if this type of model were to be applied to another route. TP time data of all late/on-time buses without wheelchair lift are included. TP OSMN and 73CE were also excluded because both were located on a branch and no available traffic information. The total data size (N) is 9,813 from the Nov. 08 dataset.

Refined TP time regression model:

tp_time_sec ~ (no_activity + board + alight_only + goto_cnt + FS + h10_16 + h17_19 + h20_21 + dir_North + cyc_fixed_flag + split_sq_cyc_fixed + LT + RT) (3-3)

Where,

tp_time_sec:	Timepoint time in seconds
no_activity:	Dummy variable
alight_only:	Dummy variable
board:	Number of boardings
goto_cnt:	Number of GoTo card users
FS:	Dummy variable, farside stop
h10_16:	Dummy variable, 10AM-4PM
h17_19:	Dummy variable, 5PM-7PM
h20_21:	Dummy variable, 8PM-9PM
dir_North:	Dummy variable, northbound bus
cyc_fixed_flag:	Dummy variable, fixed time signal
split_sq_cyc_fixed:	Green split, split_sq_cyc_fixed = $(\text{green time})^2/(\text{cycle time})$
LT:	Dummy variable, left turn
RT:	Dummy variable, right turn

The regression results of the refined RTE10 TP time model using equation (3-3) were listed in Table 3-3. The model has an intercept of 30.45 sec. There is 15.27 sec of TP time savings when there is no service activity. Each boarding will add about 5.58 sec to the TP time which is similar to the value from the preliminary model. Each alight adds 1.47 sec to TP time. A FS stop will deduct 2.57 sec from the TP time. Each GoTo card user will save 3.69 sec. i.e., 1.89 sec per GoTo user boarding. Outbound (NB) direction has 4.85 sec less TP time than inbound (SB) traffic. Left and right turning at a TP contribute additional 30.34 sec and 26.6 sec to the total TP time, respectively. This refinement resulted in only a very small decline in overall explanatory power with the new R^2 value being 0.54 and all variables retaining their correct signs. The model indicated that 54% of the data variability can be explained by the refined regression model.

Table 3-3 Refined TP Time Regression Model (Adjusted R-squared: 0.5422)

Coefficients	Estimate	t value
(Intercept)	30.45	43.58
no_activity	-15.27	-26.82
board	5.58	28.85
goto_cnt	-3.69	-6.04
alight	1.47	7.55
alight_only	-2.10	-9.29
FS	-2.57	-5.42
h10_16	4.66	8.98
h17_19	6.57	10.47
h20_21	4.81	6.11
dir_North	-4.85	-10.79
cyc_fixed_flag	0.31	21.10
split_sq_cyc_fixed	-0.16	-2.93
LT	30.34	26.46
RT	26.60	24.29

Estimated results of the refined TP model is compared with the observed distribution as displayed in Figure 3-1 for all TP nodes along RTE 10. The Root Mean Square Error (RMSE) as defined in equation (3-4), and Mean Absolute Percentage Error (MAPE) as defined in equation (3-5) are computed. The TP time model has a RMSE of 20 sec and it averagely underestimates the TP time by 1.7%. The mean estimate/measured TP time is 39.1 sec. The modeled values match the measured values very closely there is a good deal of variation within the data set which is not fully captured by the proposed model as reflected in Figure 3-2.

$$RMSE = \sqrt{\frac{\sum_1^N (t_{est} - t_{measured})^2}{N}} \quad (3\text{-}4)$$

$$MAPE = \frac{\sum_1^N (t_{est} - t_{measured})}{N} \quad (3\text{-}5)$$

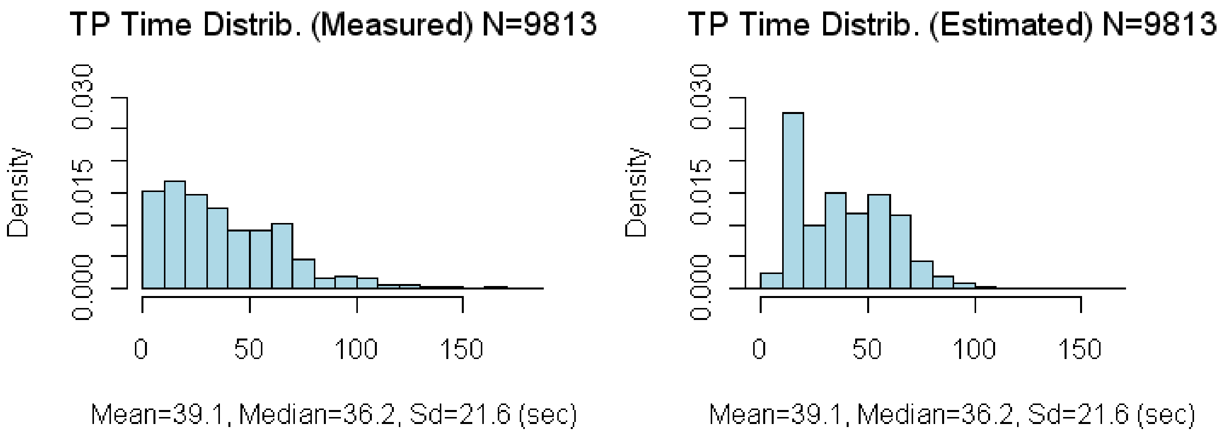


Figure 3-1 Distribution of Estimated vs. Measured TP Time (RTE 10)

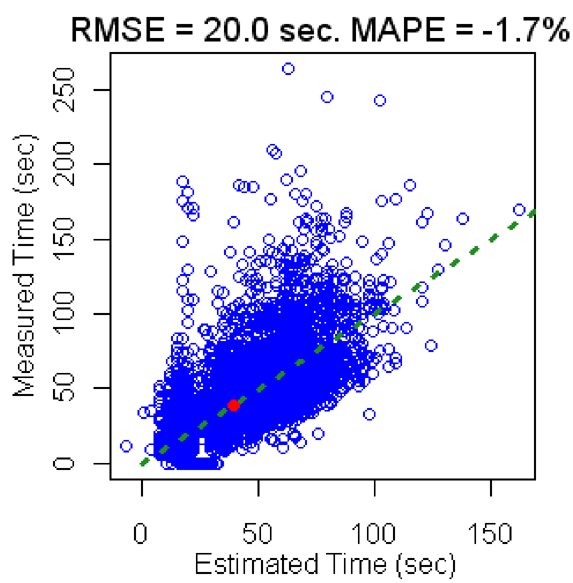


Figure 3-2 Estimated vs. Measured TP Time (Mean = 39.1 sec)

3.2 Link Travel Time Model

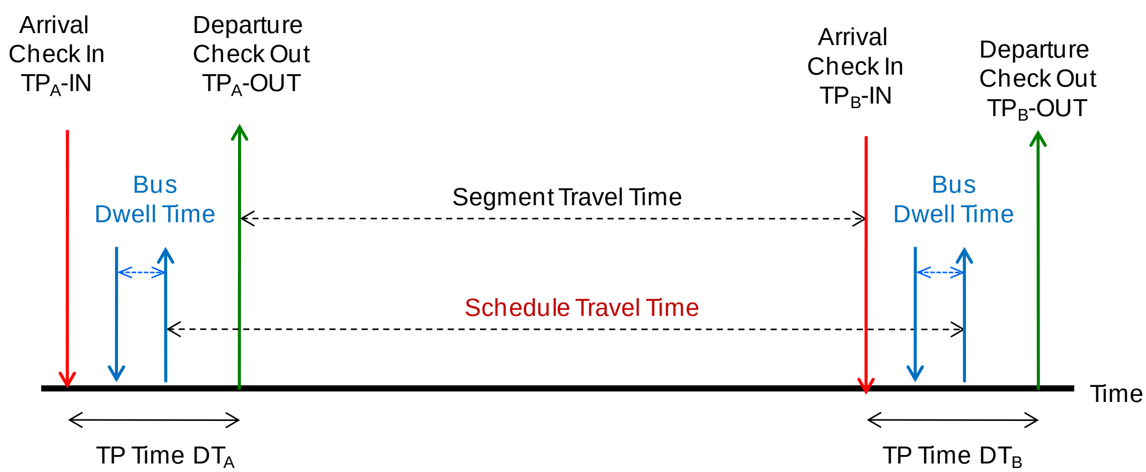
Casello et al. (2011) proposed an empirical model to predict average bus travel time of a segment between two stops. The prediction model is based on segment length, average boarding and alighting, and number of signals. Average standard deviation of travel time for OD pairs along a bus route can be predicted using the empirical model. In order to better model the link travel time, potential outliers, as described in equation (3-6), were excluded from the analysis.

$$\text{Link\_TT\_Outlier} = \text{Act\_Link\_TT} < 0, \text{ or}$$
$$(\text{Act\_Link\_TT} > Q3+1.5 \times IQR \text{ and } \text{Act\_Link\_TT} > 2 \times \text{Mean\_Link\_TT}) \quad (3\text{-}6)$$

Where,

IQR (Inter-Quartile Range) = Q3 (3rd quartile) - Q1 (1st quartile).

Table B-1 and B-2 listed the inter-TP link travel of actual and schedule travel time on route 10. Link travel time adjustment calculated based on late buses TP times at destination time point were also computed (Table C-3 & C-4). Figure 3-3 illustrated the difference between the schedule and actual link travel time. To compare actual link travel time with schedule travel time, the actual link travel time is modified as defined in equation (3-7). Distributions of the actual time and comparisons between the mean schedule time and adjusted actual travel time for each individual link were plotted in Appendix B (Figure B-13 and B-14) for NB and SB, respectively. The difference between schedule and adjusted link travel time indicated the aggressiveness the schedule and suggested necessary adjustment of schedule can be made to optimize the route running time.



Adjusted Link Travel Time (Adj. TT) = AVG(Segment Travel Time) + AVG($DT_{B\_Late\_Buses}$)

Notes: *Negative link travel time and data over Q3+1.5×IQR intervals and 2×TT_mean were excluded. IQR (Inter-quartile range) =Q3 (3^rd quartile) -Q1 (1^st quartile).*

Figure 3-3 Illustrations of Link Travel Time from TP_A to TP_B

$$Adj.\_Link\_TT = Act\_Link\_TT + Dest\_TP\_Time \quad (3\text{-}7)$$

Where,

Adj_Link_TT is the adjusted link travel time,
Act_Link_TT is the actual inter-TP travel time, and
Dest_TP_Time is the mean destination TP time of all late buses.

3.2.1 Preliminary Link Travel Time Model

A preliminary inter-TP link travel time model can be expressed as equation (3-8). Each link is initially treated as a dummy variable in the initial model. This model allows us to evaluate the level of influence from each independent variable. Other variables include hour of day, number of boarding and alighting on each link, number of stop activity, low floor bus type, late or early departure over 1-minute as described below. A refined link travel time model, shown in equation (3-9), was created by removing link dummy variables. As listed in Table 3-4, each link activity will add 5.8 sec boarding time and 2.5 sec alighting time to the travel time. A GoTo card user will save 3.4 sec in link travel time and low floor bus spends 4.1 sec less in dwell time in each link. The link travel time is averagely 4.8 shorter when a bus is late over 1-min as compared to 1.9 longer when a bus is early over 1-min.

Preliminary link travel time regression model:

t_time_sec ~ (link_board + link_alight + late_dep_1min + early_dep_1min + num_stp_activity + low_floor + h56 + h10_16 + h17_19 + h20_21 + h22_25 + LMRP.7SNI + X7SNI.3SNI + X3SNI.MA2S + MA2S.CEUN + CEUN.LWCE + LWCE.41CE + X41CE.51CE + X51CE.53UV + X53UV.73UV + X51CE.73CE + X73CE.OSMN + NOTW.OSMN + OSMN.73CE + X73CE.51CE + NOTW.73UV + X73UV.53UV + X53UV.51CE + X51CE.41CE + X41CE.LWCE + LWCE.CEUN + CEUN.1S2A + X1S2A.3SNI + X3SNI.8SNI + X8SNI.LMRP) (3-8)

Where,

Link_board:	Number of boarding on the link
Link_alight:	Number of alighting on the link
Late_dep_1min:	TP check-out time over 1-min later than schedule time
Early_dep_1min:	TP check-out time over 1-min earlier than schedule time
Num_stp_activity:	Number of stops with passenger activity on the link
Low_floor:	Low floor bus
h56:	Dummy variable, 4:30AM-6:29AM
h78:	Dummy variable, 6:30AM-8:29AM, base
h09:	Dummy variable, 8:30AM-9:29AM
h10_16:	Dummy variable, 9:30AM-4:29PM
h17_19:	Dummy variable, 4:30PM-7:29PM
h20_21:	Dummy variable, 7:30PM-9:29PM
h22_25:	Dummy variable, 9:30PM-1:29AM
XXXX.YYYY:	Dummy variable for link XXXX-YYYY

Table 3-4 Preliminary Link TT Model (Adjusted R-squared: 0.8748)

Coefficients	Estimate	t value
(Intercept)	212.03	82.22
link_board	5.76	22.74
goto_cnt	-3.41	-6.19
link_alight	2.48	9.77
late_dep_1min	-4.80	-4.59
early_dep_1min	1.90	0.68
num_stp_activity	13.38	24.99
low_floor	-4.10	-2.15
h56	-22.90	-9.06
h10_16	14.15	9.84
h17_19	26.85	15.59
h20_21	12.03	5.44
h22_25	-7.65	-3.53
CEUN.LWCE	226.94	76.00
LWCE.41CE	168.79	66.62

Coefficients	Estimate	t value
X41CE.51CE	-33.95	-12.96
X51CE.53UV	-18.75	-6.00
X53UV.73UV	66.05	20.90
X51CE.73CE	175.68	54.45
X73CE.OSMN	11.22	3.63
NOTW.OSMN	143.51	42.58
OSMN.73CE	3.28	1.06
X73CE.51CE	228.08	69.61
NOTW.73UV	69.67	19.85
X73UV.53UV	107.88	32.78
X53UV.51CE	-77.79	-23.95
X51CE.41CE	-19.07	-6.94
X41CE.LWCE	147.20	60.70
LWCE.CEUN	187.62	63.48
CEUN.1S2A	-74.24	-33.69

The preliminary model, as described in Table 3-4, has a high goodness of fit (an adjusted R^2 value of 0.87) with all variables having the expected signs and all but one (for early departures) being highly significant. The preliminary model explains 87% of link travel time variability which is quite significant. The model is refined by replacing the link dummy variables with link parameters such as number of stops, number of signals, direction, and general traffic volume as described in equation (3-9).

3.2.2 Refined Link Travel Time Model

Refined link travel time regression model:

t_time_sec ~ (link_board + goto_cnt + link_alight + late_dep_1min +
num_stp_activity +
h56 + h10_16 + h17_19 + h20_21 + h22_25 + num_stops + dir_north +
num_signal + link_vol_ln) (3-9)

Where,

link_board:	Number of boarding on the link
link_alight:	Number of alighting on the link
goto_cnt:	Number of GoTo card users
late_dep_1min:	TP check-out time over 1-min late than schedule time
num_stp_activity:	Number of stops with passenger activity on the link
low_floor:	Low floor buses
h56:	Dummy variable, 4:30AM-6:29AM
h10_16:	Dummy variable, 9:30AM-4:29PM

h17_19:	Dummy variable, 4:30PM-7:29PM
h20_21:	Dummy variable, 7:30PM-9:29PM
h22_25:	Dummy variable, 9:30PM-1:29AM
num_stops:	Number of bus stops within in the link
dir_north:	Outbound bus (North)
num_signal:	Number of signals within the link
link_vol_ln:	Link volume per lane, vehicle/hr

Table 3-5 Refined Link TT Model (Adjusted R-squared: 0.7581)

Coefficients:	Estimate	t-value
(Intercept)	74.60	19.84
link_board	6.62	19.25
goto_cnt	-2.24	-3.00
link_alight	5.86	17.62
late_dep_1min	-7.51	-5.29
num_stp_activity	5.94	8.48
low_floor	-1.48	-0.56
h56	-19.44	-5.52

Coefficients:	Estimate	t-value
h10_16	17.10	8.59
h17_19	27.65	11.60
h20_21	12.60	4.09
h22_25	-7.02	-2.28
num_stops	17.71	92.98
dir_north	-29.57	-16.74
num_signal	12.11	56.23
link_vol_ln	0.02	5.77

The refined regression model of RTE 10 inter-TP link travel time using the R-software is listed in Table 3-5. In the refined model the link dummy variables are replaced by explanatory variables, resulting in a decline in the adjusted R-squared value to 0.76. The only variable not to have the expected sign and at a strongly significant level is the dummy variable for low floor buses which has the correct sign but is not strongly significant. The model indicated 6.6 sec or 5.9 sec increases of link travel time per boarding or alighting activity within a link. When a bus is over 1-minute late, it is likely to reduce overall link travel time by about 7.5 sec. Each GoTo card user will contribute 2.2 sec of saving in link travel time. Low floor bus has 1.5 sec of travel time saving but not significant. The model suggests that the link travel time will increase by 17.7 sec whenever a bus stopped for passenger activity within the link. The outbound (NB) buses will have less link travel time by about 29.6 second. Each signalized intersection will add 12.1 sec to the overall link travel time. The link travel time also varies by hour of day as listed in the model. The refined model explains almost 76% of link travel time variability, slightly lower than the preliminary model listed in Table 3-4.

Estimated results of the refined link travel time model is compared with the observed distribution for all links along RTE 10. The estimated travel time distribution, as displayed in Figure 3-4, has the same mean, median and standard deviation as compared to the observed travel time. The RMSE and MAPE are computed as illustrated in Figure 3-5. The link travel time model has a RMSE of 1.2 min and it averagely underestimates the link travel time by 5.5%. The mean estimate/measured link travel time is 6 min.

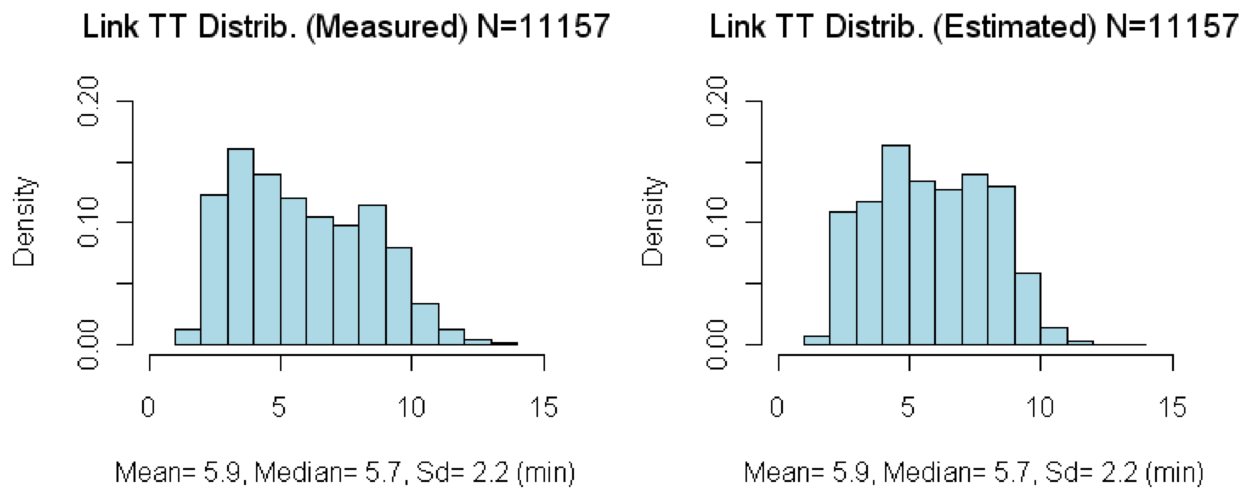


Figure 3-4 Distribution of Estimated vs. Measured Link Travel Time (RTE 10)

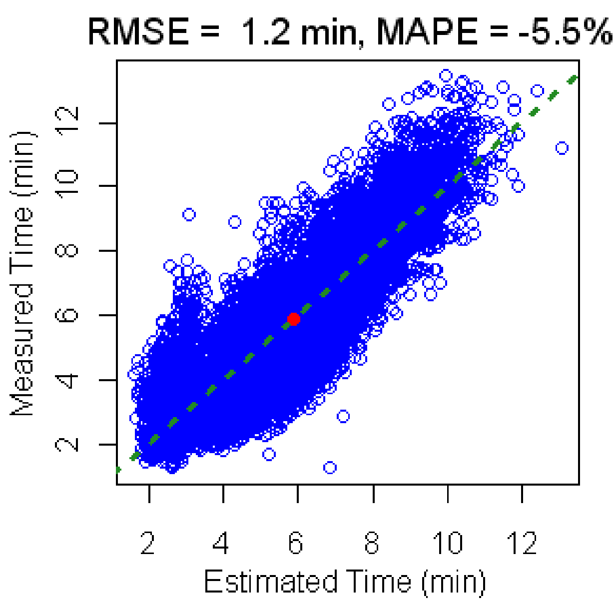


Figure 3-5 Estimated vs. Measured Link Travel Time (Mean = 6 min)

3.3 Route Model

The average route Travel Time (TT) can be computed by summing average TP time and link TT using equation (3-10). However, due to the no-additive characteristics of the link travel time standard deviation, it cannot simply be summed to estimate route travel time deviations, as described in equation (3-11).

$$Mean\ (t_{route}) = \sum Mean(DT_{TP}) + \sum Mean\ (t_{link}) \qquad (3\text{-}10)$$

$$SD^2\ (t_{route}) \neq \sum SD^2(DT_{TP}) + \sum SD^2\ (t_{link}) \qquad (3\text{-}11)$$

Casello et al. (2011) proposed a prediction model to forecast the SD (OD) for an OD route by estimating standard deviation for each individual link. The link travel time was defined as the departure time difference between two consecutive stops. Bus dwell time variability is embedded in the link travel time model. The SD (link) is generated by a regression model based on mean travel time, Volume to Capacity (v/c) ratio and number of signals in each link segment as described in equation (3-12).

$$SD(link) \sim \mathcal{F}(mean(link_{TT}), v/c, NumOfSignals) \quad (3\text{-}12)$$

Standard deviation of an OD route, SD (OD), can be expressed by including individual link SD and their covariance, as described in equation (3-13).

$$SD^2(OD) = \sum SD^2(link_i) + 2 \times \sum \sum COV(link_i, link_j) \quad (3\text{-}13)$$

Where,

$SD(OD)$ is the route SD of travel time,
$SD(link_i)$ is the link travel time SD, and
$COV(link_i, link_j)$ is the covariance between $link_i$ and $link_j$, and $i \neq j$.

Casello et al. (2011) assumed that the covariance between non-adjacent links is negligible. And the standard deviations of TT on adjacent links are equal. The resulting model underestimates standard deviation for OD pairs by about 17% which could be significant for OD with larger deviation.

In this study, empirical TP time model and inter-TP link Travel Time (TT) model are developed. Covariance between TP node and link is unknown. A route simulation model including both TP and link models are created with proper verification and validation as published by Milkovits (2008) who developed a microsimulation model of route 63 in the CTA network. The model was calibrated and validated for evaluating bus service reliability while applying different strategies.

4 MODEL CALIBRATION AND VERIFICATION

Calibration is a systematic adjustment of model parameters in order to predict model output more accurately. In addition, model verification and validation are required before the model can be used to support decision making. The data points for on-time or late buses are included in the computation and calibration process. Refined TP and link models, as described in Table 3-3 and 3-5, generalize the model output based on key known parameters. Un-modeled factors and uncertainties at individual TP or link level require adjustment to reflect observed characteristics from model outputs.

The following equation is used for the timepoint time and link travel time model calibration as discussed in section 4.1 and 4.2.

$$\hat{x} = x_i \times r_\sigma - \bar{x}_{obs}\left(\frac{r_\sigma}{r_\mu} - 1\right) \tag{4-1}$$

Where,

$\hat{x}$ is the estimate after calibration,
$\bar{x}_{obs}$ is the observed mean,
r_σ is the ratio of observed SD over un-calibrated SD,
r_μ is the ratio of observed mean over un-calibrated mean, and
x_i is the estimate before calibration.

4.1 TP Time Model

Statistics of estimated TP time at each node is computed and listed in Table 4-1 and 4-2 for NB and SB, respectively. Mean ratio, defined as average estimated TP time over average observed TP time, is calculated for each TP node. Since the refined model removes the individual node characteristics as compared to the preliminary TP time model, the model underestimates the TP time at node LWCE, 53UV and 73UV in both directions. The underestimation reaches up to 23% in NB at LWCE and 30% in SB at 73UV. TP time at node 41CE and 51CE is overestimated by the model with mean ratio ranges from 1.38 to 2.32.

To study possible causes of the overestimation at node 41CE & 51CE, the preliminary model as listed in Table 3-2 is investigated. Both nodes, N41CE and N51CE, have negative coefficient to the model in NB ranging from -10 to 14.4 sec. The SB nodes, S41CE & S51CE, have negative coefficient but with small magnitude. When TP dummy variables are removed, the generalized model tends to overestimate the TP time at these two nodes with relatively low passenger activity.

Table 4-1 RTE 10 NB TP Time Model – Observed vs. Estimated

NB	Observed		Estimated		Est. / Obs. Ratio	
Node ID	Mean	SD	Mean	SD	R_Mean	R_SD
NCEUN	46.45	22.82	46.56	12.15	1.00	0.53
NLWCE	62.69	22.84	47.99	12.25	0.77	0.54
N41CE	11.56	9.01	23.34	12.32	2.02	1.37
N51CE	18.92	16.47	26.13	12.32	1.38	0.75
N53UV	54.86	28.81	49.90	12.32	0.91	0.43
N73UV	27.78	17.75	23.49	12.27	0.85	0.69

Table 4-2 RTE 10 SB TP Time Model – Observed vs. Estimated

SB	Observed		Estimated		Est. / Obs. Ratio	
Node ID	Mean	SD	Mean	SD	R_Mean	R_SD
S73UV	38.54	28.81	27.06	12.28	0.70	0.43
S53UV	67.79	34.28	57.45	12.28	0.85	0.36
S51CE	22.67	19.36	52.65	12.31	2.32	0.64
S41CE	26.17	19.26	52.74	12.21	2.02	0.63
SLWCE	68.48	28.68	51.88	12.15	0.76	0.42
SCEUN	47.45	23.92	47.67	12.00	1.00	0.50

The Columbia Height transit center is located nearby node 41CE as shown in Figure 2-1. Route 10C actually ends at 41CE in NB and turns around toward downtown Minneapolis. In general, number of passengers alighting usually exceeds the boarding at node 41CE in NB. As shown in Figure 4-1, 90% of service activities at 41CE in NB contains only 1 or no passenger boarding (57% zero boarding, 33% single boarding). Most of the alighting at NB 41CE node occurs between 8AM and 6PM.

Passenger activity is averagely light at node 51CE in NB which located two blocks south before buses make left turn onto 53rd Avenue. As displayed in Figure 4-2, 95% of service activities at 51CE NB contains only 1 or no passenger boarding (77% zero boarding, 18% single boarding). Average alighting is between 1 or 2 passengers at this TP node. Statistics of the modified/calibrated model vs. observed are listed in Table 4-3 and 4-4.

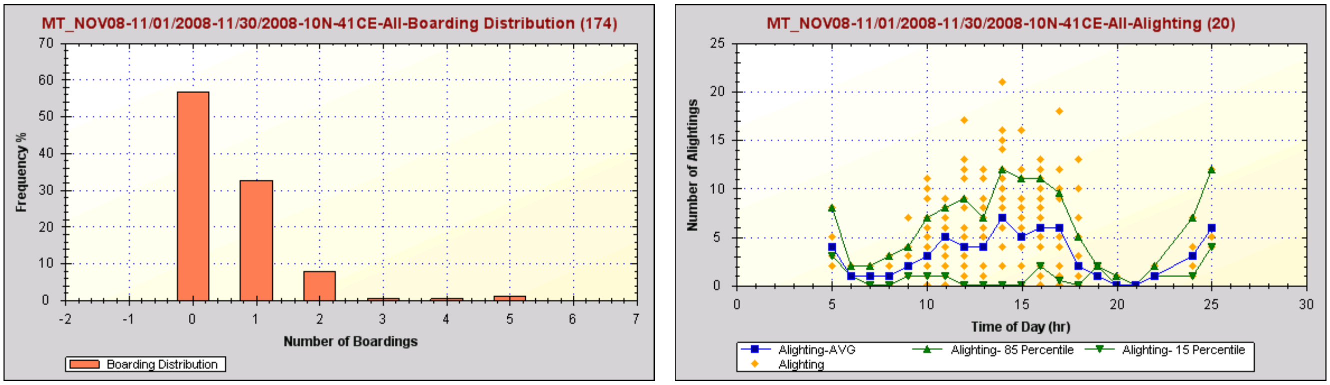


Figure 4-1 TP 41CE NB Boarding Distribution and Alighting by TOD

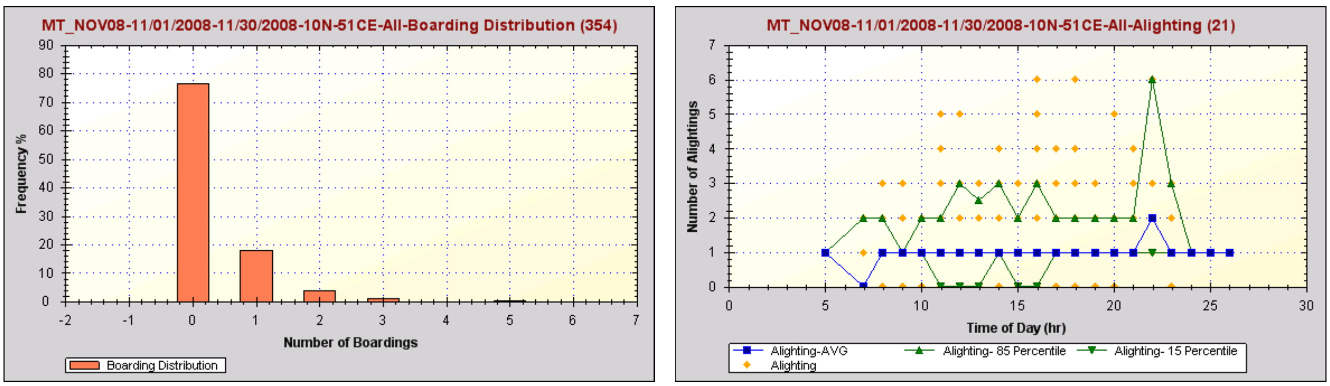


Figure 4-2 TP 51CE NB Boarding Distribution and Alighting by TOD

Table 4-3 Modified RTE 10 NB TP Time Model – Observed vs. Estimated

NB	**Observed**		**Model (Modified)**		**Est. / Obs. Ratio**	
Node ID	**Mean**	**SD**	**Mean**	**SD**	**R_Mean**	**R_SD**
NCEUN	46.45	22.82	47.11	22.72	**1.01**	**1.00**
NLWCE	62.69	22.84	63.40	22.57	**1.01**	**0.99**
N41CE	11.56	9.01	11.53	8.61	**1.00**	**0.96**
N51CE	18.92	16.47	19.05	16.29	**1.01**	**0.99**
N53UV	54.86	28.81	55.50	28.45	**1.01**	**0.99**
N73UV	27.78	17.75	28.06	17.59	**1.01**	**0.99**

Table 4-4 Modified RTE 10 SB TP Time Model – Observed vs. Estimated

SB	Observed		Model (Modified)		Est. / Obs. Ratio	
Node ID	Mean	SD	Mean	SD	R_Mean	R_SD
S73UV	38.54	28.81	38.39	27.05	**1.00**	**0.94**
S53UV	67.79	34.28	67.82	32.11	**1.00**	**0.94**
S51CE	22.67	19.36	22.58	18.10	**1.00**	**0.93**
S41CE	26.17	19.26	26.83	18.03	**1.03**	**0.94**
SLWCE	68.48	28.68	68.51	27.12	**1.00**	**0.95**
SCEUN	47.45	23.92	47.91	22.79	**1.01**	**0.95**

4.2 Link Travel Time Model

Statistics of estimated link travel time is computed and listed in Table 4-5 and 4-6 for both NB and SB, respectively. Mean ratio, defined as estimated over observed link travel time, is calculated for comparisons. In average, the refined TP to TP link model underestimates link travel time at link 53UV-73UV and 73UV-NOTW by 15% and 33% in NB (19% and 49% in SB), respectively. Both links are highway segments with posted speed limit of 88.5 km/h (55 mph). The model overestimates 41CE-51CE (41%) link in NB and 53UV-51CE (44%) and 51CE-41CE (31%) in SB. Statistics of the modified model vs. observed are listed in Table 4-7 and 4-8. Standard deviations of estimated link travel time are relatively close to the observed deviations.

Table 4-5 Comparisons of RTE 10 NB Link Travel Time – Observed vs. Estimated

NB	Observed (min)		Estimated (min)		Est. / Obs. Ratio	
Link ID	Mean	SD	Mean	SD	R_Mean	R_SD
CEUN-LWCE	9.56	1.37	9.00	0.90	0.94	0.66
LWCE-41CE	7.93	1.30	7.80	0.60	0.98	0.46
41CE-51CE	4.27	0.94	6.00	0.60	1.41	0.64
51CE-53UV	3.72	0.74	3.60	0.30	0.97	0.41
53UV-73UV	5.41	0.72	4.60	0.40	0.85	0.56
73UV-NOTW	3.86	0.61	2.60	0.20	0.67	0.33

Table 4-6 Comparisons of RTE 10 SB Link Travel Time – Observed vs. Estimated

SB	Observed (min)		Estimated (min)		Est. / Obs. Ratio	
Link ID	Mean	SD	Mean	SD	R_Mean	R_SD
NOTW-73UV	5.10	0.98	2.60	0.30	0.51	0.31
73UV-53UV	6.19	1.23	5.00	0.50	0.81	0.41
53UV-51CE	2.85	0.51	4.10	0.30	1.44	0.59
51CE-41CE	4.75	0.96	6.20	0.50	1.31	0.52
41CE-LWCE	7.31	1.21	6.70	0.50	0.92	0.41
LWCE-CEUN	8.87	1.24	8.60	0.60	0.97	0.48

Table 4-7 Modified NB RTE 10 Link Travel Time Comparisons (Observed vs. Modified)

NB	Observed (min)		Modified Model (min)		Est. / Obs. Ratio	
Link ID	Mean	SD	Mean	SD	R_Mean	R_SD
CEUN-LWCE	9.56	1.37	9.65	1.40	**1.01**	**1.02**
LWCE-41CE	7.93	1.30	7.87	1.44	**0.99**	**1.11**
41CE-51CE	4.27	0.94	4.26	0.97	**1.00**	**1.04**
51CE-53UV	3.72	0.74	3.81	0.85	**1.03**	**1.15**
53UV-73UV	5.41	0.72	5.38	0.66	**0.99**	**0.92**
73UV-NOTW	3.86	0.61	3.93	0.74	**1.02**	**1.22**

Table 4-8 Modified SB RTE 10 Link Travel Time Comparisons (Observed vs. Modified)

SB	Observed (min)		Modified Model (min)		Est. / Obs. Ratio	
Link ID	Mean	SD	Mean	SD	R_Mean	R_SD
NOTW-73UV	5.10	0.98	5.21	0.92	**1.02**	**0.94**
73UV-53UV	6.19	1.23	6.09	1.17	**0.98**	**0.95**
53UV-51CE	2.85	0.51	2.88	0.48	**1.01**	**0.95**
51CE-41CE	4.75	0.96	4.78	1.00	**1.01**	**1.04**
41CE-LWCE	7.31	1.21	7.28	1.13	**1.00**	**0.93**
LWCE-CEUN	8.87	1.24	8.77	1.28	**0.99**	**1.04**

4.3 Timepoint On-Time Performance (OTP)

In addition to TP time and link travel time calibration, TP adherence verification is perform to ensure correctness. Timepoint adherence is defined as follows.

$$t_{adherence} = t_{departure} - t_{schedule} \tag{4-2}$$

Where,

$t_{adherence}$ is the schedule adherence, $t_{adherence} > 0, late;\ t_{adherence} < 0, early$
$t_{departure}$ is the actual departure time, and
$t_{schedule}$ is the schedule time at TP.

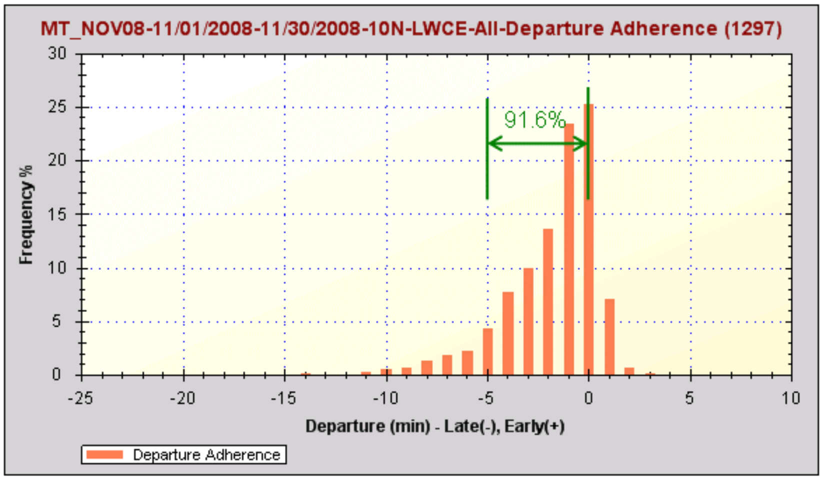


Figure 4-3 TP Schedule Adherence at LWCE NB

For example, the NB node LWCE has an On-Time Performance (OTP) of 91.6%, as plotted in Figure 4-3, when using the 5-min later and 1-min early criteria. Estimated schedule adherence at each TP is verified and compared with observed performance at listed in Table 4-9 and 4-10 for NB and SB, respectively. The average on-time performance errors between observed and simulated trips in both NB and SB are all within 1-min as listed in Table 4-9 and 4-10. The schedule adherence from the observed data, as shown in Figure 4-4 and 4-5, are general left skewed because early buses will tend to hold at TP. The modified model tends to overestimate early buses with like-normal on-time performance distribution. More comparisons of schedule adherence at each TP are listed in Appendix H.

Table 4-9 RTE 10 NB Adherence Comparisons

NB	Observed (min)		Estimated (min)		Est - Obs
Node ID	**Mean**	**Stdev**	**Mean**	**Stdev**	**(min)**
NCEUN	-1.79	1.86	-1.74	1.36	0.05
NLWCE	-1.81	2.16	-1.64	1.59	0.17
N41CE	-1.27	2.32	-2.05	2.26	-0.78
N51CE	-1.69	2.35	-1.98	2.72	-0.29
N53UV	-2.00	2.41	-1.76	3.21	0.24
N73UV	-1.87	2.41	-1.89	3.65	-0.02

Table 4-10 RTE 10 SB Adherence Comparisons

SB	Observed (min)		Estimated (min)		Est - Obs
Node ID	Mean	Stdev	Mean	Stdev	(min)
S73UV	-0.94	1.26	-0.91	1.71	0.03
S53UV	-1.17	1.42	-1.01	2.26	0.16
S51CE	-1.33	1.59	-0.76	2.65	0.57
S41CE	-1.19	1.65	-0.81	3.35	0.38
SLWCE	-1.25	1.68	-1.24	4.38	0.01
SCEUN	-0.95	2.10	-1.95	5.33	-1.00

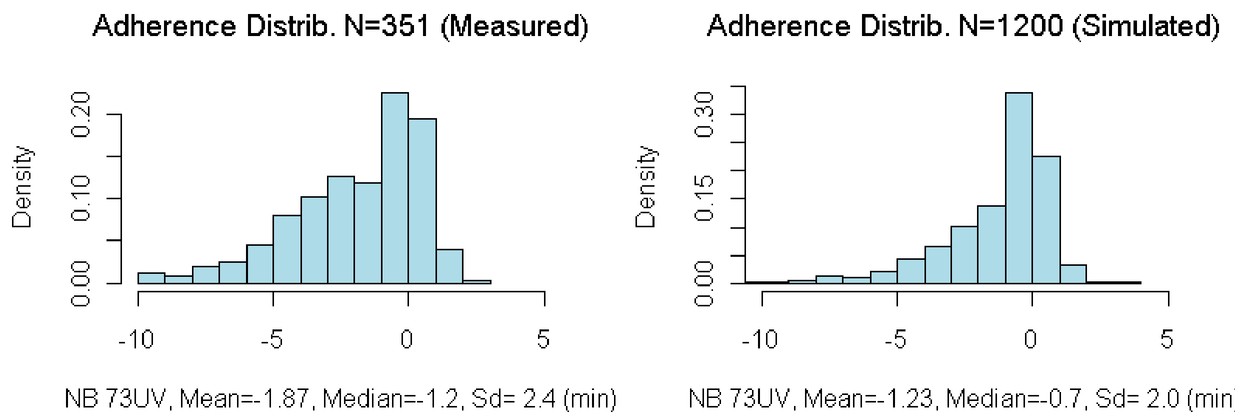


Figure 4-4 Comparisons of TP Adherence at NB 73UV

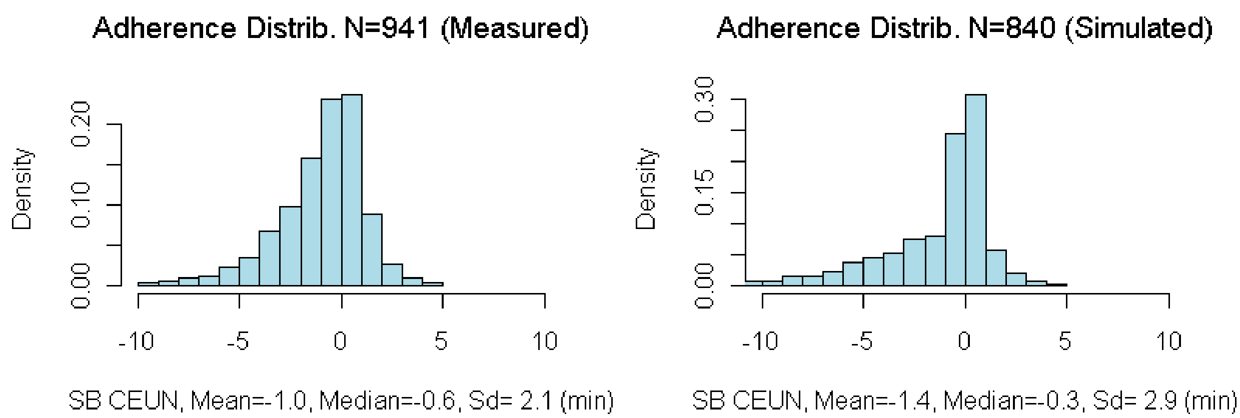


Figure 4-5 Comparisons of TP Adherence at SB CEUN

The On-Time Performance (OTP) of all datasets are compared and displayed in Figure 4-6 and 4-7 for NB and SB trips, respectively. Overall, SB trips have better OTP at LWCE, 41CE, and 51CE because they are located closer to at the beginning of SB trips. The Apr. 09 dataset has the worst schedule adherence as compared to the other datasets in these three TPs. In NB, the OTP at node 41CE dropped from 78% in Nov. 08 to 61% in Apr. 09. Similar trends are also observed at LWCE and 51CE in NB as illustrated in Figure 4-6. The OTP in Apr. 09 might be related to construction along Central Avenue in north Minneapolis. The declining OTP from Oct. 09 to Oct. 10 is caused by the 2-min running time reduction in Dec. 09 as listed in Table 1-1. As shown in Figure 2-12 and 2-13, the schedule reduction was mostly adjusted among the CEUN-LWCE and LWCE-41CE links. Lateness threshold for TSP request is reduced from 5-min to 3-min threshold by the City of Minneapolis and Metro Transit in Nov. 10. It is expected to see OTP improvement in these three TPs after Nov. 10.

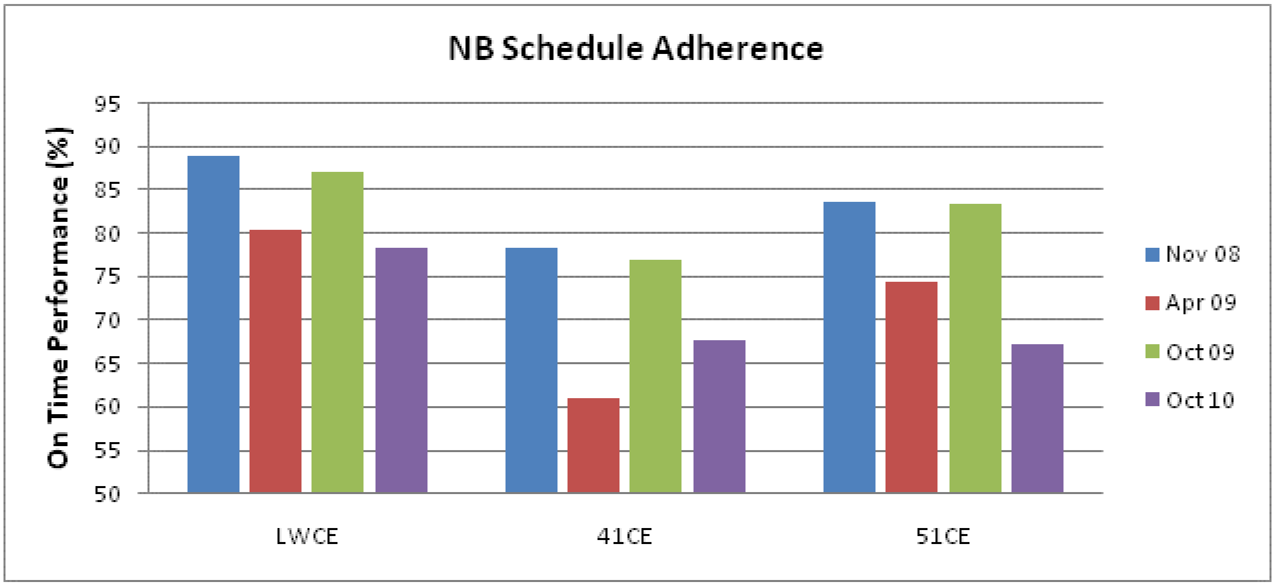


Figure 4-6 RTE10 NB On-Time Performance by Time Point

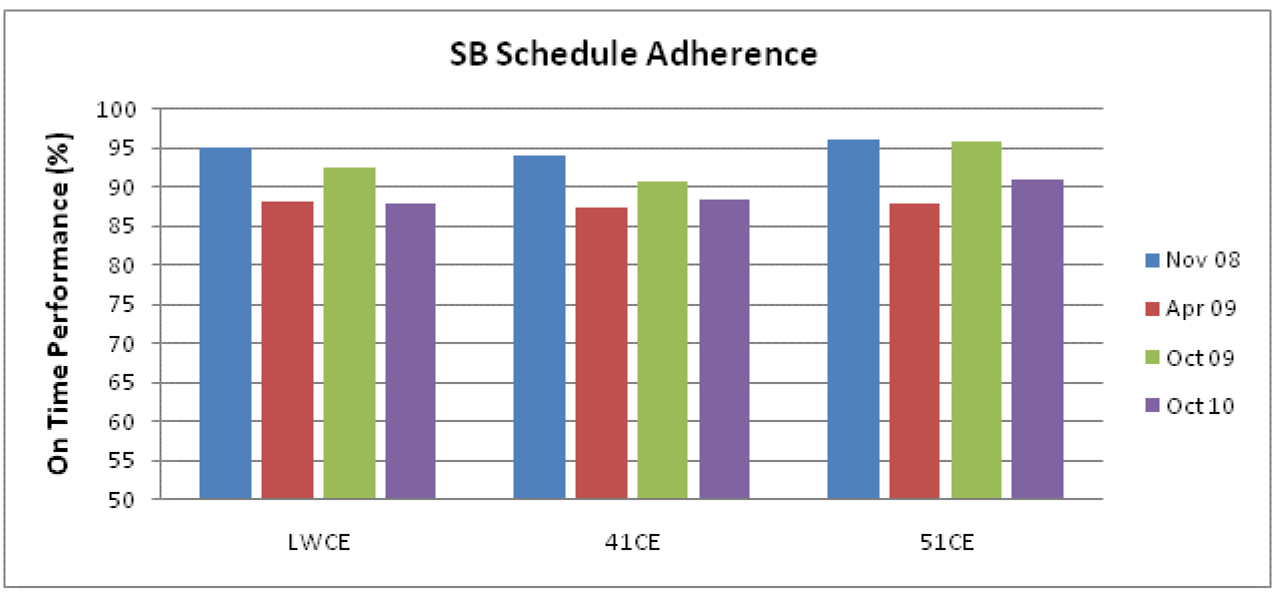


Figure 4-7 RTE10 SB On-Time Performance by Time Point

4.4 Trip Travel Time

After TP time and link TT calibration and verification, trip travel time is compared between the observed data and results from the simulation model, Table 4-11. Trip travel time distribution of NB trips between node CEUN and NOTW are plotted in Figure 4-8. The NB trips (for buses less than 5-min late) have average trip TT of 39.6 min (SD=3.7 min) as compared to 37.9 min (SD=6.0 min) of TT from the simulation model. The NB TT distribution from the trip model has large variance. Trip travel time distribution of SB trips from node NOTW to CEUN are plotted in Figure 4-9. The SB trips have average trip TT of 40.9 min (SD=3.6 min) as compared to 39.1 min (SD=5.9 min) of TT from the simulation model. The SB TT distribution from the trip model is comparable to the observed data with larger deviation.

Table 4-11 Statistics of Trip Travel Time Comparisons

Trip Travel Time	Observed (min)		Estimated (min)	
CEUN - NOTW	Mean	Stdev	Mean	Stdev
NB	39.60	3.70	37.9	6.0
SB	40.90	3.60	39.1	5.9

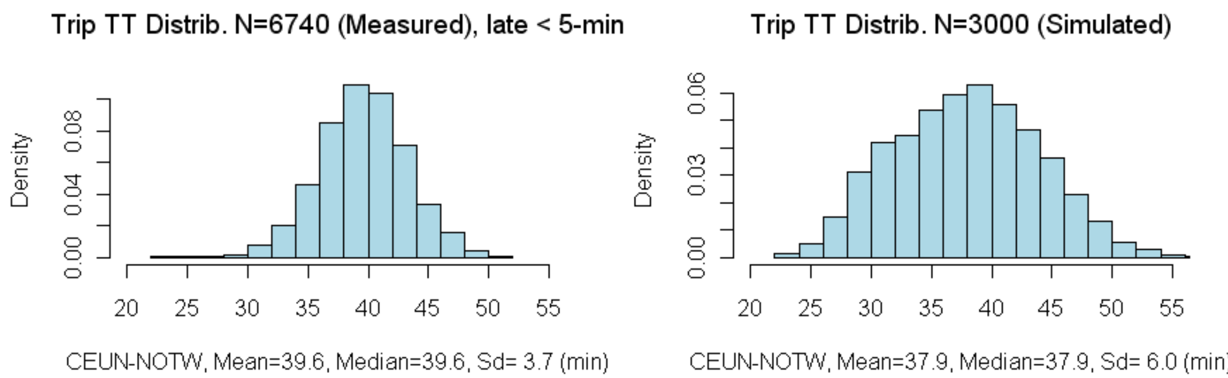


Figure 4-8 RTE 10 NB Trip Travel Time Comparisons

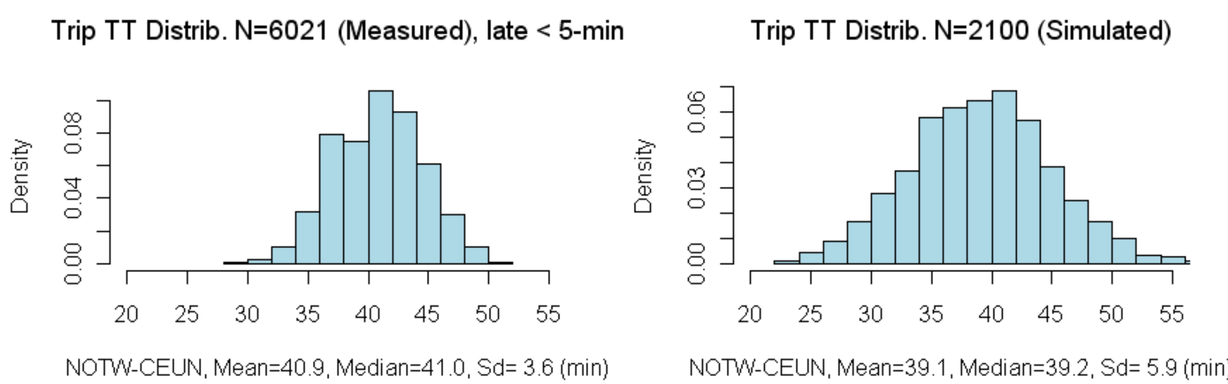


Figure 4-9 RTE 10 SB Trip Travel Time Comparisons

4.5 Local vs. Limited Stop Service

Link segments between node CEUN and 51CE, where route 10 and 829 overlaps, are studied. Route 829 was a limited stop service on Central Avenue. It was later replaced by route 59 in 2010. As illustrated in Figure 4-10, blue and crimson bars represent the observed average travel time of RTE 10 and 829 processed from the AVL/APC dataset between timepoint CEUN and 51CE for both directions. Green bars are the simulated mean trip travel time from the calibrated trip model after 480 simulation runs. Within this route segment, the RTE10 model slightly overestimates travel time in SB and underestimates travel time in NB. Statistics of the observed versus the simulated trip travel time for both routes are listed in Table 4-12.

In order to simulate the limited stop service of RTE 829, number of stops between TPs from the calibrated RTE 10 model was reduced accordingly using the list in Table 4-13. In addition, estimated travel time of RTE 829 is computed by assuming that 2/3 of riders will go to upstream and downstream stops, respectively and the other 1/3 will choose other mode or different route. Simulated mean travel time of RTE 829 is plotted in purple bars as shown in Figure 4-10.

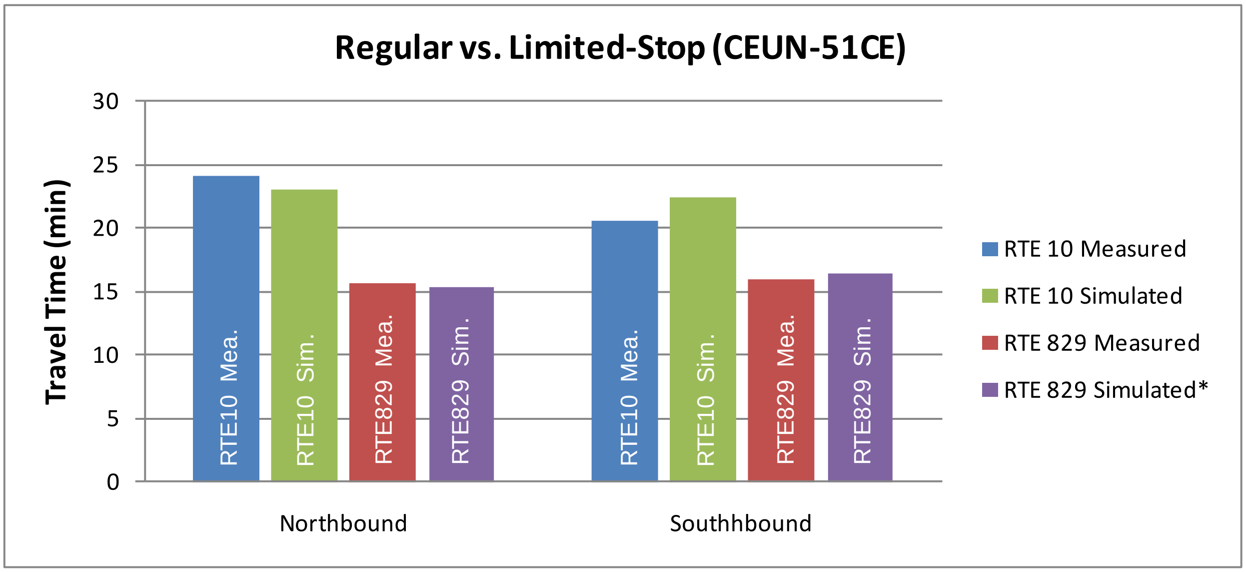


Figure 4-10 Trip Travel Time Comparison of RET10 (Regular) vs. RTE 829 (Limited Stop)

Table 4-12 Statistics of Measured vs. Simulated Travel Time of RTE 10 and 829

Travel Time		RTE 10			RTE 829		
Trip	Data Type	Mean	SD	N	Mean	SD	N
Northbound CEUN-51CE	Measured	24.07	3.94	438	15.61	2.04	20
	Simulated	23.00	2.20	480	15.30	1.21	480
Southbound 51CE-CEUN	Measured	20.61	2.82	871	15.93	2.21	13
	Simulated	22.40	1.50	336	16.37	1.17	336

Table 4-13 Number of Stops between Time Points (RTE 10 vs. RTE 829)

Northbound	Number of Stops		Southbound	Number of Stops	
	RTE 829	RTE 10		RTE 829	RTE 10
CEUN-LWCE	1	12	LWCE-CEUN	0	10
LWCE-41CE	3	13	41CE-LWCE	3	10
41CE-51CE	1	9	51CE-41CE	1	9

4.6 Impact of Signal Priority

In 2009 and 2010, Transit Signal Priority (TSP) was instrumented on Metro Transit buses and installed at all signalized intersections between node CEUN and 51CE along the Central Avenue. The four separate months of dataset covers the implementation and operation periods of TSP. Travel time distributions are plotted in Figure 4-11. Scheduled versus observed travel time statistics for each dataset in both directions are listed in Table 4-14. In NB, the observed trip travel time in Oct. 10 is reduced by 6% as compared to the travel time in Nov. 08 when the scheduled travel time reduced by 13% as listed in Table 4-15. In SB, the observed trip travel time in Oct. 10 is reduced by 4% as compared to the travel time in Nov. 08 when the scheduled travel time reduced by 5%. Lateness threshold for TSP request is reduced from 5-min to 3-min threshold by the City of Minneapolis and Metro Transit in Nov. 10. It is expected to see further travel time improvement after Nov. 10.

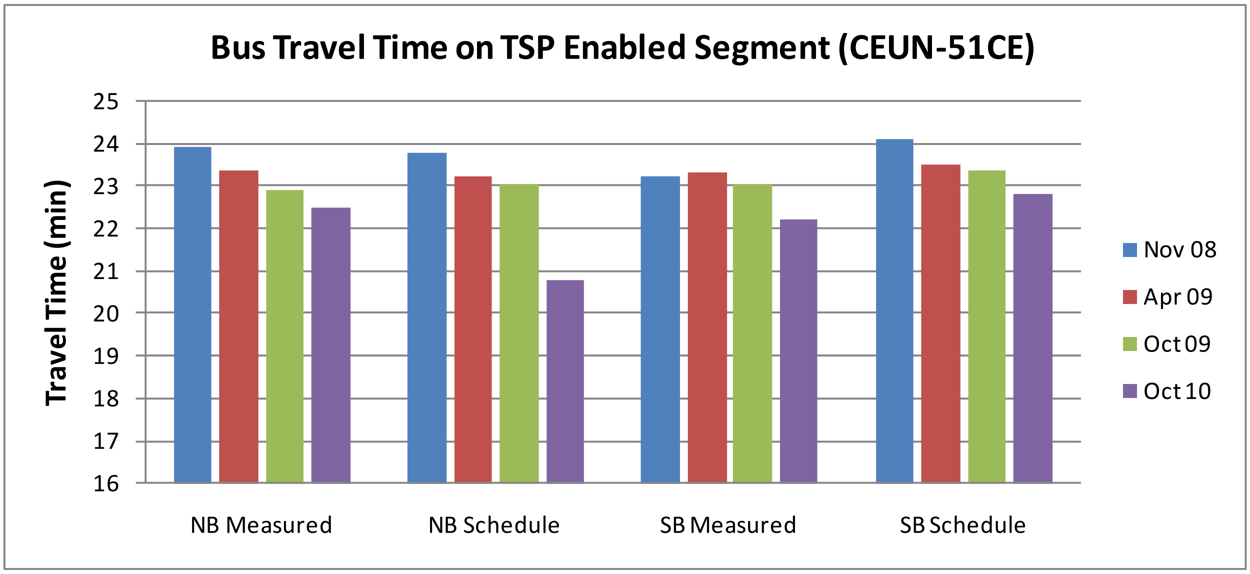


Figure 4-11 Trip Travel Time Comparisons on TSP Enabled Links

Table 4-14 Travel Time Statistics of TSP Enabled Links

Trip Travel Time		Nov 08		Apr 09		Oct 09		Oct 10	
Trip	**Data Type**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**
Northbound CEUN-51CE	**Measured**	23.90	3.18	23.38	4.02	22.92	3.08	22.48	4.13
	Schedule	23.79	2.03	23.24	1.77	23.06	1.88	20.79	1.95
Southbound 51CE-CEUN	**Measured**	23.25	3.34	23.34	3.81	23.04	2.59	22.24	2.58
	Schedule	24.11	2.05	23.50	1.76	23.38	1.85	22.80	1.98

Table 4-15 RTE10 Travel Time Reduction

TT Reduction (Oct 10 - Nov 08)/Nov 08		
Northbound CEUN-51CE	**Measured**	**-6%**
	Schedule	**-13%**
Southbound 51CE-CEUN	**Measured**	**-4%**
	Schedule	**-5%**

5 SIMULATION TOOL

A web-based simulation tool was developed based on the TP time and link travel time models discussed in previous sections. This application allows transit planner to experiment different scenario and evaluate the potential impact of transit strategies. For example, to evaluate the travel time impact of different mixture of fare payment type, stop consolidation or converting local to limited stop service.

5.1 Web-based Java Application

A trip time model of route 10 is developed using the Java technology. The simulation and data analysis interfaces are illustrated in Figure 5-1 and 5-2, respectively. The simulated can be visualized at TP, link, or route level.

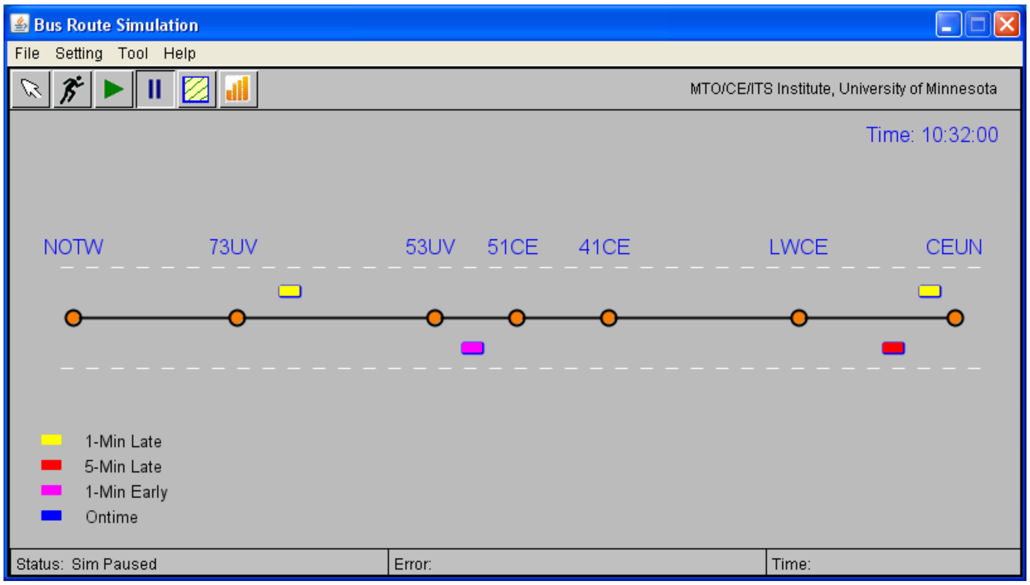


Figure 5-1 Route Simulation Model (GUI)

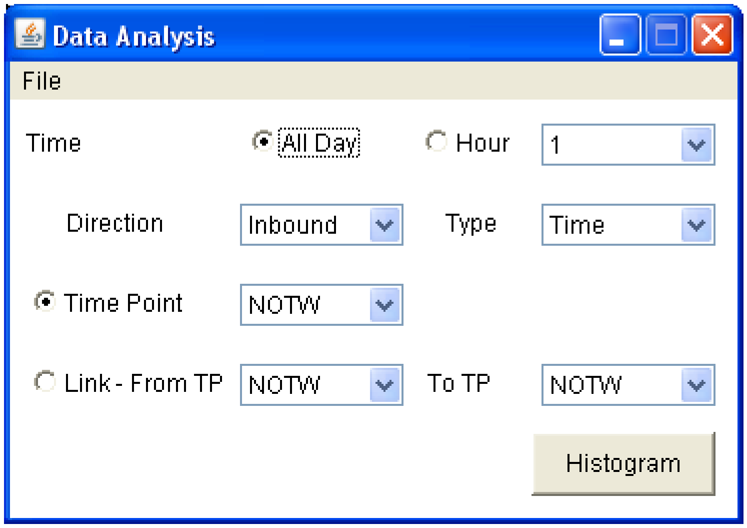


Figure 5-2 Simulation and Data Analysis Interface

5.2 Simulation Results

Simulation results can be visualized through the simulation user's interface. A sample NB TP time distribution of node LWCE has a mean TP time of 1 min as shown in Figure 5-3. Figure 5-4 illustrates the simulated versus observed on-time performance of node 51CE in SB direction. The measured on-time performance is left skewed. Simulated resulted is normally distributed. Distribution of link travel time from 53UV to 73UV is plotted in Figure 5-5. The observed link travel time has wider distribution than the simulated. The time-space diagram of a simulated NB trip is plotted in Figure 5-6.

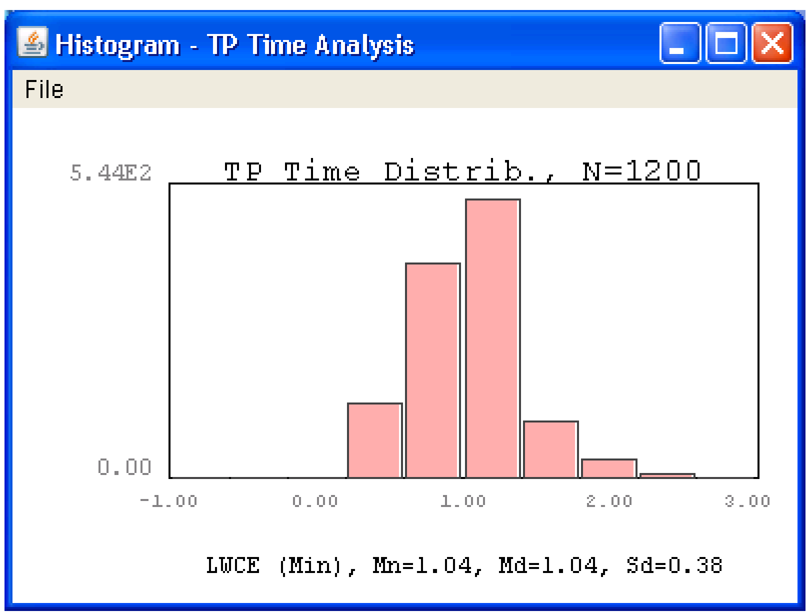


Figure 5-3 TP Time Distribution – NB LWCE

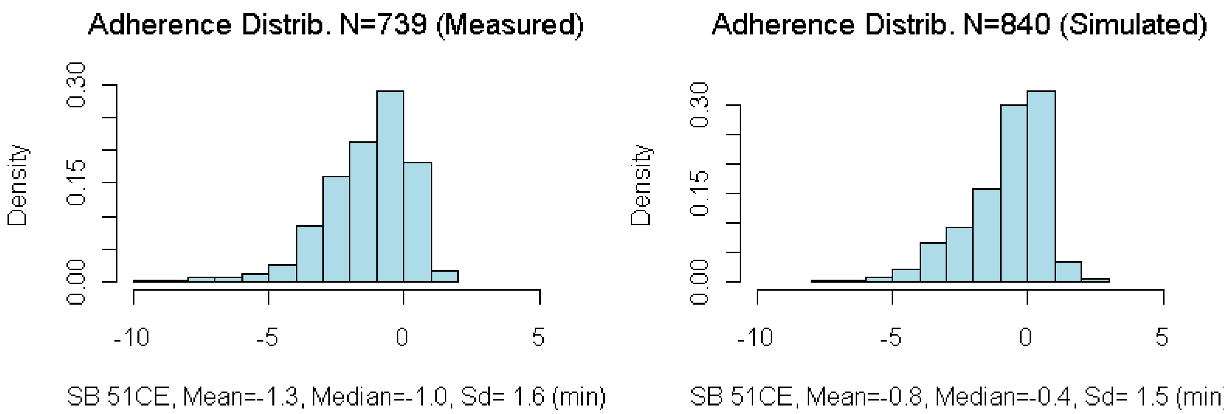


Figure 5-4 Comparisons of On-Time Performance – SB 51CE

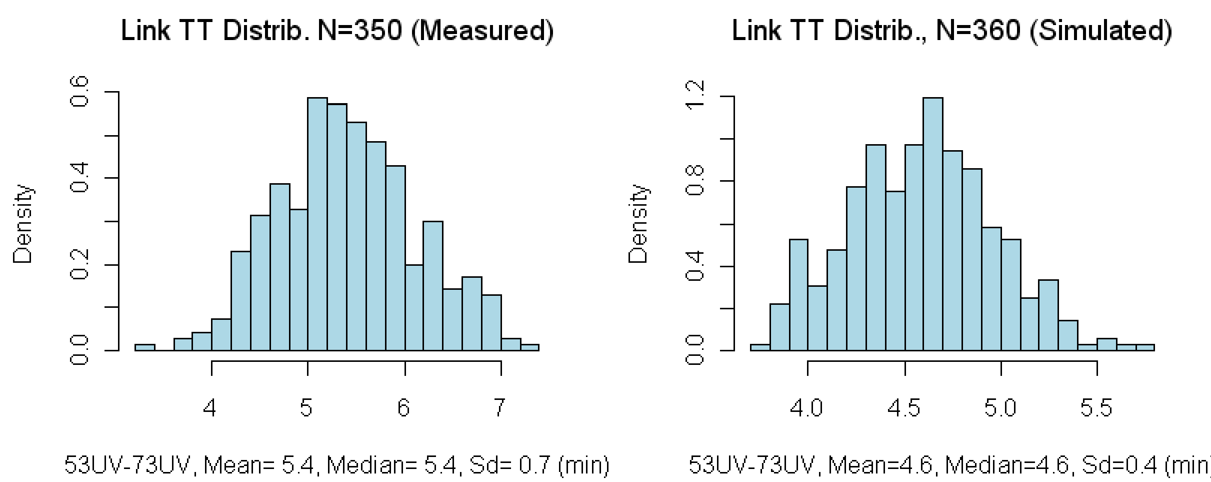


Figure 5-5 Measured vs. Simulated Link Travel Time (53UV-73UV)

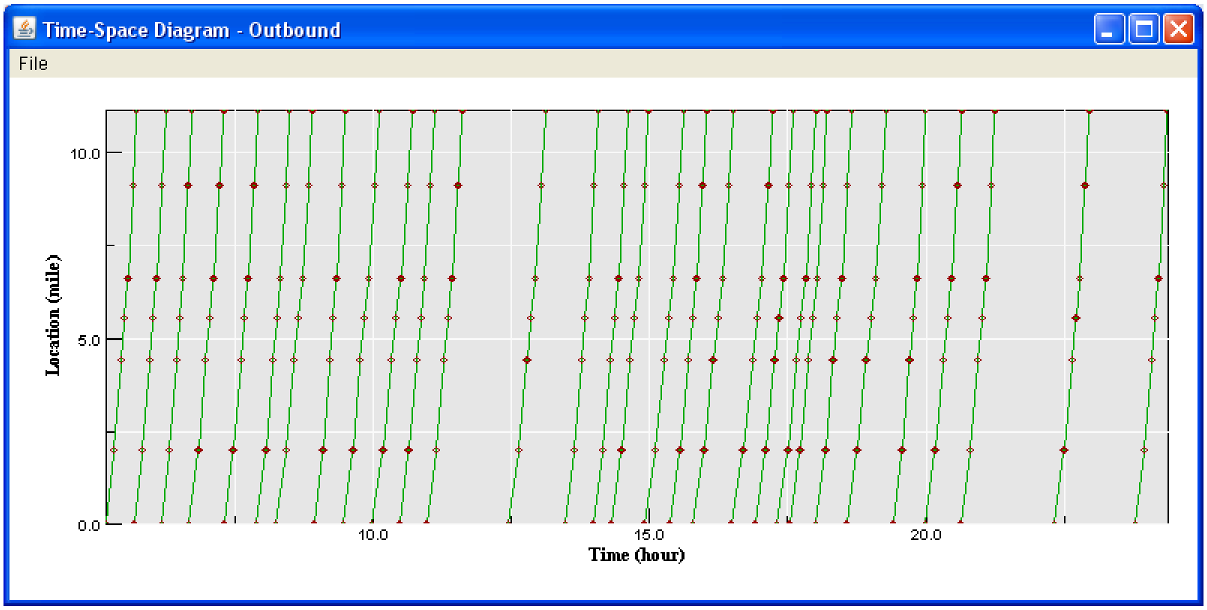


Figure 5-6 Time-Space Diagram of a Simulated NB trip

6 SUMMARY AND DISCUSSION

We have developed a transit data analysis methodology to process AVL/APC and AFC data systematically. A SQL-based database server was configured and setup to host transit data and to process data through SQL scripts. A data processing framework presents opportunities in assisting transit agencies to evaluate the performance of transit network systematically and to develop robust and effective operating plans. A route travel time model, including TP time model and link travel time model, were developed using the outputs from the transit data processing framework previously developed. The route-based transit simulation model can support Metro Transit in evaluating different schedule plans, stop consolidations, and other strategies. The transit model provides an opportunity to predict and forecast the impact of service changes in planning phase.

In 2010, Metro Transit initiated a study on 11 local bus routes (as listed in Table 6-1) to upgrade current operation to Bus Rapid Transit (BRT) or equivalent services as another way to improve ridership and quality of service. The developed route model can be a useful supportive tool for planner to evaluate the impact of trip travel time with regard to different transit strategies. As part of our future work, we would like to investigate the transferability of the model to other urban local routes, study the impact of wheelchair lift events and investigate transit rider's Origin to Destination (OD) pattern as well as travel behavior.

Table 6-1 Arterial Corridors under Evaluation for Bus Rapid Transit (from Metro Transit)

1. Central Avenue I-694/Columbia Heights to Downtown Minneapolis	**7. East 7th Street** Maplewood Mall to Downtown St. Paul
2. West Broadway Robinsdale Transit Center to Downtown Minneapolis	**8. West 7th Street** Mall of America to Downtown St. Paul
3. Chicago Avenue Mall of America to Downtown Minneapolis	**9. Snelling Avenue** Hiawatha 46th St. Station to Rosedale Mall
4. Hennepin Avenue West Lake Station to Downtown Minneapolis	**10. Robert Street** Mendota Road to Downtown St. Paul
5. American Boulevard Mall of America to Normandale Lakes / SW Station	**11. Nicollet Avenue** American Blvd to Downtown Minneapolis
6. Lake Street Uptown to Downtown St. Paul	

A comment from Metro Transit concerning that this TP-based trip model does not include wheelchair lift events. Wheelchair deployment usually adds substantial time to bus trip time thus makes transit planning and scheduling department difficult to determine appropriate schedule for running time. Deployment time of each wheelchair lift varies and could take several minutes. The statistics of RTE 10 wheelchair deployments for the four months of the dataset are listed in

Table 6-2. Over 50% of the wheelchair lifts occurred within the CBD area (8SNI, 7SNI, 3SNI, MA2S and 1S2A). Outside the CBD, most of wheelchair lift events occurred at TP CEUN and LWCE. Figure 6-1 illustrates the September pick of 2010 wheelchair lift data by TP. In the 2010 September pick dataset from Metro Transit, 420 wheelchair lift events (39%) occurred at timepoint 7SNI. There were 117 (11%) lift cycles at LWCE and 247 (23%) lift cycles at NOTW, respectively. Figure 6-2 displays the wheelchair lift cycle distribution of 6 key TPs by time of day. There is no specific pattern of the lift use. However, most of the lift cycles occurred between 10 AM and 5 PM. At TP 41CE, over 30% of the wheelchair lifts occurred at 10 AM. Similarly, at TP 51CE, 30% of the lifts occurred at 5AM. It is possible that wheelchair riders regularly take the RTE 10 bus from these TPs to downtown (e.g. TP 7SNI) for work.

One possible solution is to model the wheelchair events and include the lift use model in the TP based trip model. However, the wheelchair lift events were recorded when the lift cycle was completed. Duration of a wheelchair lift is not currently available from the ADCS.

Table 6-2 RTE10 Wheelchair Lift Statistics

Timepoint	Nov. 08		Apr. 09		Oct. 09		Oct. 10	
Name	Count	%	Count	%	Count	%	Count	%
8SNI	20	10.5%	37	15.1%	19	7.2%	18	5.1%
7SNI	57	30.0%	54	22.0%	48	18.3%	165	46.6%
3SNI	13	6.8%	7	2.9%	54	20.5%	21	5.9%
MA2S	6	3.2%	6	2.4%	11	4.2%	13	3.7%
1S2A	1	0.5%	2	0.8%	18	6.8%	16	4.5%
CEUN	47	24.7%	61	24.9%	80	30.4%	24	6.8%
LWCE	21	11.1%	34	13.9%	13	4.9%	51	14.4%
41CE	9	4.7%	16	6.5%	8	3.0%	21	5.9%
51CE	13	6.8%	22	9.0%	2	0.8%	15	4.2%
53UV	2	1.1%	1	0.4%	1	0.4%	3	0.8%
OSMN	1	0.5%	5	2.0%	9	3.4%	7	2.0%
Total	190	100%	245	100%	263	100%	354	100%

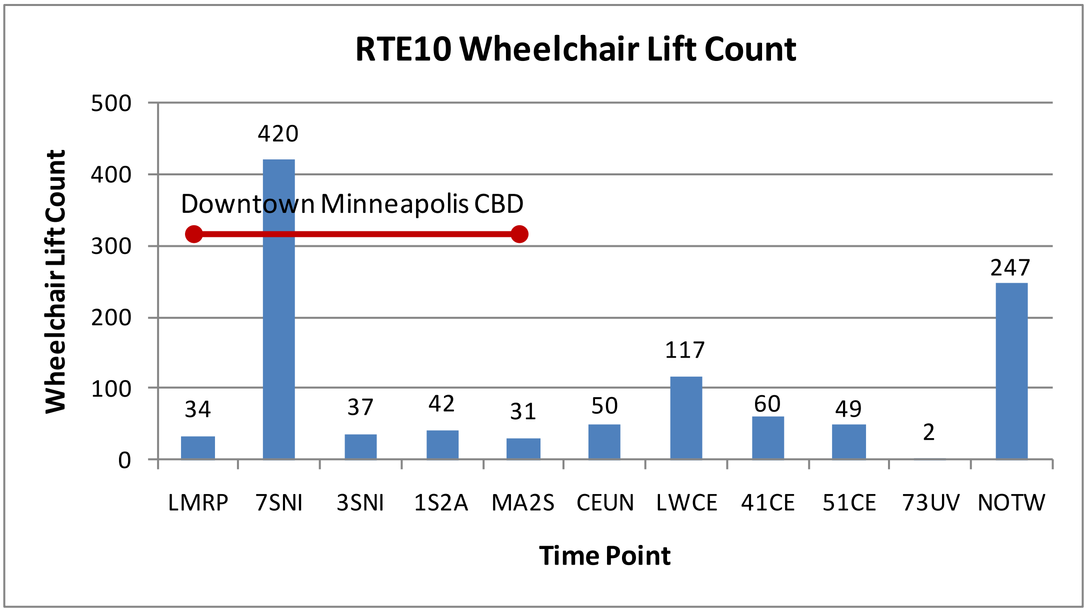


Figure 6-1 RTE10 Wheelchair Lift Counts by TP (Data Source: Metro Transit, 2010 September Pick)

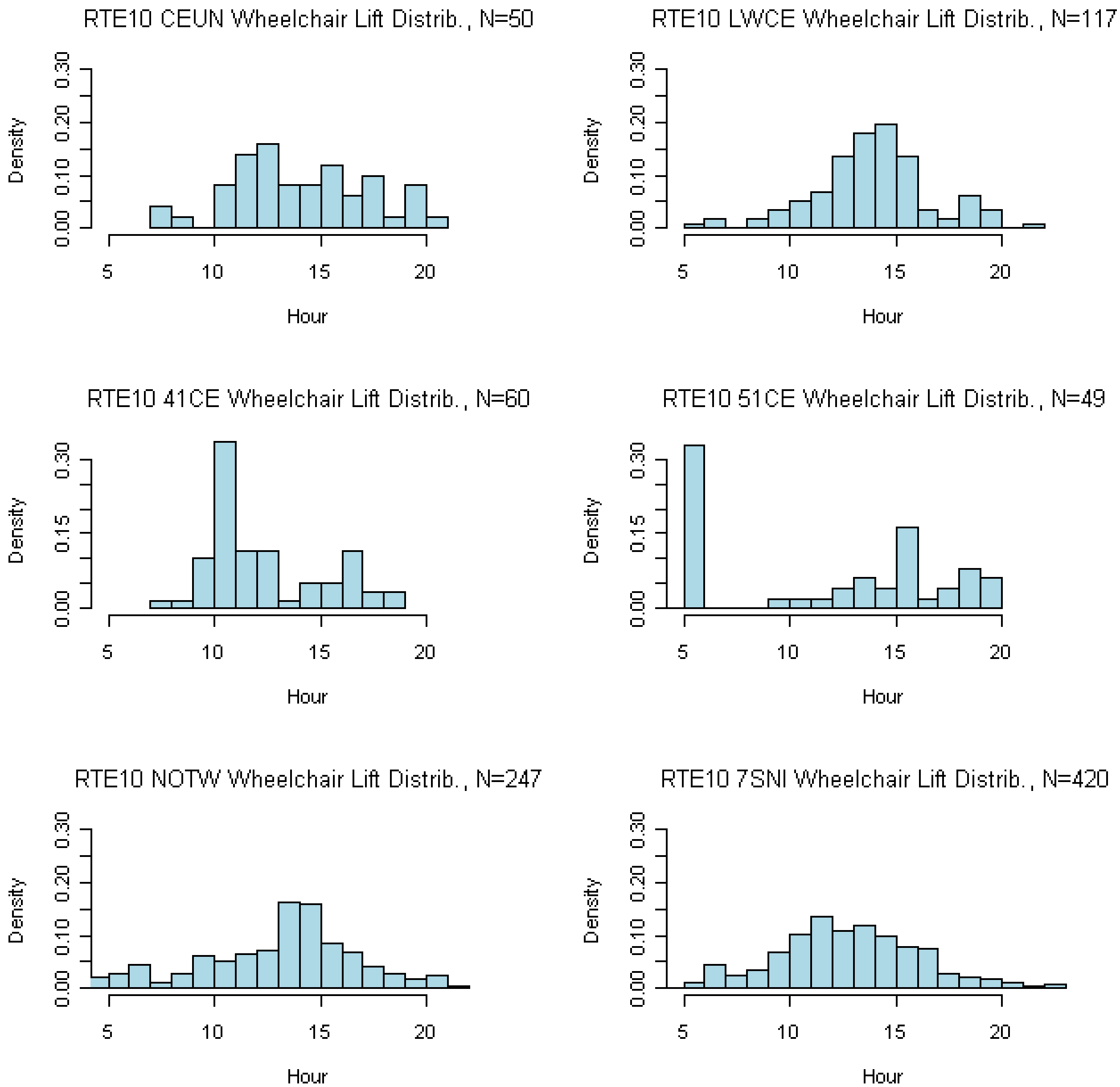


Figure 6-2 RTE10 Wheelchair Lift Counts of TP by Time of Day (Data Source: Metro Transit, 2010 September Pick)

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APPENDIX A: DATA ANALYSIS FLOWCHART AND PROCEDURES

A.1 Analysis Flowchart

The data processing and analysis flowchart is illustrated in Figure A-1.The upper three blocks are the functions implemented in the transit performance analyst application. The modeling and simulation blocks are implemented in the trip model simulation application.

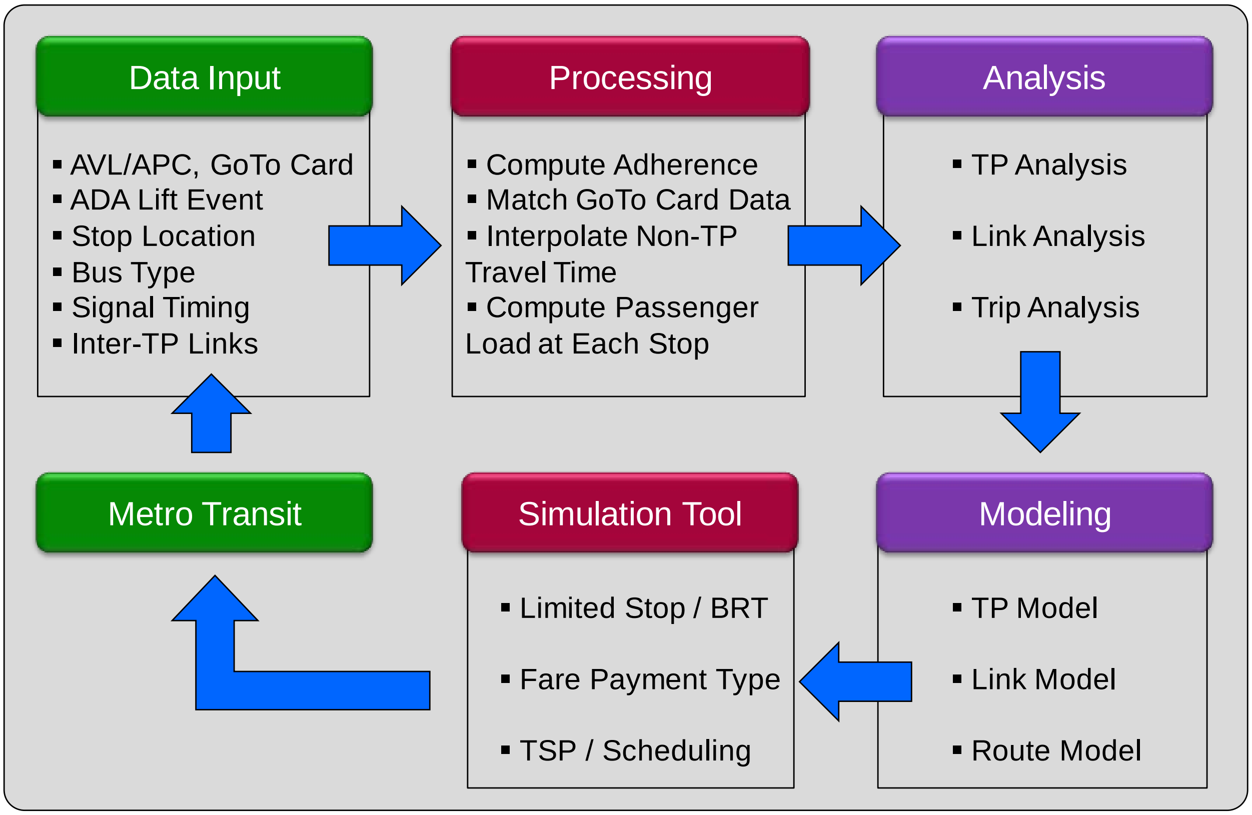


Figure A-1 Data Processing and Analysis Flowchart

A.2 Timepoint Analysis

- Load AVL/APC (MS Access Db format) & lift_cycle_event (csv) to RTE10_APR09 & RTE10_OCT09 DB
- Load CUBIC data (csv) to RTE10_APR09 or RTE10_OCT09 DB
- Name APC data in MSSQL as t_APC_POC
- Name cubic data in MSSQL as CUBIC_DATA_XXX_XX
- Name lift event data to Lift_Cycle_Events
- Load/import stop_location table from MTNov08 DB
- Load/import sites_2009 table from MTNov08 DB
- Load/import 'buses' table from MTNov08 DB
- Load/import 'RTE10_Cycle_Split_Vol_byHr' table from MTNov08 DB
- Load/import 'RTE_10_TP_links_intx' table from MTNov08 DB

- Check for missing node_id in the t_apc_poc data. recover node_id by locateing site_id and reassign node_id accordingly

Under ~RTE10\ dir
- Run 'create_tp_adherence_table_with_vehid_lift' sql script
- Run 'create_cubic_matched_table' script to create 'cubic_matched' table in AFC_RTE10_APR09 DB
- Run 'create_stop_time_table' script

*** Change VB program DB connection to RTE10_APR_09 or RTE10_OCT_09, VB program
- Change mySQlConnection, mySQlConnection1, mySQlConnection2 DB pointed to 'RTE10_Apr09' or 'RTE10_Oct10' correspondingly, 4 places including 3 SQLconnections & sub 'btn_AFC_lat_long_Click'

- Click 'Interpolate Non-TP Stop Time' to generate stop_time table, results in stop_time table

- Click 'Match AFC' button (modify VB code if necessary) from ***BusAnalysis*** project, results stored in cubic_matched table

- Run 'RTE10_stop_sequence_by_trip_w_gotocard' sql script to compute pass_load
- Export data to CSV file and compute pass_load based on board, alight column
- Save file to RTE10_Aprxx_load.csv or RTE10_Octxx_load.csv

- Add the following header to the RTE10_xxx_load.csv file
line_id,service_id,veh_id,calendar_id,time_bracket_start,block_number,trip_number,node_id,site_id,line_direction,sched_time,act_arr_at_tp,act_dep_at_tp,stop_sequence_number,board,alight,AFC_cnt,pass_load

- Import RTE10_APR09_Load to RTE10_APR09 DB, or RTE10_OCT09_Load to RTE10_OCT09 DB, respectively

- Run 'RET10_parameters_late_afc_1min_early_no_lift_signal' script for all nodes w/ signal only, (OR run 'RET10_get_dwell_parameters_late_afc_1min_early_no_lift' script for all stops w/o signal)

- Export data for analysis

A.3 Link Travel Time Analysis

- Run 'create_tp2tp_travel_time_table' script to create tp2tp_travel_time table

- Modify path in VB program (BusAnalysis->frmMain->Button_Link_Travel_Time) to reflect desired file output directory

- Click 'modeling' button from 'Transit Performance analysis 2009-2010' VB application by choosing line_ID and direction from the drop-down menu

- Import output files, RTE_10N_LinkTT_WK_afc.csv, RTE_10S_LinkTT_WK_afc.csv, to SQL DB

- Run 'link_intx_join.sql' script to join intersection info to new table (saved to) RTE_10N_LinkTT_WK_afc_intx.csv, or RTE_10S_LinkTT_WK_afc_intx.csv

- Open xx.csv (e.g. RTE_10N_LinkTT_WK_afc_intx.csv) file and replace 'NULL' with '0' add 'no_activity' (board=0 & alight=0), 'alight_only' and 'dir_North' columns from Excel speadsheet functions

- Run 'trip_TT_NB.sql', 'trip_TT_SB.sql'

- Copy folder C:\Chenfu\Transit_Data\APC_AVL_data_Rte10\Oct10_Processed to H drive then to M6400 PC

- Use 'RET10_parameters_late_buses_afc_1min_early_no_lift_node.csv' file to prepare 'RET10_parameters_late_buses_afc_1min_early_no_lift_node_procXLS.xls' file with 2 tabs (dwell_para & dwell_estimates)

- Perform analysis on M6400 PC using the R code under C:\Chenfu\Henry_Liu\UMN CTS bus project\Data\RTE10\R_code

APPENDIX B: TP TIME AND LINK TRAVEL TIME

B.1 Timepoint Time Statistics and Comparisons (Nov. 08)

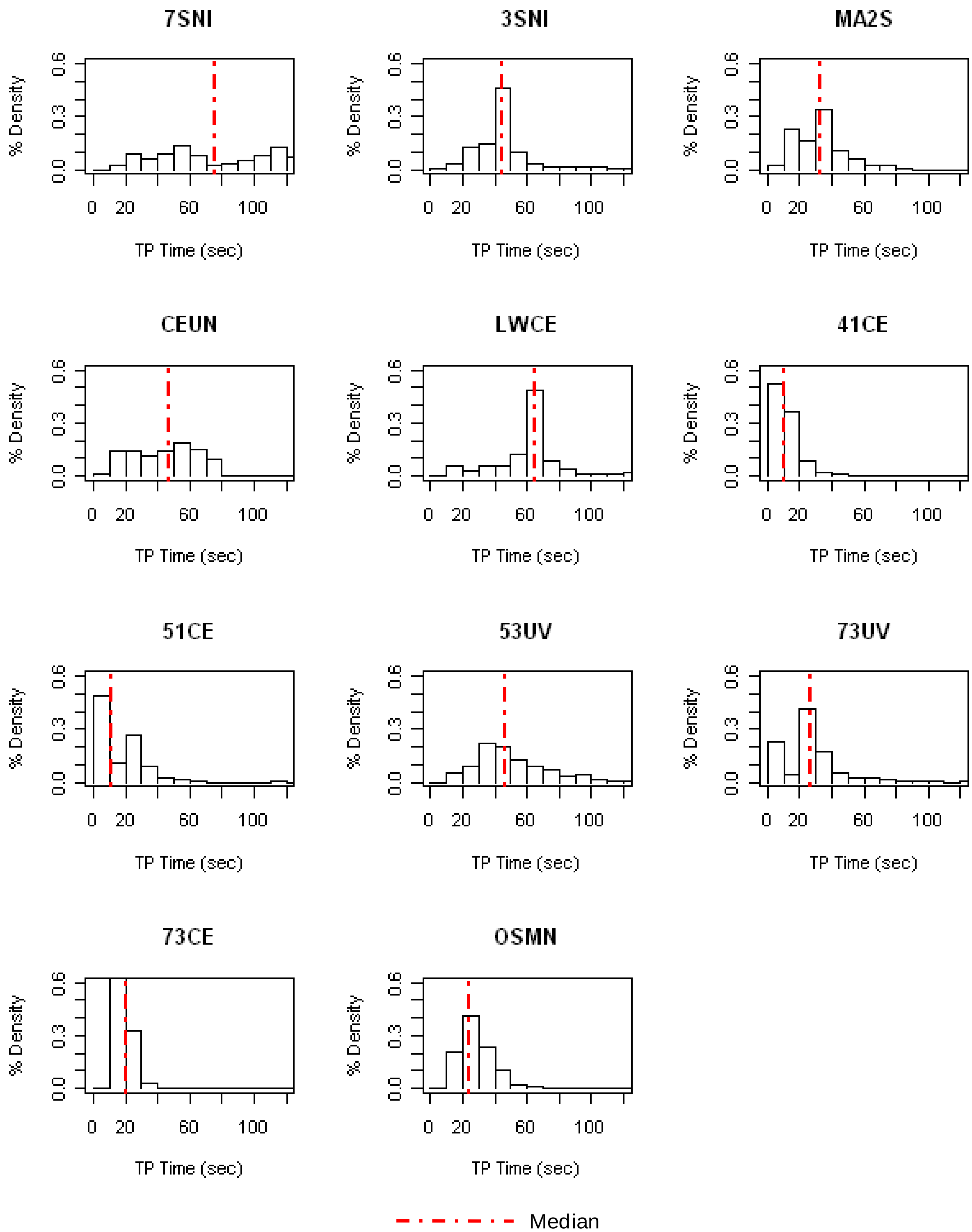


Figure B-1 Route 10 NB Timepoint Time Distribution (Exclude Terminal TP & Lift Event)

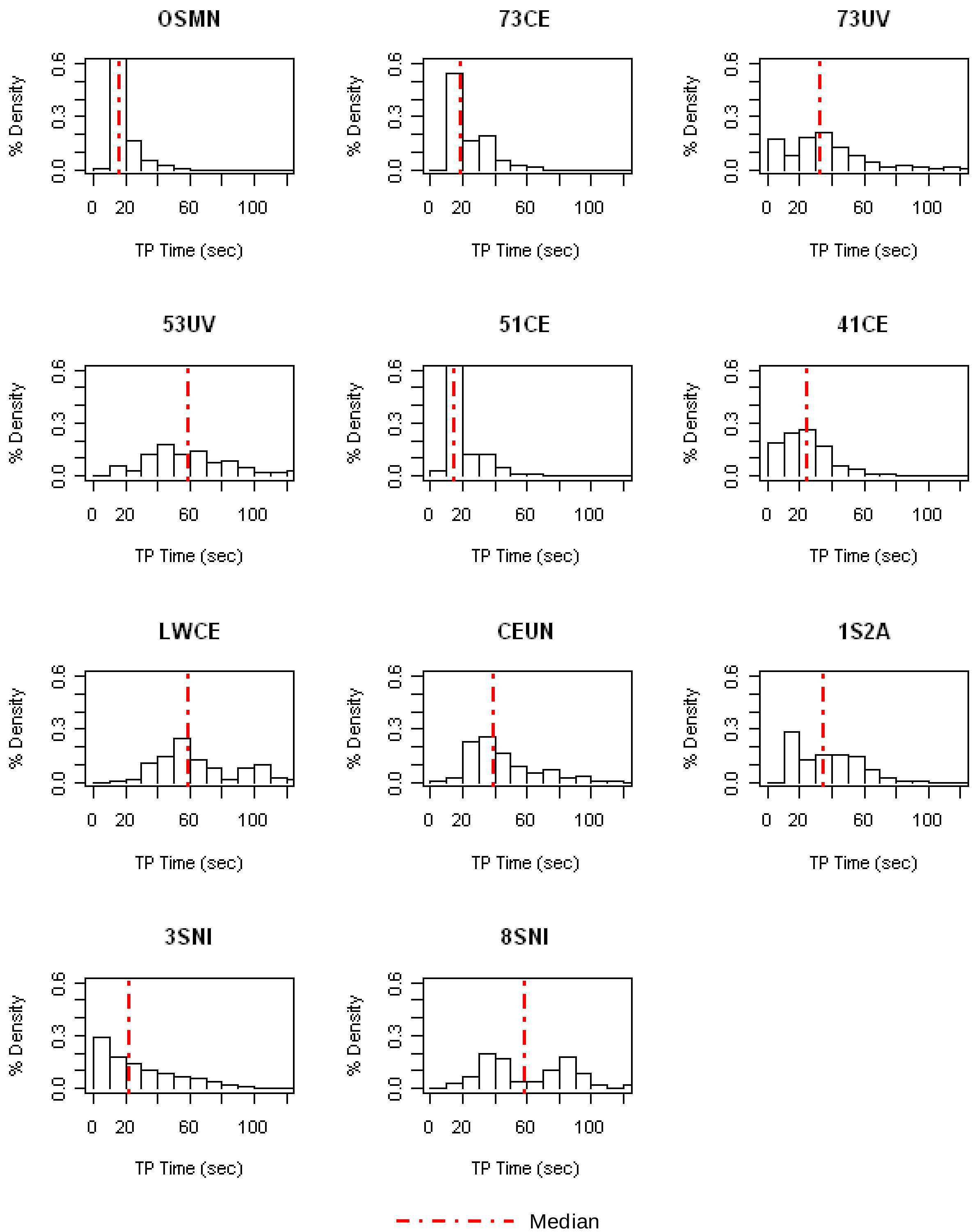


Figure B-2 Route 10 SB Timepoint Time Distribution (Exclude Terminal TP & Lift Event)

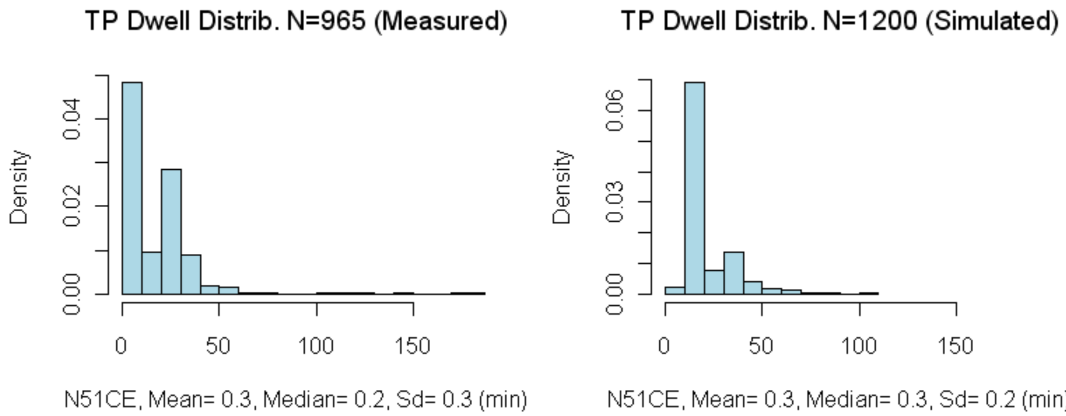


Figure B-3 Measured vs. Simulated TP Time (NB-51CE)

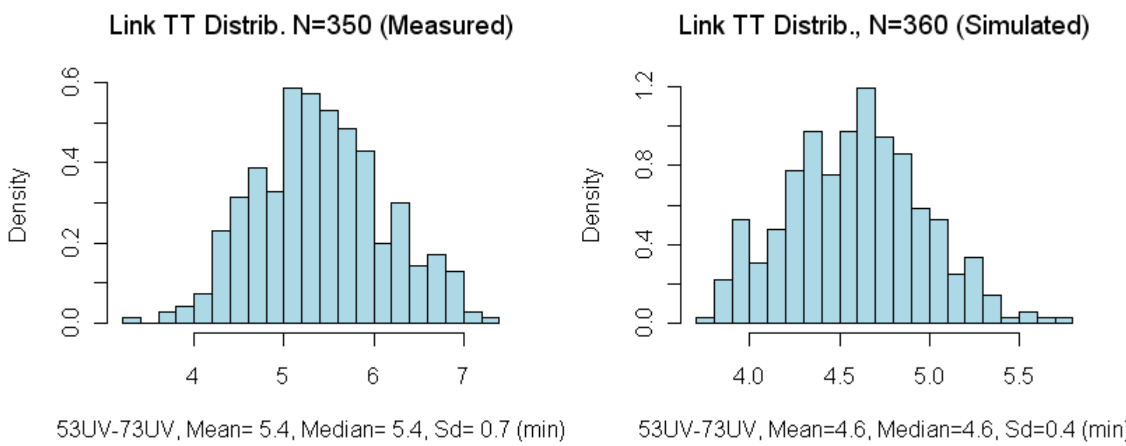


Figure B-4 Measured vs. Simulated Link Travel Time (53UV-73UV)

B.2 Timepoint Time by Activity (Nov. 08 dataset)

B.2.1 Local Buses Arriving Late at Near-Side – TP Time by Activity (All Routes)

Local Late Nearside, Board=NULL and Alight=NULL for dwell time <= 5 min

Total Late NS Null Count (dwell<= 5 min) = 35,544, Mean = 25.2, Median = 19, STDEV = 20.0

Total Late NS NOT Null Count (dwell<= 5 min) = 49,089

Minimum { Median(0,1), Median(1,0) } - Median (NULL) = 37 – 19 = 18 sec

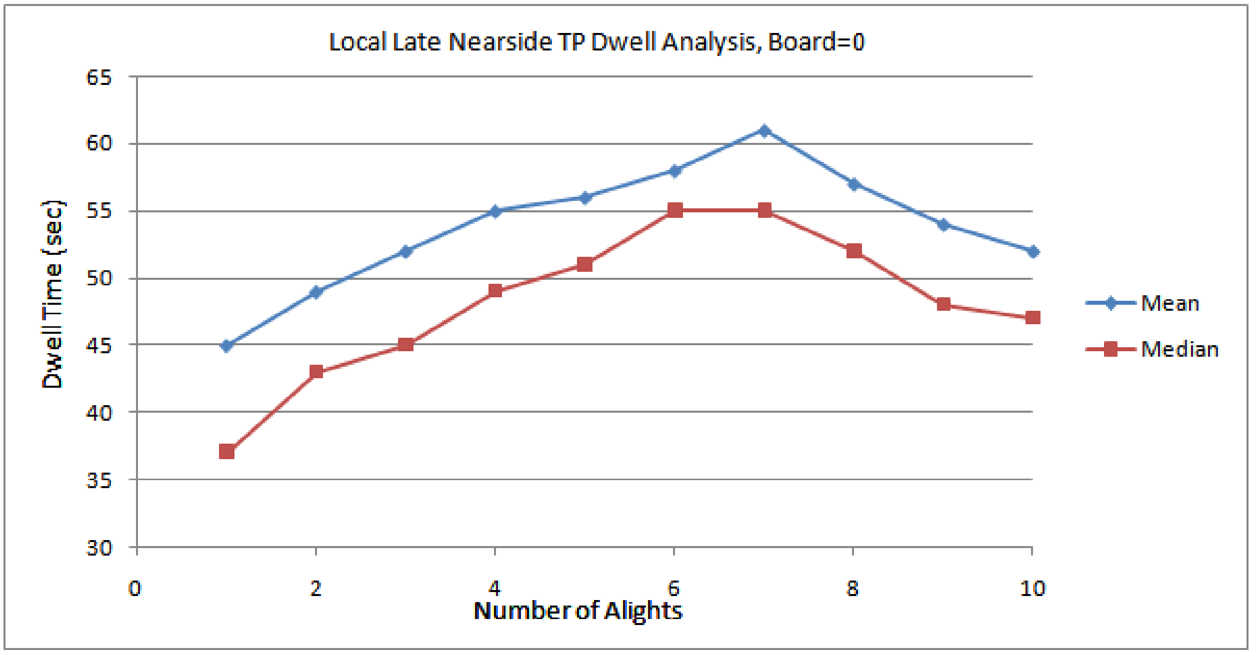


Figure B-5 Alight Only TP Time (Late Arrival at Nearside)

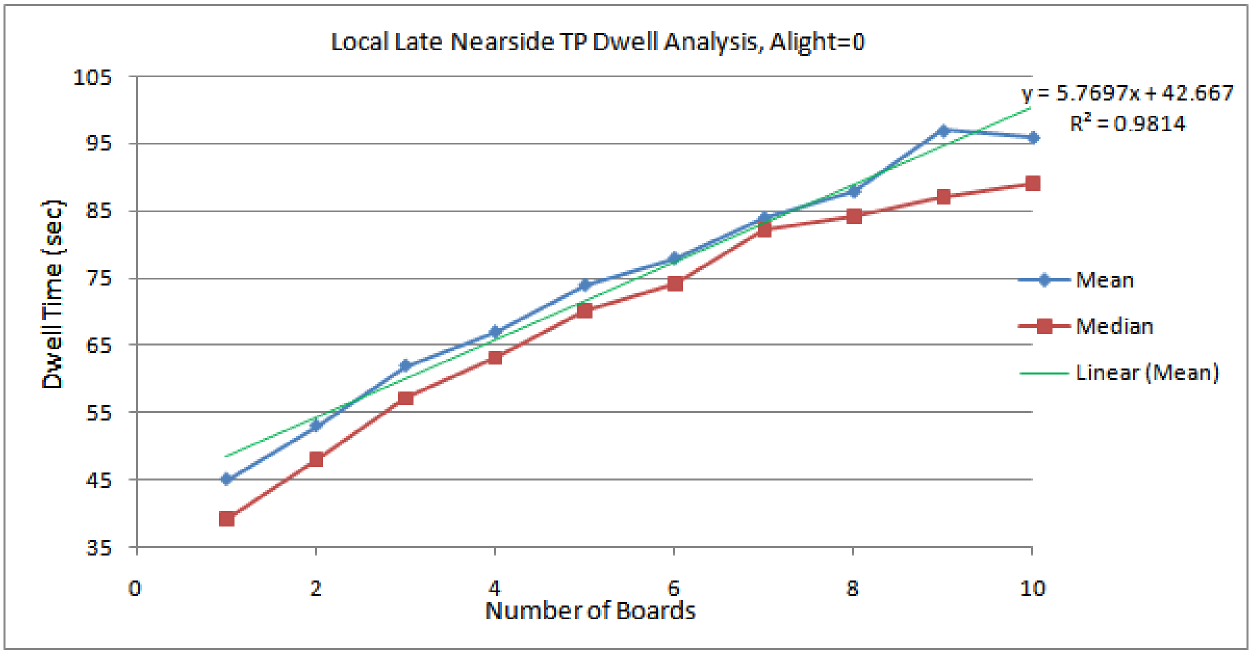


Figure B-6 Board Only TP Time (Late Arrival at Nearside)

B.2.2 Local Buses Arriving Late at Far-Side - TP Time by Activity (All Routes),

Local Late Far-side, Board=NULL and Alight=NULL for dwell time <= 5 min
Total Late FS Null Count (dwell<=5 min) = 15,590, Mean = 18.6, Median = 13, STDEV = 16.0
Total Late FS NOT Null Count (dwell<= 5 min) = 20,956
Minimum { Median(0,1), Median(1,0) } - Median (NULL) = 31 – 13 = 18 sec

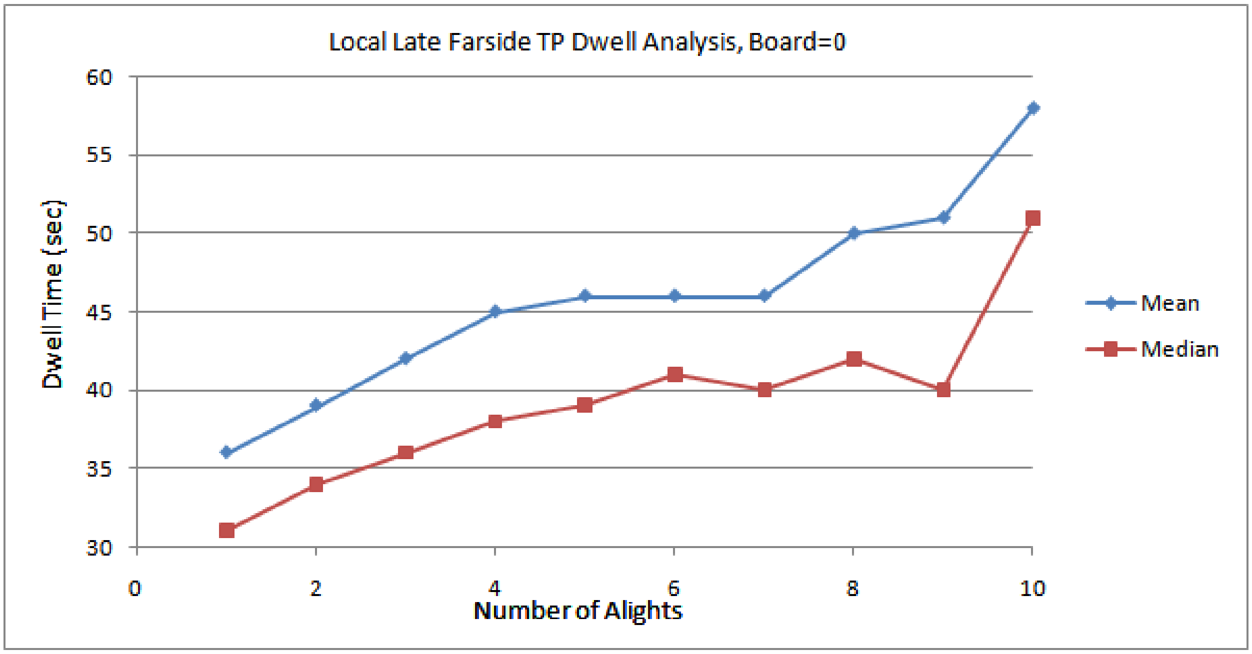


Figure B-7 Alight Only TP Time (Late Arrival at Farside)

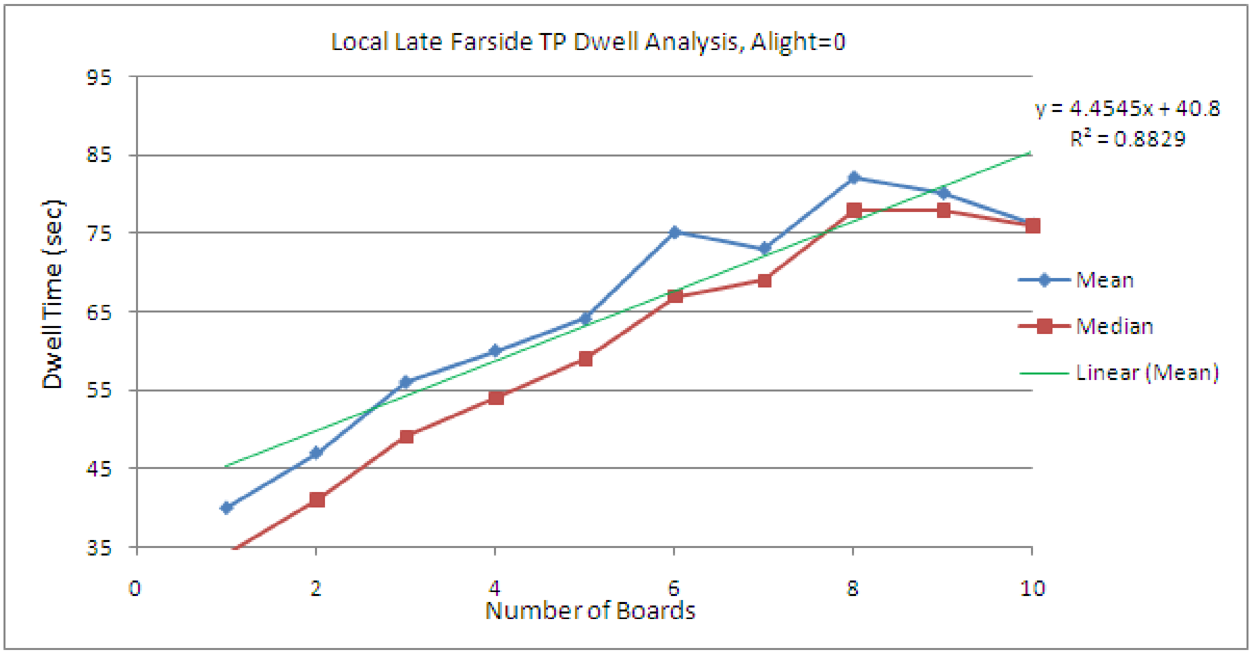


Figure B-8 Board Only TP Time (Late Arrival at Farside)

B.2.3 Local Buses Arriving Early at Near-Side - Dwell Time by Activity (All Routes),

Local Early Nearside, Board=NULL and Alight=NULL for dwell time <= 5 min
Total Early NS Null Count (dwell<= 5 min) = 23,845, Mean = 46.5, Median = 34, STDEV = 39.9
Total Early NS NOT Null Count (dwell <= 5 min) = 36,150
Minimum { Median(0,1), Median(1,0) } - Median (NULL) = 54 – 34 = 20 sec

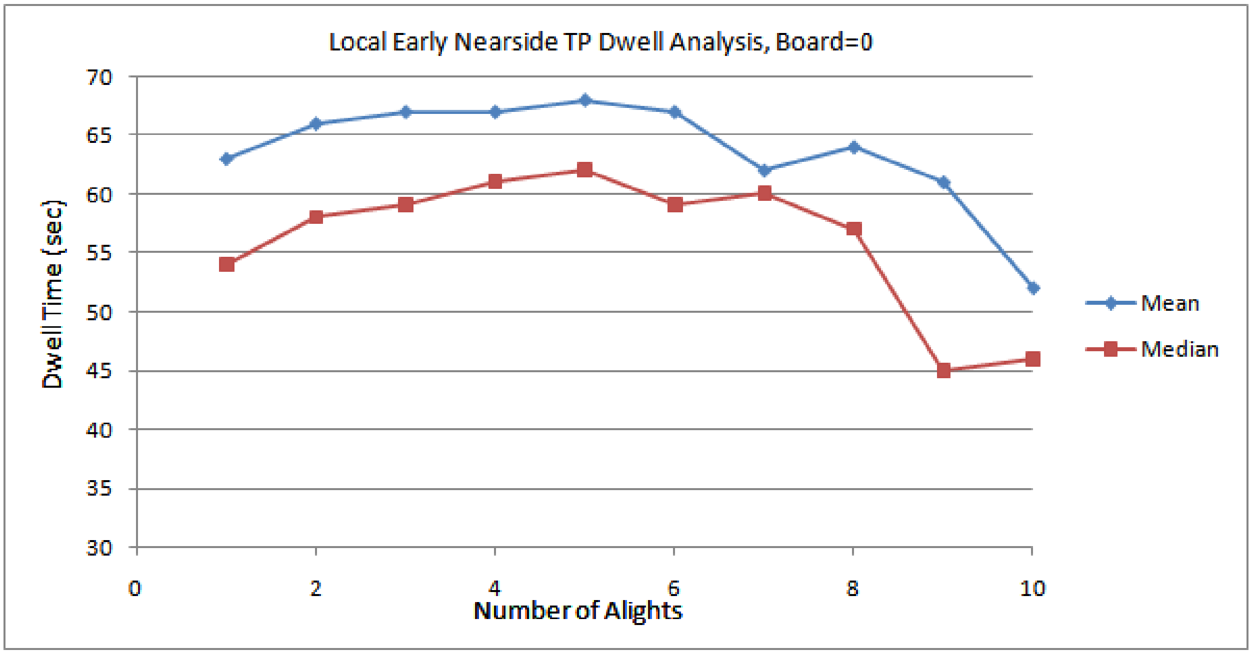


Figure B-9 Alight Only TP Time (Early Arrival at Nearside)

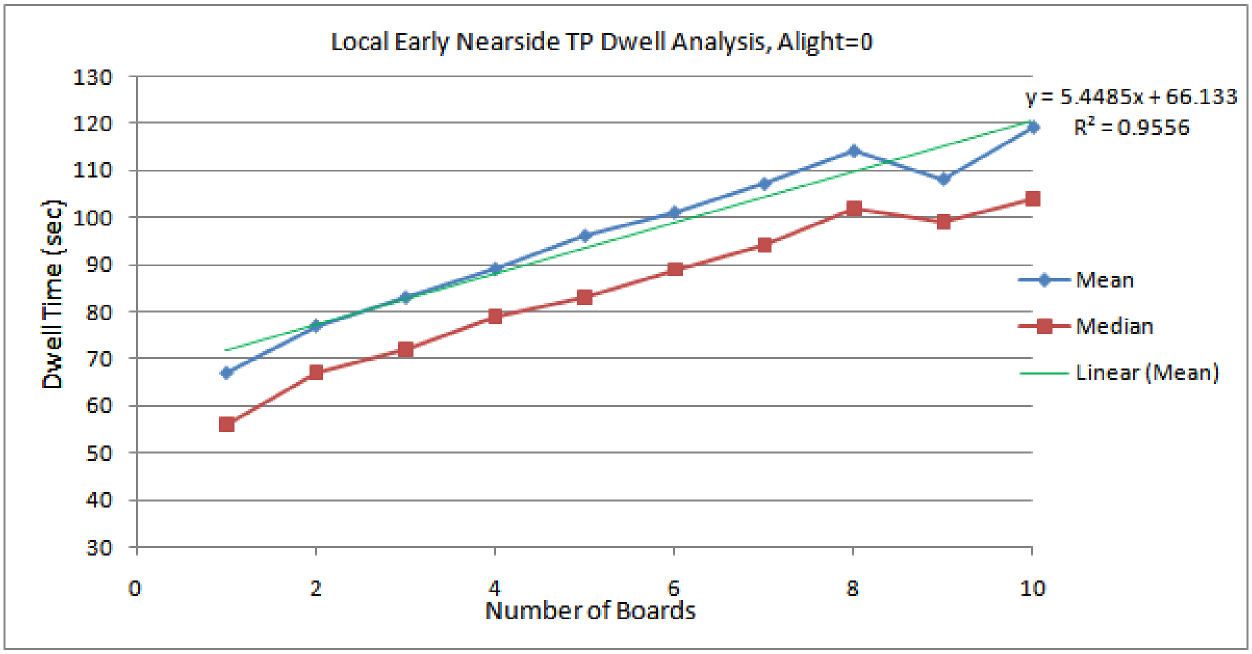


Figure B-10 Board Only TP Time (Early Arrival at Nearside)

B.2.4 Local Buses Arriving Early at Far-Side - Dwell Time by Activity (All Routes),

Local Early Far-side, Board=NULL and Alight=NULL for dwell time <= 5 min

Total Early FS Null Count (dwell<=5 min) =7,442, Mean = 37.8, Median = 23, STDEV = 35.0

Total Early FS NOT Null Count (dwell<= 5 min) = 12,875

Minimum { Median(0,1), Median(1,0) } - Median (NULL) = 40 – 23 = 17 sec

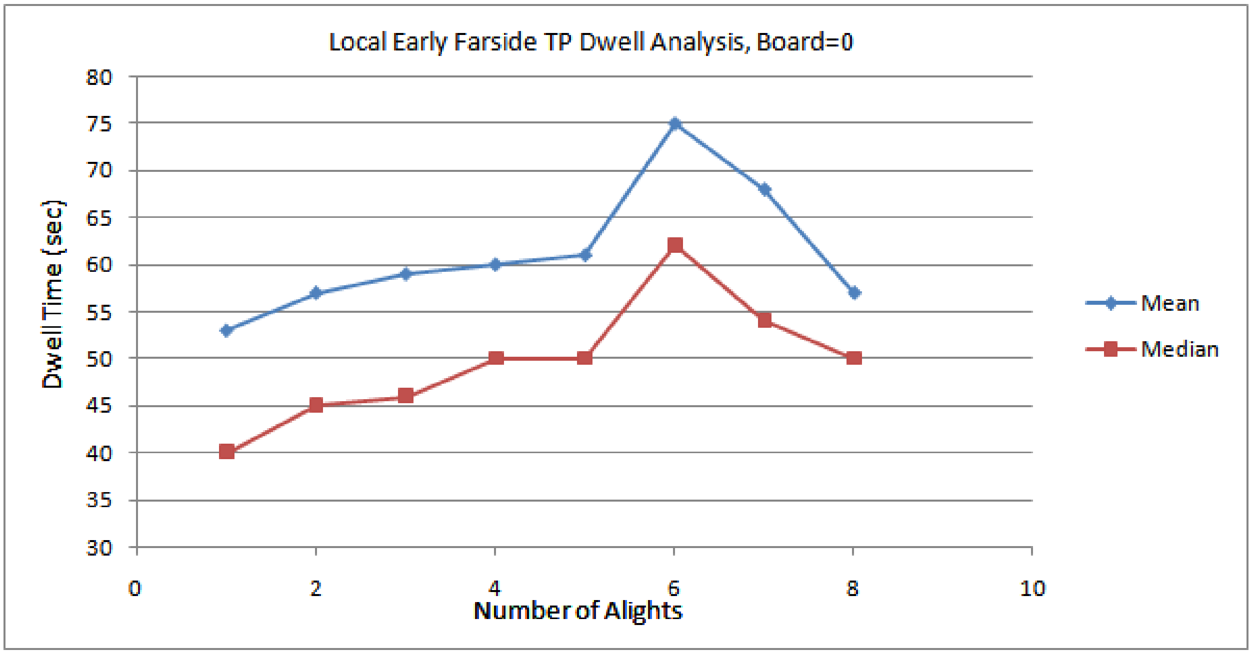


Figure B-11 Alight Only TP Time (Early Arrival at Farside)

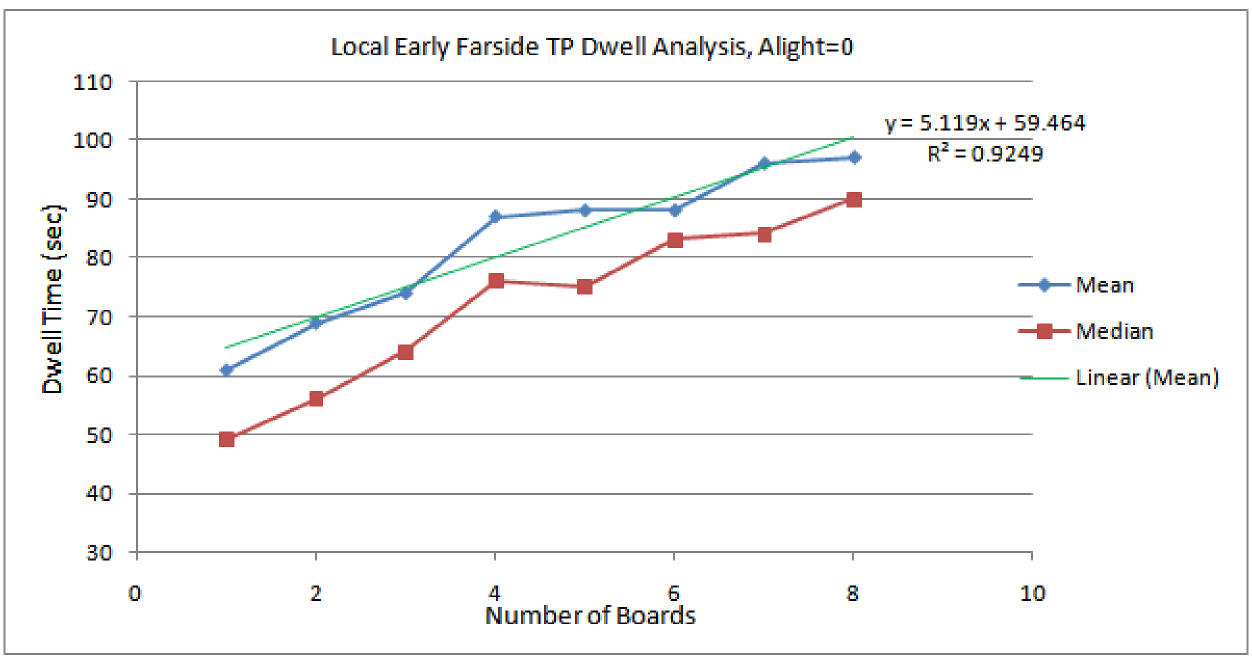
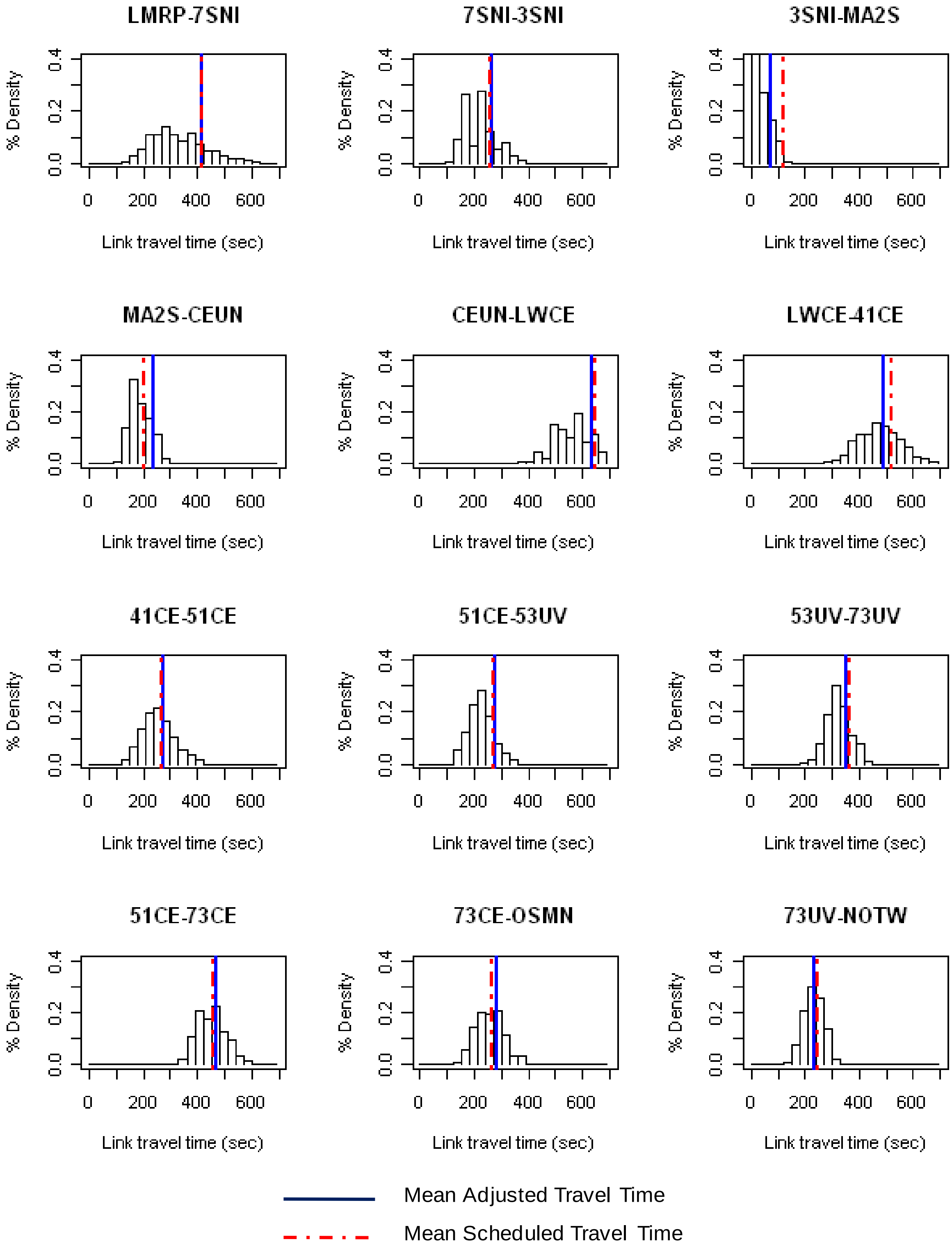


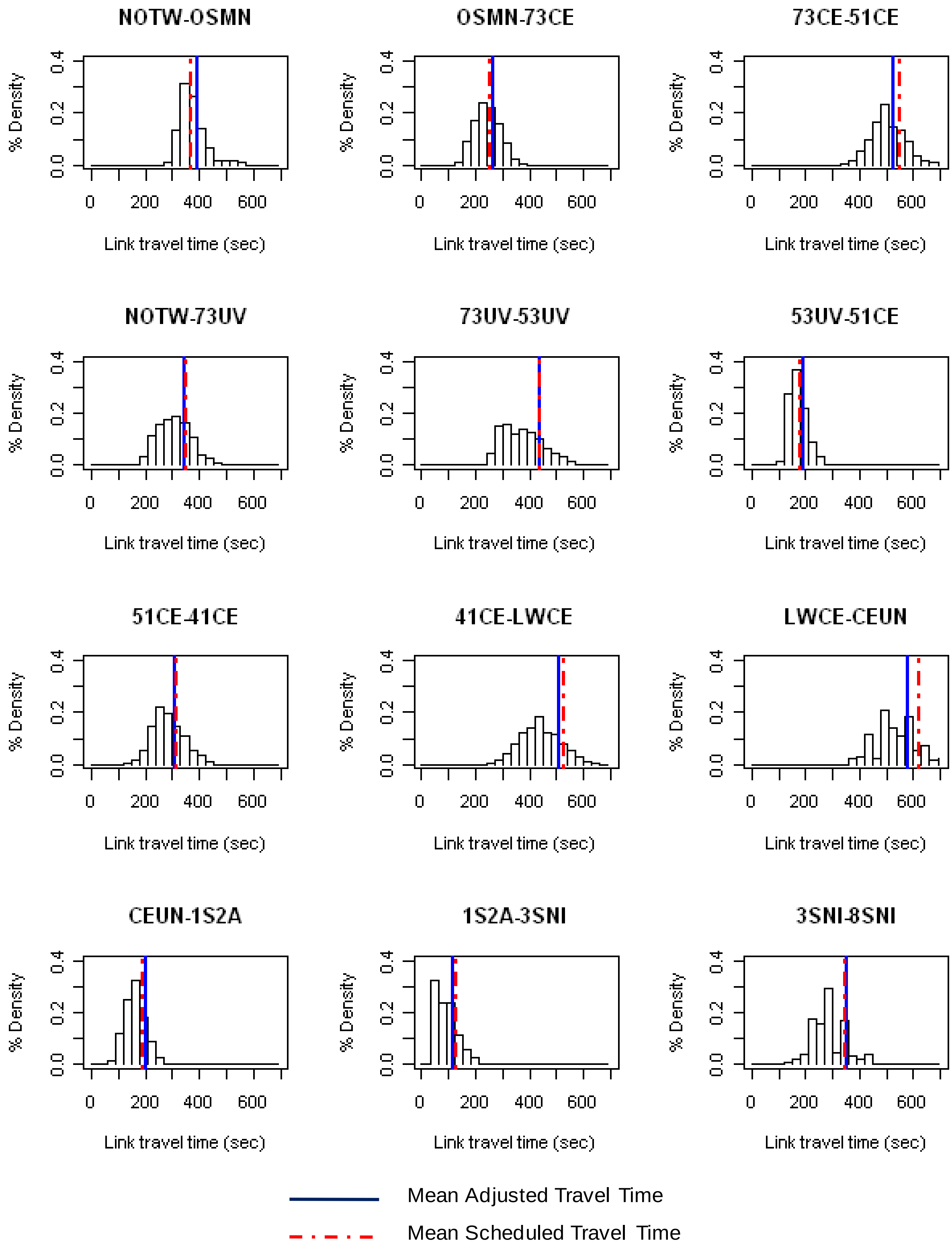
Figure B-12 Board Only TP Time (Early Arrival at Farside)

B.3 Link Travel Time Statistics (Nov. 08)



Note: Adjusted Link Travel Time = Actual Travel (Mean) + Destination TP Time (Mean of late/on-time buses)

Figure B-13 Route 10 NB Link Travel Time Distribution



Note: Adjusted Link Travel Time = Actual Travel (Mean) + Destination TP Time (Mean of late/on-time buses)

Figure B-14 Route 10 SB Link Travel Time Distribution

B.4 Link Travel Time Comparisons

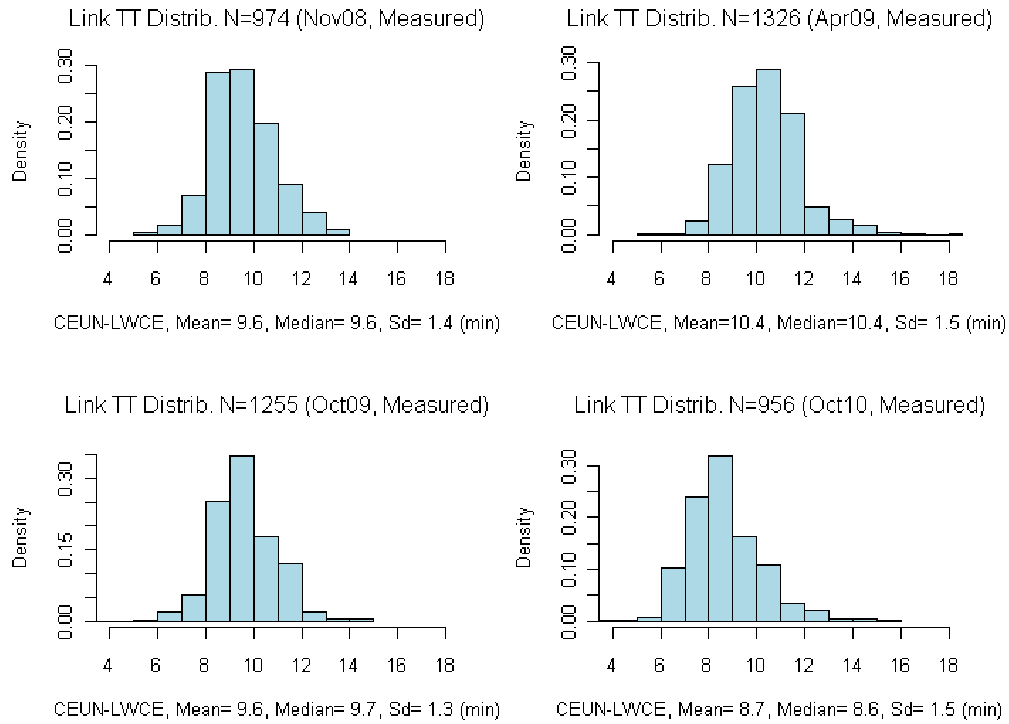


Figure B-15 Link Travel Time Comparison (CEUN-LWCE, NB)

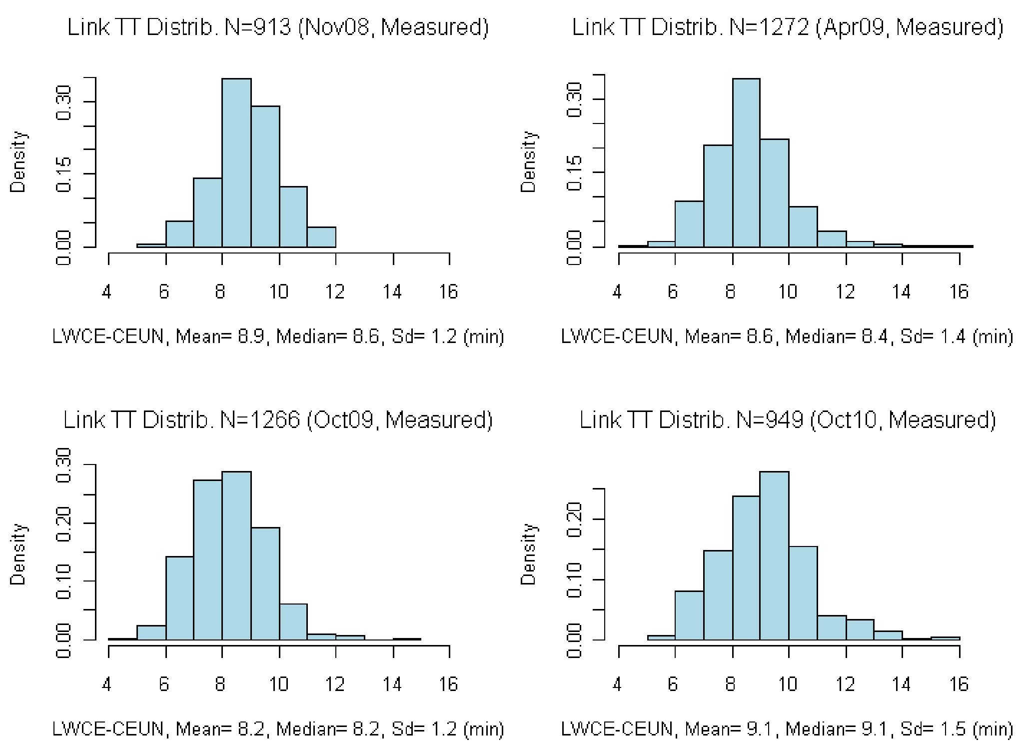


Figure B-16 Link Travel Time Comparison (LWCE-CEUN, SB)

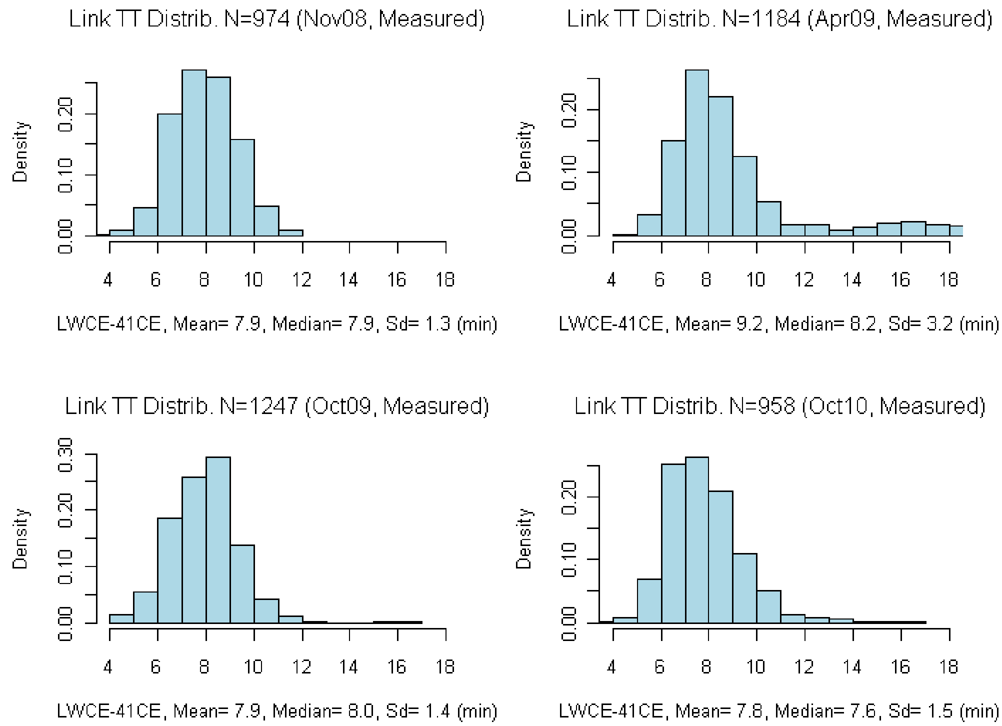


Figure B-17 Link Travel Time Comparison (LWCE-41CE, NB)

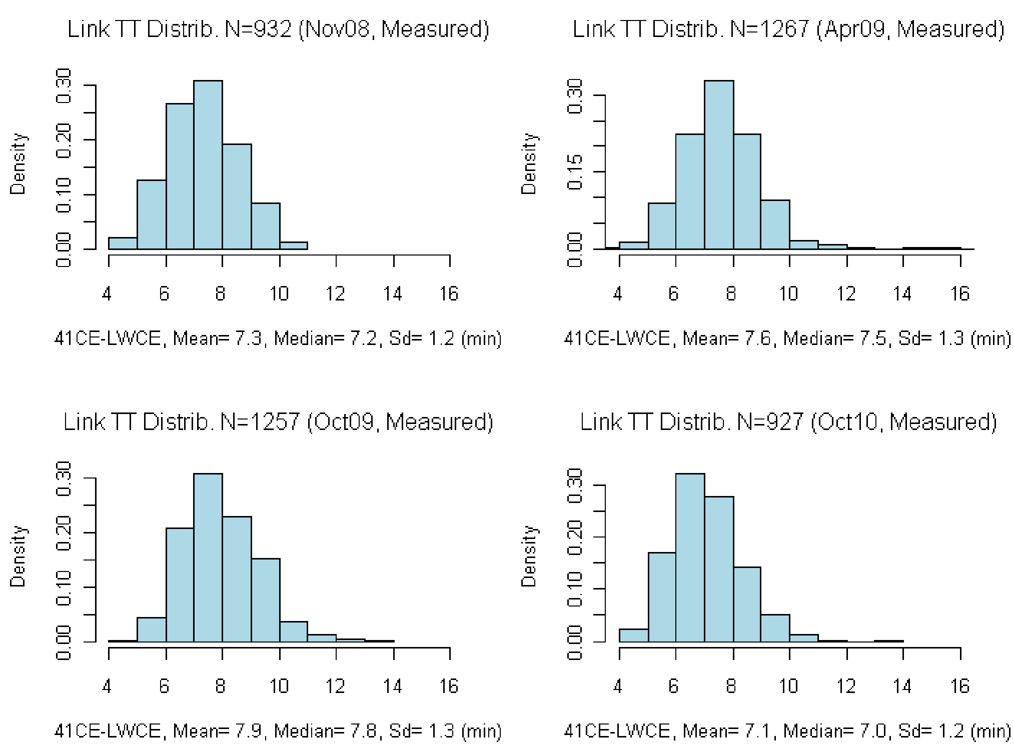


Figure B-18 Link Travel Time Comparison (41CE-LWCE, SB)

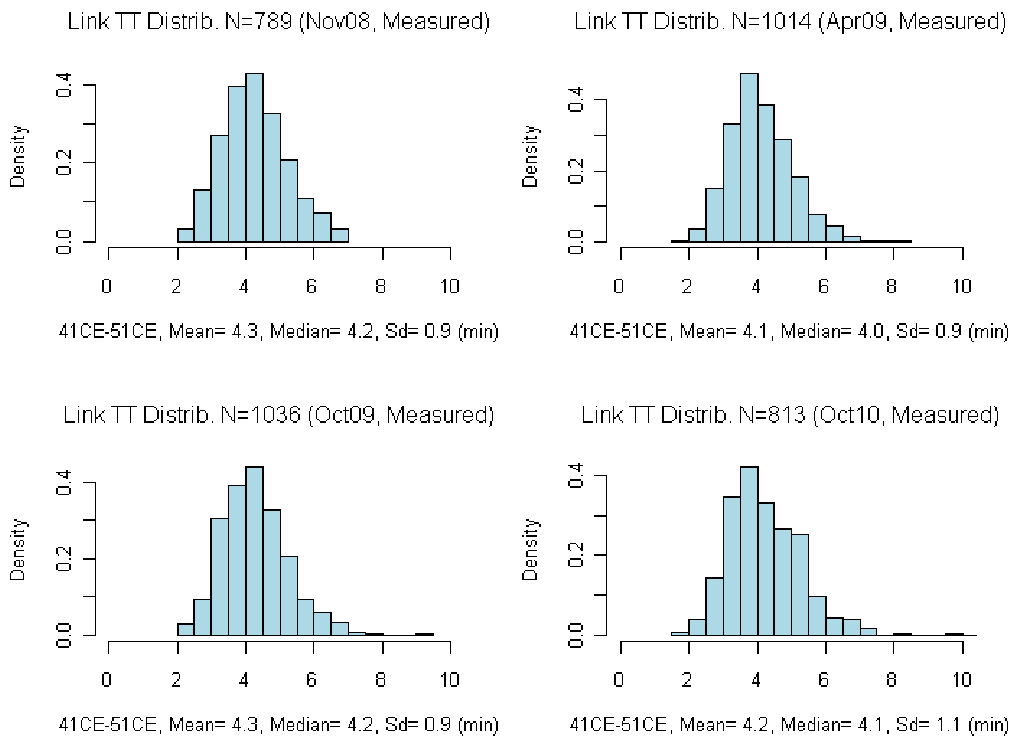


Figure B-19 Link Travel Time Comparison (41CE-51CE, NB)

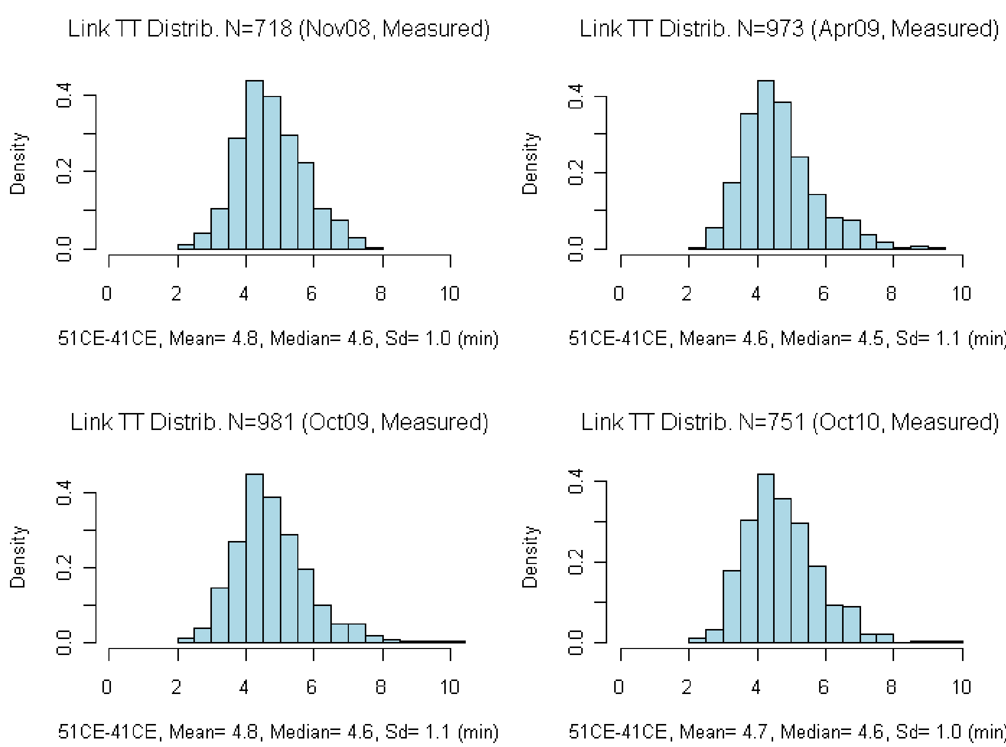


Figure B-20 Link Travel Time Comparison (51CE-41CE, SB)

Table B-1 NB Link Travel Time Comparisons (Measured vs. Scheduled)

Northbound		Nov 08		Apr 09		Oct 09		Oct 10	
Link ID	Travel Time	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
CEUN-LWCE	Measured	9.56	1.37	10.44	1.46	9.63	1.32	8.67	1.47
	Schedule	10.83	0.85	10.11	0.76	10.09	0.78	9.02	0.81
LWCE-41CE	Measured	7.93	1.30	9.16	3.17	7.93	1.36	7.82	1.60
	Schedule	8.67	0.70	8.66	0.65	8.64	0.66	7.56	0.73
41CE-51CE	Measured	4.27	0.94	4.13	0.93	4.28	0.94	4.23	1.05
	Schedule	4.49	0.62	4.50	0.60	4.50	0.61	4.40	0.58
51CE-53UV	Measured	3.72	0.74	3.79	0.85	3.64	0.83		
	Schedule	4.55	0.61	4.49	0.62	4.51	0.64	4.51	0.64
53UV-73UV	Measured	5.41	0.72	6.95	1.96	5.48	0.79		
	Schedule	6.11	0.53	6.06	0.50	6.05	0.52	6.05	0.52
73UV-NOTW	Measured	3.86	0.61	4.13	1.02	4.03	0.92	4.15	0.82
	Schedule	4.04	0.38	4.03	0.37	4.04	0.37	4.11	0.31

Table B-2 SB Link Travel Time Comparisons (Measured vs. Scheduled)

Southbound		Nov 08		Apr 09		Oct 09		Oct 10	
Link ID	Travel Time	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
LWCE-CEUN	Measured	8.87	1.24	8.62	1.44	8.25	1.25	9.15	1.53
	Schedule	10.31	1.04	9.88	0.88	9.87	0.87	8.82	0.95
41CE-LWCE	Measured	7.31	1.21	7.58	1.28	7.90	1.28	7.09	1.31
	Schedule	8.77	0.63	8.68	0.55	8.67	0.56	7.61	0.58
51CE-41CE	Measured	4.75	0.96	4.65	1.06	4.76	1.06	4.74	1.05
	Schedule	5.21	0.57	5.04	0.50	5.05	0.49	5.01	0.44
53UV-51CE	Measured	2.85	0.51	2.78	0.54	2.86	0.56		
	Schedule	3.00	0.00	3.00	0.00	3.00	0.00	3.00	0.00
73UV-53UV	Measured	6.19	1.23	7.05	1.86	6.32	1.23		
	Schedule	7.33	0.61	7.26	0.64	7.32	0.62	7.32	0.62
NOTW-73UV	Measured	5.12	0.98	6.01	2.66	5.70	2.37	5.58	1.40
	Schedule	5.95	0.97	5.80	0.94	5.85	0.94	5.81	0.99

B.5 Trip Travel Time Comparisons

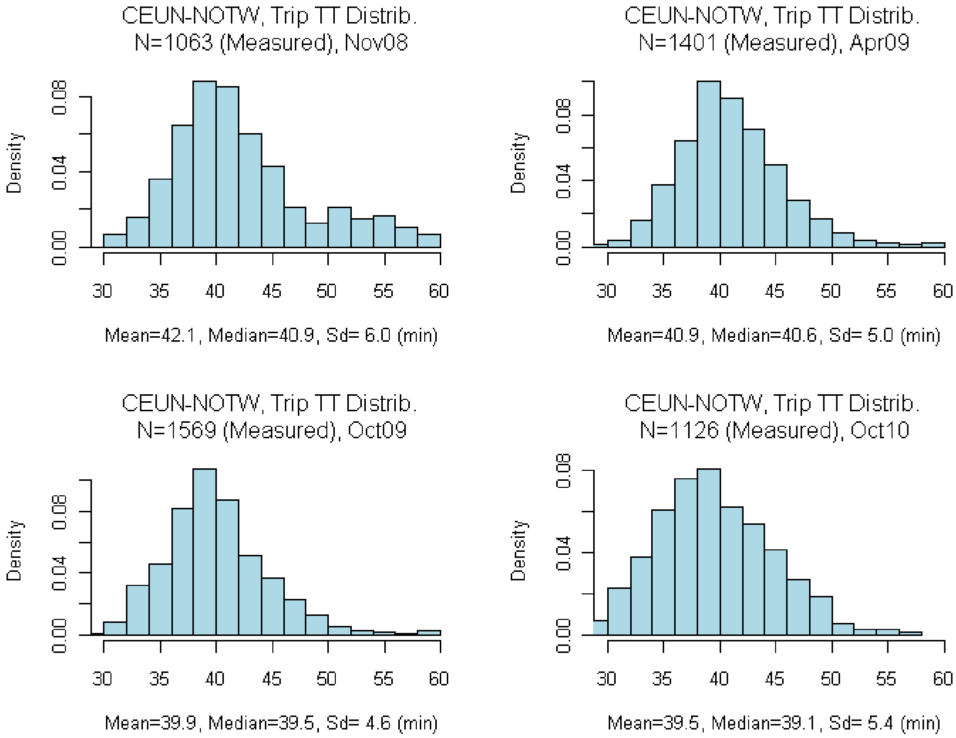


Figure B-21 NB Measured Trip Travel Time

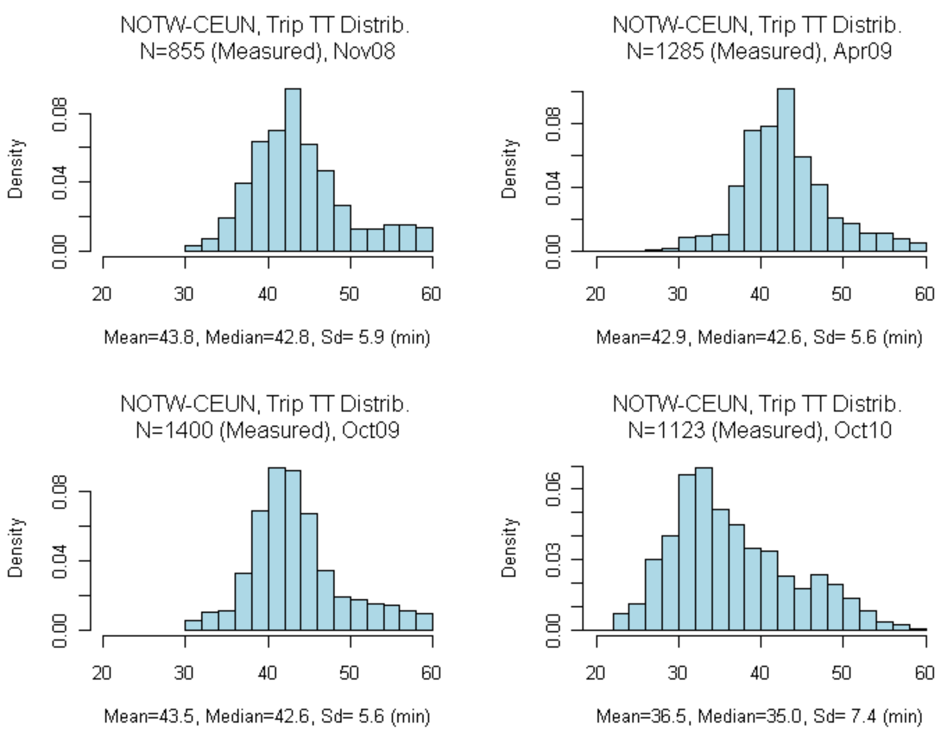


Figure B-22 SB Measured Trip Travel Time

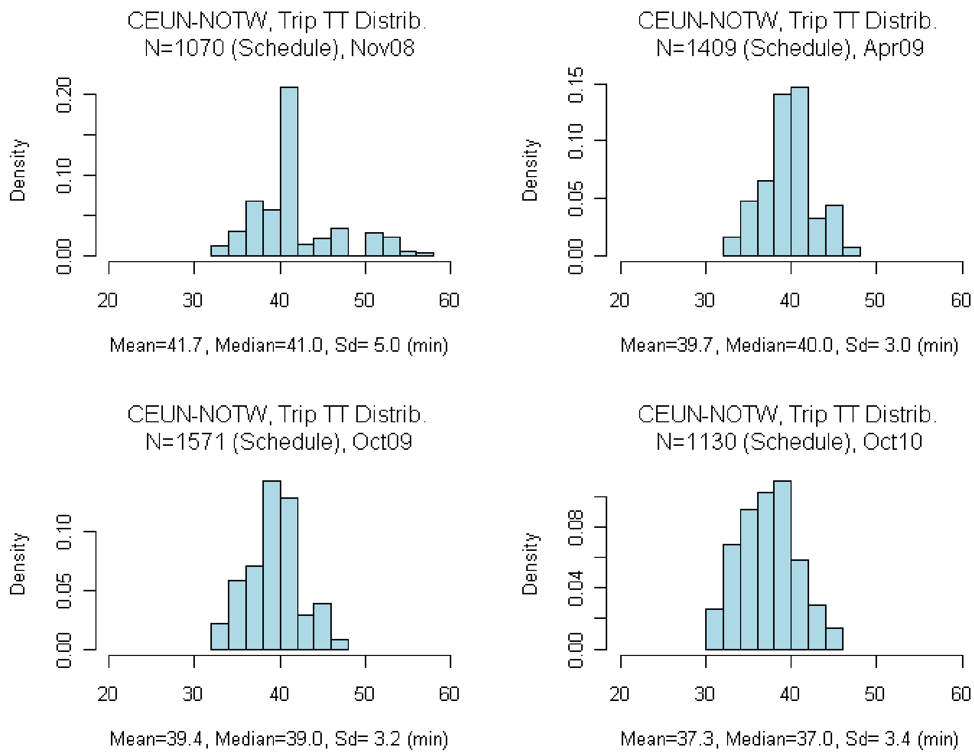


Figure B-23 NB Scheduled Trip Travel Time

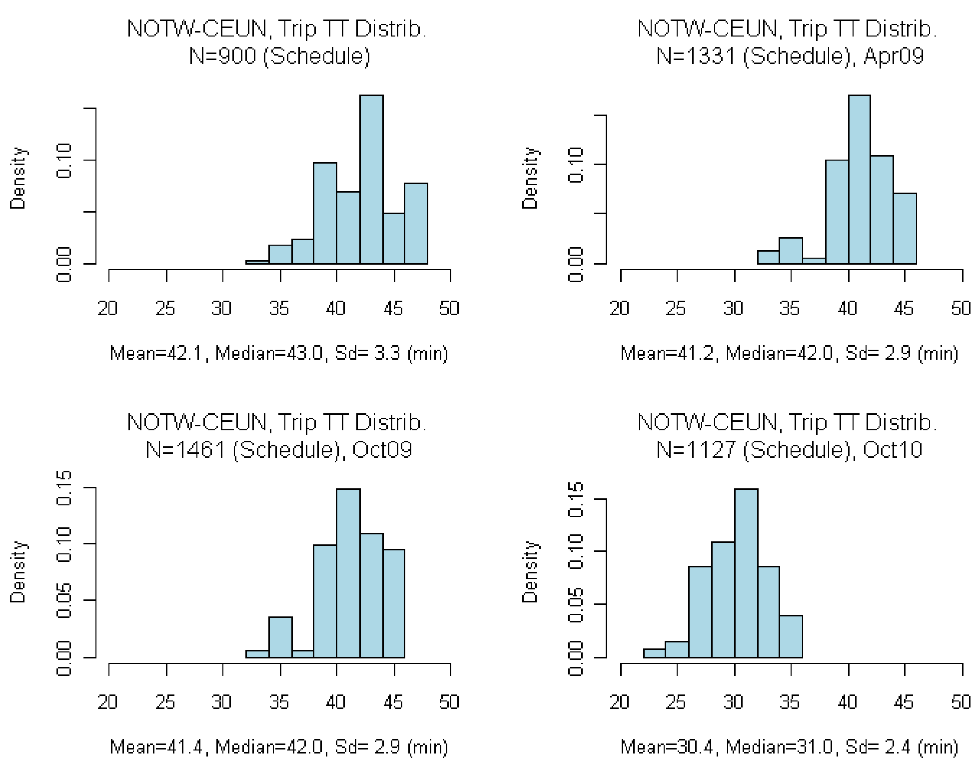


Figure B-24 SB Scheduled Trip Travel Time

Table B-3 NB/SB Measured vs. Scheduled Travel Time Comparisons

Trip Travel Time		Nov 08		Apr 09		Oct 09		Oct 10	
Trip	**Data Type**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**
Northbound CEUN-NOTW	**Measured**	42.14	6.00	40.90	5.02	39.87	4.56	39.48	5.37
	Scheduled	41.75	5.03	39.72	2.96	39.45	3.16	37.26	3.37
Southbound NOTW-CEUN	**Measured**	43.81	5.87	42.94	5.63	43.50	5.58	45.41	7.40
	Scheduled	42.13	3.30	41.19	2.94	41.41	2.94	39.18	2.91

APPENDIX C: RTE 10 LINK TRAVEL TIME ADJUSTMENTS

C.1 Outlier Removal

Table C-1 Summary of RTE 10 NB Link Travel Time Outliers Removal

Link	Data	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	N	% removed
LMRP-7SNI	Original	132	249	316.5	340.4	393.2	1598	916	1.2%
	Processed	132	249	315	332.3	391	678	905	
7SNI-3SNI	Original	104	161	223	222.1	247	1109	907	0.6%
	Processed	104	161	222.5	219.9	246	423	902	
3SNI-MA2S	Original	1	21	32	44.89	62	1079	921	1.4%
	Processed	1	21	32	42.38	61	123	908	
MA2S-CEUN	Original	108	159	186	192.3	219	390	922	0.1%
	Processed	108	159	186	192.1	219	360	921	
CEUN-LWCE	Original	335	512	577	575.5	632.2	945	980	0.0%
	Processed	335	512	577	575.5	632.2	945	980	
LWCE-41CE	Original	173	420	475	479.7	531	2081	982	0.1%
	Processed	173	420	475	478	531	877	981	
41CE-51CE	Original	135	216	253	259.3	296	1161	797	0.3%
	Processed	135	216	252	257.8	296	447	795	
51CE-53UV	Original	121	192.8	224	227	254	486	360	0.3%
	Processed	121	192.5	224	226.3	253.5	407	359	
53UV-73UV	Original	203	297	324	328.6	352.5	536	359	0.0%
	Processed	203	297	324	328.6	352.5	536	359	
51CE-73CE	Original	75	412	451	453	487	669	369	0.0%
	Processed	75	412	451	453	487	669	369	
73CE-OSMN	Original	102	215	255	257.1	290	474	369	0.0%
	Processed	102	215	255	257.1	290	474	369	
73UV-NOTW	Original	142	207	232	250.6	259	1437	361	1.9%
	Processed	142	207	231	233.1	257.8	462	354	
OSMN-NOTW	Original	258	325	343	349.2	367.5	547	359	0.0%
	Processed	258	325	343	349.2	367.5	547	359	

Table C-2 Summary of RTE 10 SB Link Travel Time Outliers Removal

Link	Data	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	N	% removed
NOTW-OSMN	Original	290	345.2	374.5	510.5	435	1842	354	12.1%
	Processed	290	342	367	401.9	400	1013	311	
OSMN-73CE	Original	141	208	239	241.1	274	365	357	0.0%
	Processed	141	208	239	241.1	274	365	357	
73CE-51CE	Original	358	467	503	509.2	551	753	355	0.0%
	Processed	358	467	503	509.2	551	753	355	
NOTW-73UV	Original	192	271.8	323.5	482.5	387.5	1933	326	14.4%
	Processed	192	263	309	328.9	353	953	279	
73UV-53UV	Original	238	311	370	374.8	424	664	325	0.0%
	Processed	238	311	370	374.8	424	664	325	
53UV-51CE	Original	108	148.5	167	174	194	354	331	0.3%
	Processed	108	148.2	167	173.4	193.5	304	330	
51CE-41CE	Original	141	245	280	321.6	328	23520	736	0.1%
	Processed	141	245	280	290	328	584	735	
41CE-LWCE	Original	263	386	434	442.4	490	2199	939	0.1%
	Processed	263	386	434	440.5	490	805	938	
LWCE-CEUN	Original	300	492.8	523	540.7	582	2129	940	0.1%
	Processed	300	492.5	523	539	582	926	939	
CEUN-1S2A	Original	77	140	163.5	196.5	191	24360	946	1.0%
	Processed	77	139	163	167.4	190	390	937	
1S2A-3SNI	Original	28	47	86	89.84	115	740	944	1.2%
	Processed	28	46	85	87.29	114	214	933	
3SNI-8SNI	Original	125	244	281	289.7	338	801	940	0.4%
	Processed	125	244	281	288.1	338	574	936	
8SNI-LMRP	Original	2	160	180	189.5	220.2	2141	904	1.0%
	Processed	2	160	180	185.3	217.5	378	895	

C.2 Link Travel Time Adjustments

Table C-3 Statistics of RTE 10 NB Actual, Adjusted and Schedule Travel Time (Fit: |Adj. TT – Schedule| ≤ 30 sec)

Link	Type	Min.	Median	Mean	Adj.	Adj. TT	Max.	SD	N	SE	Fit
LMRP-7SNI	actual	132	312	329.4	86.53	415.93	609	95.75	897	3.20	X
	schedule	300	420	416.7		416.7	540	71.11			
7SNI-3SNI	actual	104	222	217.6	47.47	265.07	376	58.54	891	1.96	X
	schedule	240	240	257.9		257.9	300	27.48			
3SNI-MA2S	actual	1	32	42.38	33.17	75.55	123	27.94	908	0.93	?
	schedule	120	120	120		120	120	0.00			
MA2S-CEUN	actual	108	185	190.6	46.01	236.61	307	38.23	912	1.27	?
	schedule	180	180	204.5		204.5	300	35.84			
CEUN-LWCE	actual	335	576	573.6	63	636.6	806	82.21	974	2.63	X
	schedule	480	660	650		650	720	51.19			
LWCE-41CE	actual	173	474	475.8	11.56	487.36	692	77.59	973	2.49	?
	schedule	420	540	520.6		520.6	600	42.03			
41CE-51CE	actual	135	252	256.5	19.32	275.82	415	56.14	790	2.00	X
	schedule	180	240	269.9		269.9	360	37.51			
51CE-53UV	actual	121	223	223.1	54.58	277.68	339	44.65	351	2.38	X
	schedule	240	240	274.2		274.2	360	37.50			
53UV-73UV	actual	203	323	324.9	27.79	352.69	434	43.01	350	2.30	X
	schedule	300	360	367		367	420	31.88			
51CE-73CE	actual	75	450	449.9	20.35	470.25	599	55.48	363	2.91	X
	schedule	420	420	456.7		456.7	540	45.50			
73CE-OSMN	actual	102	253	254.8	30.75	285.55	396	51.37	364	2.69	X
	schedule	240	240	263.1		263.1	300	29.23			
73UV-NOTW	actual	142	230	231.7	0	231.7	327	36.49	351	1.95	X
	schedule	180	240	242.7		242.7	300	22.65			
OSMN-NOTW	actual	258	342	344.8	0	344.8	423	29.40	347	1.58	X
	schedule	300	360	374.7		374.7	420	30.12			

Table C-4 Statistics of RTE 10 SB Actual, Adjusted and Schedule Travel Time (Fit: |Adj. TT – Schedule| ≤ 30 sec)

Link	Type	Min.	Median	Mean	Adj.	Adj. TT	Max.	SD	N	SE	Fit
NOTW-OSMN	actual	290	364	372.6	18.77	391.37	569	47.44	292	2.78	X
	schedule	360	360	370		370	420	22.39			
OSMN-73CE	actual	141	239	241.1	25.16	266.26	365	45.94	357	2.43	X
	schedule	240	240	252.9		252.9	300	24.71			
73CE-51CE	actual	358	502	506.9	21.84	528.74	669	58.85	351	3.14	X
	schedule	480	540	549.5		549.5	600	38.16			
NOTW-73UV	actual	192	306	307.2	37.7	344.9	550	59.01	266	3.62	X
	schedule	240	360	353.6		353.6	480	57.19			
73UV-53UV	actual	238	368	371.5	66.54	438.04	569	73.96	321	4.13	X
	schedule	360	420	440.3		440.3	480	36.63			
53UV-51CE	actual	108	167	171.2	21.84	193.04	260	30.82	323	1.71	X
	schedule	180	180	180		180	180	0.00			
51CE-41CE	actual	141	277	285.3	25.33	310.63	452	57.46	718	2.14	X
	schedule	240	300	313.3		313.3	360	34.49			
41CE-LWCE	actual	263	434	438.8	68.37	507.17	645	72.79	932	2.38	X
	schedule	420	540	526.6		526.6	600	37.84			
LWCE-CEUN	actual	362	520	533.5	47.85	581.35	715	73.04	908	2.42	?
	schedule	480	600	619.2		619.2	720	62.25			
CEUN-1S2A	actual	77	162	163.3	39.95	203.25	267	36.74	911	1.22	X
	schedule	120	180	191.2		191.2	300	42.49			
1S2A-3SNI	actual	28	85	87.29	29.8	117.09	214	42.10	933	1.38	X
	schedule	120	120	130.2		130.2	180	22.58			
3SNI-8SNI	actual	125	280	285.6	67.12	352.72	479	61.76	926	2.03	X
	schedule	300	360	347.9		347.9	420	51.72			
8SNI-LMRP	actual	91	179	182.3	0	182.3	310	42.19	875	1.43	?
	schedule	180	240	257.7		257.7	300	28.64			

APPENDIX D: BUS ROUTE 10 TRIP DATA

D.1 Route #10 Map

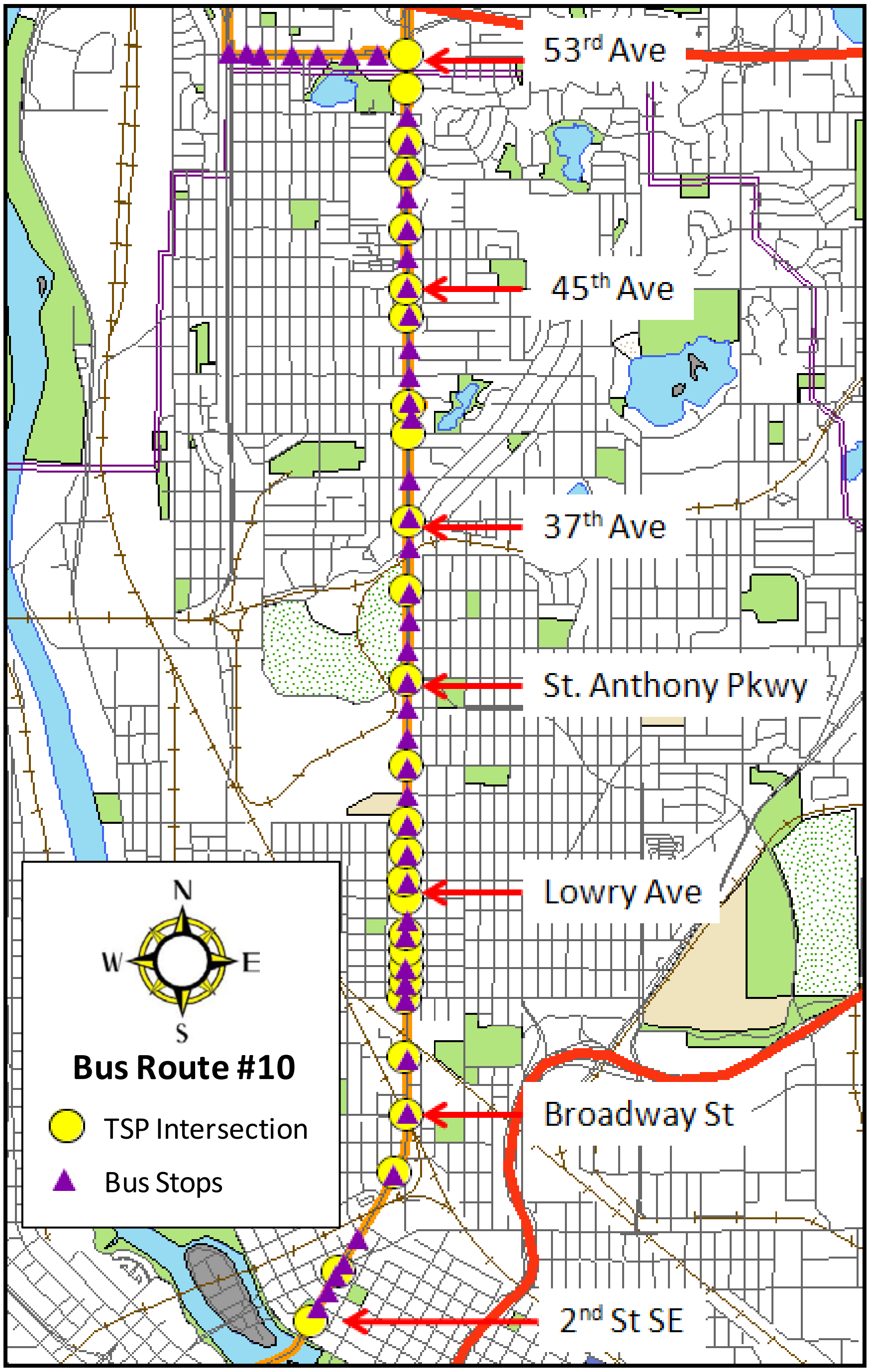


Figure D.1 Map of Route #10

D.2 Intersections of Bus Route #10

ID	Intersection On	Intersection At	TSP_Equipped
1	Central Ave	53th Ave NE	1
2	Central Ave	52th Ave NE	1
3	Central Ave	50th Ave NE	1
4	Central Ave	49th Ave NE	1
5	Central Ave	47th Ave NE	1
6	Central Ave	45th Ave NE	1
7	Central Ave	44th Ave NE	1
8	Central Ave	41st Ave NE	1
9	Central Ave	40th Ave NE	1
10	Central Ave	37th Ave NE	1
11	Central Ave	35th Ave NE	1
12	Central Ave	St Anthony Pkwy	1
13	Central Ave	29th Ave NE	1
14	Central Ave	27th Ave NE	1
15	Central Ave	26th Ave NE	1
16	Central Ave	Lowry	1
17	Central Ave	24th Ave NE	1
18	Central Ave	22nd Ave NE	1
19	Central Ave	20th Ave NE	1
20	Central Ave	19th Ave NE	1
21	Central Ave	18th half Ave NE	1
22	Central Ave	18th Ave NE	1
23	Central Ave	14th Ave NE	1
24	Central Ave	Broadway St NE	1
25	Central Ave	Spring St NE	1
26	Central Ave	Hennepin and 5th	1
27	Central Ave	2nd St SE	1

Figure D.1 Route #10 TSP Intersections

D.3 Stops of Bus Route #10

stop_seq	site_id	site_on	site_at	node_id	corner_desc
1	42837	LEAMINGTON RAMP	UPPER LEVEL	LMRP	NEAR SIDE
2	52104	11 ST S	MARQUETTE AV S	1 2A	FAR SIDE
3	17991	NICOLLET MALL	10 ST S		NEAR SIDE
4	17992	NICOLLET MALL	9 ST S		NEAR SIDE
5	17993	NICOLLET MALL	8 ST S	7S2A	NEAR SIDE
6	17994	NICOLLET MALL	7 ST S	7SNI	NEAR SIDE
7	17995	NICOLLET MALL	6 ST S		NEAR SIDE
8	17996	NICOLLET MALL	6 ST / 5 ST S		MID BLOCK
9	17997	NICOLLET MALL	4 ST S	4NIC	NEAR SIDE
10	17998	NICOLLET MALL	4 ST / 3 ST S	3SNI	MID BLOCK
11	17999	NICOLLET MALL	WASHINGTON AV S		NEAR SIDE
12	19315	WASHINGTON AV S	MARQUETTE AV S	MA2S	NEAR SIDE
13	51382	3 AV S	WASHINGTON AV		FAR SIDE
14	14952	CENTRAL AV	UNIVERSITY AV SE	CEUN	NEAR SIDE
15	14953	CENTRAL AV	4 ST SE		NEAR SIDE
16	14954	CENTRAL AV	5 ST SE		NEAR SIDE
17	40953	CENTRAL AV NE	HENNEPIN E / 6 ST		MID BLOCK
18	17224	CENTRAL AV NE	7 ST SE		FAR SIDE
19	17219	CENTRAL AV NE	SPRING ST		NEAR SIDE
20	17215	CENTRAL AV NE	BROADWAY ST		FAR SIDE
21	17211	CENTRAL AV NE	14 AV NE		NEAR SIDE
22	17209	CENTRAL AV NE	18 AV NE		NEAR SIDE
23	17206	CENTRAL AV NE	18 1/2 AV NE		NEAR SIDE
24	17205	CENTRAL AV NE	19 AV NE		NEAR SIDE
25	17201	CENTRAL AV NE	22 AV NE		NEAR SIDE
26	17198	CENTRAL AV NE	23 AV NE		NEAR SIDE
27	17194	CENTRAL AV NE	LOWRY AV	LWCE	NEAR SIDE
28	52073	CENTRAL AV NE	26 AV NE		NEAR SIDE
29	17190	CENTRAL AV NE	27 AV NE		NEAR SIDE
30	17189	CENTRAL AV NE	28 AV NE		NEAR SIDE
31	17186	CENTRAL AV NE	29 AV NE		NEAR SIDE
32	17185	CENTRAL AV NE	30 AV NE		NEAR SIDE
33	17182	CENTRAL AV NE	31 AV NE		NEAR SIDE
34	17181	CENTRAL AV NE	ST ANTHONY PKWY		NEAR SIDE
35	17178	CENTRAL AV NE	33 AV NE		NEAR SIDE
36	17177	CENTRAL AV NE	34 AV NE		NEAR SIDE
37	17174	CENTRAL AV NE	35 AV NE		NEAR SIDE
38	17172	CENTRAL AV NE	COLUMBIA PKWY		ACROSS FROM

39	17169	CENTRAL AV NE	37 AV NE		FAR SIDE
40	17168	CENTRAL AV NE	39 AV NE		NEAR SIDE
41	17164	COL HTS TRANSIT CTR	40 AV / 41 AV NE	4 CE	MID BLOCK
42	17163	CENTRAL AV NE	41 AV NE	41CE	FAR SIDE
43	17160	CENTRAL AV NE	42 AV		NEAR SIDE
44	17159	CENTRAL AV NE	43 AV		NEAR SIDE
45	17156	CENTRAL AV NE	44 AV NE		FAR SIDE
46	17155	CENTRAL AV NE	45 AV		FAR SIDE
47	17152	CENTRAL AV NE	46 AV		FAR SIDE
48	17151	CENTRAL AV NE	47 AV		FAR SIDE
49	17148	CENTRAL AV NE	#4801		FAR SIDE
50	17147	CENTRAL AV NE	49 AV		FAR SIDE
51	17144	CENTRAL AV NE	50 AV		NEAR SIDE
52	17143	CENTRAL AV NE	51 COURT	51CE	NEAR SIDE
53	14163	53 AV NE	TARGET - E ENTRANCE	53TA	FAR SIDE
54	14165	53 AV NE	MONROE ST NE		NEAR SIDE
55	14170	53 AV NE	SULLIVAN DR		ACROSS FROM
56	14174	53 AV NE	7 ST		NEAR SIDE
57	14178	53 AV NE	5 ST		NEAR SIDE
58	14179	53 AV NE	4 ST		NEAR SIDE
59	40887	UNIVERSITY AV (HWY 47)	53 AV NE	53UV	FAR SIDE
60	40226	UNIVERSITY AV (HWY 47)	57 AV NE		FAR SIDE
61	40228	UNIVERSITY AV (HWY 47)	61 AV NE		FAR SIDE
62	40235	UNIVERSITY AV (HWY 47)	MISSISSIPPI ST	MIUV	FAR SIDE
63	40898	UNIVERSITY AV NE	MISSISSIPPI / 69 AV		MID BLOCK
64	40230	UNIVERSITY AV (HWY 47)	69 AV NE		FAR SIDE
65	40232	UNIVERSITY AV (HWY 47)	73 AV NE	73UV	FAR SIDE
66	49280	UNIVERSITY AV (HWY 47)	OSBORNE RD NE		FAR SIDE
67	49383	UNIVERSITY AV (HWY 47)	81 AV NE		FAR SIDE
68	42381	NORTHTOWN TRANSIT	LOCAL STOP	NOTW	NEAR SIDE

Figure D.2 List of route #10 NB stops

stop_seq	site_id	site_on	site_at	node_id	corner_desc
1	42381	NORTHTOWN TRANSIT	LOCAL STOP	NOTW	NEAR SIDE
2	49384	UNIVERSITY AV (HWY 47)	81 AV NE		FAR SIDE
3	40237	UNIVERSITY AV (HWY 47)	OSBORNE RD NE		FAR SIDE
4	40234	UNIVERSITY AV (HWY 47)	73 AV NE	73UV	FAR SIDE
5	40231	UNIVERSITY AV (HWY 47)	69 AV NE		FAR SIDE
6	40889	UNIVERSITY AV NE	69 AV / MISSISSIPPI		MID BLOCK
7	40236	UNIVERSITY AV (HWY 47)	MISSISSIPPI ST	MIUV	FAR SIDE
8	42212	UNIVERSITY AV (HWY 47)	SATELLITE LANE		FAR SIDE
9	40229	UNIVERSITY AV (HWY 47)	61 AV NE		FAR SIDE
10	40227	UNIVERSITY AV (HWY 47)	57 AV NE		FAR SIDE
11	14182	53 AV NE	UNIVERSITY AV SVC RD	53UV	FAR SIDE
12	14177	53 AV NE	5 ST NE		NEAR SIDE
13	14173	53 AV NE	7 ST		NEAR SIDE
14	14169	53 AV NE	SULLIVAN DR		NEAR SIDE
15	14166	53 AV NE	MONROE ST NE		ACROSS FROM
16	14168	53 AV NE	TARGET - E ENTRANCE		ACROSS FROM
17	17138	CENTRAL AV NE	53 AV NE	53CE	FAR SIDE
18	17141	CENTRAL AV NE	52 AV NE		FAR SIDE
19	17142	CENTRAL AV NE	51 AV NE	51CE	NEAR SIDE
20	17145	CENTRAL AV NE	50 AV NE		NEAR SIDE
21	17146	CENTRAL AV NE	49 AV NE		FAR SIDE
22	17149	CENTRAL AV NE	48 AV NE		FAR SIDE
23	17150	CENTRAL AV NE	47 AV NE		ACROSS FROM
24	17153	CENTRAL AV NE	46 AV NE		FAR SIDE
25	17154	CENTRAL AV NE	45 AV NE		FAR SIDE
26	17157	CENTRAL AV NE	44 AV NE		NEAR SIDE
27	17158	CENTRAL AV NE	43 AV NE		NEAR SIDE
28	17161	CENTRAL AV NE	42 AV NE		NEAR SIDE
29	17162	CENTRAL AV NE	41 AV NE	41CE	NEAR SIDE

30	17165	CENTRAL AV NE	40 AV NE	4 CE	NEAR SIDE
31	17166	CENTRAL AV NE	39 AV NE		NEAR SIDE
32	17170	CENTRAL AV NE	37 AV NE		NEAR SIDE
33	17171	CENTRAL AV NE	COLUMBIA PKWY		NEAR SIDE
34	17175	CENTRAL AV NE	35 AV NE		ACROSS FROM
35	17179	CENTRAL AV NE	33 AV NE		ACROSS FROM
36	17180	CENTRAL AV NE	ST ANTHONY PKWY		FAR SIDE
37	17183	CENTRAL AV NE	31 AV NE		ACROSS FROM
38	17187	CENTRAL AV NE	29 AV NE		ACROSS FROM
39	17188	CENTRAL AV NE	28 AV / 27 AV NE		MID BLOCK
40	17195	CENTRAL AV NE	LOWRY AV NE	LWCE	NEAR SIDE
41	17196	CENTRAL AV NE	24 AV NE		NEAR SIDE
42	17200	CENTRAL AV NE	22 AV NE		NEAR SIDE
43	17204	CENTRAL AV NE	19 AV NE		NEAR SIDE
44	17207	CENTRAL AV NE	18 1/2 AV NE		NEAR SIDE
45	17208	CENTRAL AV NE	18 AV NE		NEAR SIDE
46	17212	CENTRAL AV NE	14 AV NE		NEAR SIDE
47	17216	CENTRAL AV NE	BROADWAY ST		FAR SIDE
48	17220	CENTRAL AV NE	SPRING ST		FAR SIDE
49	17225	CENTRAL AV NE	7 ST SE		NEAR SIDE
50	17227	CENTRAL AV NE	HENNEPIN AV E		NEAR SIDE
51	46801	CENTRAL AV	4 ST SE	CEUN	FAR SIDE
52	12282	CENTRAL AV	2 ST SE		ACROSS FROM
53	19270	3 AV S	1 ST / 2 ST S		MID BLOCK
54	19308	WASHINGTON AV S	3 AV / 2 AV S	1S2A	MID BLOCK
55	17976	NICOLLET MALL	3 ST S	3SNI	NEAR SIDE
56	52320	NICOLLET MALL	4 ST S		NEAR SIDE
57	17978	NICOLLET MALL	5 ST S		NEAR SIDE
58	17979	NICOLLET MALL	6 ST S		NEAR SIDE
59	17980	NICOLLET MALL	7 ST S	7SMA	NEAR SIDE
60	17981	NICOLLET MALL	8 ST S	8SNI	NEAR SIDE
61	17982	NICOLLET MALL	8 ST / 9 ST S		MID BLOCK
62	17983	NICOLLET MALL	9 ST / 10 ST S		MID BLOCK
63	42837	LEAMINGTON RAMP	UPPER LEVEL	LMRP	NEAR SIDE

Figure D.3 List of route #10 SB stops

APPENDIX E: SELECTED R CODE

E.1 Trip Travel Time

```
par(mfrow=c(2,2))
# == NB, Apr09
data<-read.csv("~Data/RTE10/APR09/RTE10_DWELL/RTE_10N_TripTT_WK.csv", header=T)
avl_data=subset(data$tt_min, data$tt_min<60)
avl_mean=mean(avl_data)
avl_sd=sd(avl_data)
avl_mid=median(avl_data)
asize=length(avl_data)
hist(avl_data, breaks=26, xlab=sprintf("Mean=%4.1f, Median=%4.1f, Sd=%4.1f (min)",avl_mean,avl_mid,avl_sd),
main=sprintf("CEUN-NOTW, Trip TT Distrib. \nN=%d (Measured), Apr09",asize),freq=F, font.main=1, col="lightblue", xlim=c(30,55))

sched_data=data$sched_t_min
sched_mean=mean(sched_data)
sched_sd=sd(sched_data)
sched_mid=median(sched_data)
size=length(sched_data)
hist(sched_data, breaks=8, xlab=sprintf("Mean=%4.1f, Median=%4.1f, Sd=%4.1f (min)",sched_mean,sched_mid,sched_sd),
main=sprintf("CEUN-NOTW, Trip TT Distrib. \nN=%d (Schedule), Apr09",size),freq=F, font.main=1, col="lightblue", xlim=c(30,55))


# == NB, Oct09
data2<-read.csv("~Data/RTE10/OCT09/RTE10_DWELL/RTE_10N_TripTT_WK.csv", header=T)
avl_data2=subset(data2$tt_min, data2$tt_min<60)
avl_mean2=mean(avl_data2)
avl_sd2=sd(avl_data2)
avl_mid2=median(avl_data2)
asize=length(avl_data2)
hist(avl_data2, breaks=16, xlab=sprintf("Mean=%4.1f, Median=%4.1f, Sd=%4.1f (min)",avl_mean2,avl_mid2,avl_sd2),
main=sprintf("CEUN-NOTW, Trip TT Distrib. \nN=%d (Measured), Oct09",asize),freq=F, font.main=1, col="lightblue", xlim=c(30,55))

sched_data2=data2$sched_t_min
sched_mean2=mean(sched_data2)
sched_sd2=sd(sched_data2)
sched_mid2=median(sched_data2)
size=length(sched_data2)
hist(sched_data2, breaks=8, xlab=sprintf("Mean=%4.1f, Median=%4.1f, Sd=%4.1f (min)",sched_mean2,sched_mid2,sched_sd2),
main=sprintf("CEUN-NOTW, Trip TT Distrib. \nN=%d (Schedule), Oct09",size),freq=F, font.main=1, col="lightblue", xlim=c(30,55))

stat=c(avl_mean, avl_sd, avl_mean2, avl_sd2)
stat
stat2=c(sched_mean, sched_sd, sched_mean2, sched_sd2)
stat2

t.test(avl_data, avl_data2)
t.test(sched_data, sched_data2)
```

E.2 Link Travel Time Comparisons

```
# ==NB ==========================================================================
my_link="73UV-NOTW"
# ==========================================================================
# Measured TT Oct10
path4="~Data/RTE10/Oct10/RTE10_DWELL/RTE_10N_LinkTT_WK_afc.csv"
data4<-read.csv(path4, header=T)

# plot TP histogram ==============================================================================
link_TT=subset(data4, link_id==my_link & data4$t_time_sec>0 & data4$t_time_sec<1800)
t_time_min=link_TT$t_time_sec/60
avg=mean(t_time_min)
stdev=sd(t_time_min)
med=median(t_time_min)
size=length(t_time_min)
hist(t_time_min, breaks=16, xlab=sprintf("%s, Mean=%4.1f, Median=%4.1f, Sd=%4.1f (min)",my_link,avg,med,stdev),
main=sprintf("Link TT Distrib. N=%d (Oct10, Measured)",size),freq=F, font.main=1, col="lightblue", xlim=c(4,18))
t4=t_time_min

mea=c(mean(t4),sd(t4))
```

```
mea

t_sched4=subset(data4$tt_sched_sec, data4$link_id==my_link)/60
sched=c(mean(t_sched4), sd(t_sched4))
sched

# ==SB =======================================================================
my_link="LWCE-CEUN"
# ===========================================================================
# Measured TT Oct10
path4="~Data/RTE10/Oct10/RTE10_DWELL/RTE_10S_LinkTT_WK_afc.csv"
data4<-read.csv(path4, header=T)

# plot TP histogram =====================================================================
link_TT=subset(data4, link_id==my_link & data4$t_time_sec>0 & data4$t_time_sec<1800)
t_time_min=link_TT$t_time_sec/60
avg=mean(t_time_min)
stdev=sd(t_time_min)
med=median(t_time_min)
size=length(t_time_min)
hist(t_time_min, breaks=16, xlab=sprintf("%s, Mean=%4.1f, Median=%4.1f, Sd=%4.1f (min)",my_link,avg,med,stdev),
main=sprintf("Link TT Distrib. N=%d (Oct10, Measured)",size),freq=F, font.main=1, col="lightblue", xlim=c(4,18))
t4=t_time_min

mea=c(mean(t4),sd(t4))
mea

t_sched4=subset(data4$tt_sched_sec, data4$link_id==my_link)/60
sched=c(mean(t_sched4), sd(t_sched4))
sched
```

E.3 Timepoint Time Statistics

```
pathNov08="~Data/RTE10/Nov08_Model/RTE10_DWELL/RET10_get_dwell_parameters_late_buses_afc_1min_early_no_lift_estimate.csv"
dataNov08<-read.csv(pathNov08, header=T)

pathApr09="~Data/RTE10/APR09/RTE10_DWELL/RET10_get_dwell_parameters_late_buses_afc_1min_early_no_lift_estimate.csv"
dataApr09<-read.csv(pathApr09, header=T)

pathOct09="~Data/RTE10/OCT09/RTE10_DWELL/RET10_get_dwell_parameters_late_buses_afc_1min_early_no_lift_estimate.csv"
dataOct09<-read.csv(pathOct09, header=T)

TP='73UV'
#TP='LWCE'
#TP='LWCE'

DIR=0
#DIR=0 #South
dataNov08 = subset(dataNov08, node_id==TP & dir_North==DIR)
dataApr09 = subset(dataApr09, node_id==TP & dir_North==DIR)
dataOct09 = subset(dataOct09, node_id==TP & dir_North==DIR)

#==========================================
dwell_tp_Nov08=dataNov08$Est_Dwell_min
dwell_tp_Apr09=dataApr09$Est_Dwell_min
dwell_tp_Oct09=dataOct09$Est_Dwell_min

stat=c(mean(dwell_tp_Nov08), sd(dwell_tp_Nov08), mean(dwell_tp_Apr09), sd(dwell_tp_Apr09), mean(dwell_tp_Oct09), sd(dwell_tp_Oct09))
stat

=== INDIVIDUAL DATASET
pathOct10="~Data/RTE10/OCT10/RTE10_DWELL/RET10_get_dwell_parameters_late_buses_afc_1min_early_no_lift_estimate.csv"
dataOct10<-read.csv(pathOct10, header=T)
TP='CEUN'

DIR=1
#DIR=0 #South
dataOct10 = subset(dataOct10, node_id==TP & dir_North==DIR)
```

```
#============================================
dwell_tp_Oct10=dataOct10$Est_Dwell_min

stat=c(mean(dwell_tp_Oct10), sd(dwell_tp_Oct10))
stat
```

E.4 Timepoint Time Comparison

```
data<-read.csv("~/RTE10_LateBus_Dwell_Model_1min_early_no_lift_no_CBD_signal_3.csv", header=T)
attach(data)

# NCEUN ====================================
node_name='NCEUN'
node=subset(data, dir_node==node_name )
node_dwell_sec=node$dwell_min*60.0
node_dwell_mean=mean(node_dwell_sec)
node_dwell_stdev=sd(node_dwell_sec)

sim_data<-read.csv("~NCEUN.dat", header=T)
sim_dwell_sec=sim_data$min*60
sim_dwell_mean=mean(sim_dwell_sec)
sim_dwell_stdev=sd(sim_dwell_sec)
result=c(node_dwell_mean, node_dwell_stdev, sim_dwell_mean, sim_dwell_stdev, node_dwell_mean/sim_dwell_mean)
result
var.test(node_dwell_sec, sim_dwell_sec, alternative ="two.sided", conf.level=0.95)

# SCEUN ====================================
node_name='SCEUN'
node=subset(data, dir_node==node_name )
node_dwell_sec=node$dwell_min*60.0
node_dwell_mean=mean(node_dwell_sec)
node_dwell_stdev=sd(node_dwell_sec)

sim_data<-read.csv("~SCEUN.dat", header=T)
sim_dwell_sec=sim_data$min*60
sim_dwell_mean=mean(sim_dwell_sec)
sim_dwell_stdev=sd(sim_dwell_sec)
result=c(node_dwell_mean, node_dwell_stdev, sim_dwell_mean, sim_dwell_stdev, node_dwell_mean/sim_dwell_mean)
result
var.test(node_dwell_sec, sim_dwell_sec, alternative ="two.sided", conf.level=0.95)
```

APPENDIX F: ADCS DATA STRUCTURE

F.1 AVL/APC Data

Table F-1 AVL Data Structure

Data Name	Data Type	Sample Data
DUMMY1	varchar	USE
SERIAL_NBR	nvarchar	160038651076743
TRANSACTION_DATE	smalldatetime	4/13/2009
TRANSACTION_TIME	smalldatetime	17:05:20
TRANSACTION_STATUS	int	0
FACID	smallint	113
DEVICE_ID	nvarchar	BIV08336
ROUTE_NUMBER	int	10
FARE_INSTRUMENT_ID	int	28673
RIDERS	int	1
USE_TYPE	int	9
EMPLOYEE_ID	smallint	3870
BUS_ID	smallint	804
RUN_ID	nvarchar	2034
SERVICE_TYPE	int	8
OPERATOR_ID	smallint	4
LAT_LONG_DATA	nvarchar	[NULL]
FARE_PRODUCT	nvarchar	CSC C-Pass
PRODUCT_USE_LOAD_ID	smallint	0
PRODUCT_USE_LOAD_SHORT_DESC	nvarchar	Pass A Use
DUMMY2	nvarchar	4/13/2009 18:34
DIRECTION	varchar	N
LAT	real	44.970826
LON	real	-93.37266

F.2 APC Data

Table F-2 APC Data Structure

Data Name	Data Type	Sample Data
calendar_id	int	120081104
calendar_date	smalldatetime	11/4/2008 0:00
veh_id	int	1137
time_bracket_start	int	18300
time_bracket_end	int	23580
block_number	smallint	1498
trip_number	smallint	9
service_id	nvarchar	WK
line_id	nvarchar	25
line_direction	nvarchar	South
line_direction_number	smallint	1
pat_id	smallint	16
stop_sequence_number	smallint	81
node_id	nvarchar	37SV
site_id	int	14155
site_latitude	real	45.035942
site_longitude	real	-93.218445
board	smallint	3
alight	smallint	0
load_w_layovers	smallint	NULL
sched_time	int	20580
act_arr_at_tp	int	20569
apc_msg_time	int	20580
act_dep_at_tp	int	20629
confidence	smallint	NULL
trip_level_accuracy	smalling	92
seg_from	nvarchar	37SV
seg_to	nvarchar	INSV
merge_startdate	smalldatetime	NULL
run_number	int	2016
odometer	int	2297
act_dist_from_sched_ft	int	15
flg_bad_day	smallint	NULL
flg_badtrip	smallint	0
flg_apc_fixed_at_common_tp	smallint	0
flg_apc_count_was_interleaved	smallint	0
flg_bad_bus	smallint	0
xmit_msg_id	money	240809597
sched_tp_adhere_vl_percent	smallint	99

F.3 AFC Data

Table F-3 GoTo Card Data Structure

Data Name	Data Type	Sample Data
SPECIAL_SERIAL_NBR	varchar	169839992287800000
TRANSACTION_DATE	varchar	11/28/2008
TRANSACTION_TIME	varchar	5:28:24
TRANSACTION_STATUS	varchar	0
FACID	varchar	113
DEVICE_ID	varchar	BIV05651
ROUTE_NUMBER	varchar	9
FARE_INSTRUMENT_ID	varchar	20737
RIDERS	varchar	1
USE_TYPE	varchar	9
EMPLOYEE_ID	varchar	68258
BUS_ID	varchar	903
RUN_ID	varchar	2403
SERVICE_TYPE	varchar	11
OPERATOR_ID	varchar	4
LAT_LONG_DATA	varchar	02ae334afa6f3f0b
DUMMY2	varchar	11/28/2008 8:25
latitude	float	44.970826
longitude	float	-93.37266

F.4 Lift Use Events

Table F-4 Lift Use Event Data Structure

Data Name	Data Type	Sample Data
CALENDAR_ID	decimal	120081101
SERVICE_ABBR	nvarchar	SAT
BLOCK_ABBR	nvarchar	1001
ROUTE_ABBR	nvarchar	2
TRIP_SERIAL_NUMBER	decimal	2
PROPERTY_TAG	nvarchar	702
TIME_POINT_ID	int	1412
GEO_NODE_ABBR	nvarchar	51581
LATITUDE	decimal	44.9619176
LONGITUDE	decimal	-93.292108
MESSAGE_TIME	int	15176
ODOMETER	int	241
time_point_name	nvarchar	22HE
lift_flag	int	1

Figure F-5 Vehicle Type Data Structure

Data Name	Data Type	Sample Data
Garage	varchar	NICL
Vehicle	int	483
Group	varchar	R
Type	varchar	R
Description	varchar	40 ft.
Seats	tinyint	42
APC	tinyint	1
Artic	tinyint	0
Low_Floor	tinyint	0

APPENDIX G: SQL SCRIPTS

G.1 Timepoint Adherence

```
IF EXISTS(SELECT TABLE_NAME FROM INFORMATION_SCHEMA.TABLES WHERE TABLE_NAME = 'tp_adherence')
DROP TABLE tp_adherence
go

create view t_apc_poc_lift as
select a.*, b.lift_event/b.lift_event as lift_flag from t_apc_poc a
left join lift_cycle_events b
on
a.calendar_id=b.calendar_id and
a.line_id=b.route and
a.block_number=b.block and
a.trip_number=b.trip and
a.service_id=b.svc and
a.node_id=b.time_point
go

create table tp_adherence (
calendar_id int,
line_id int,
line_direction varchar(8),
veh_id int,
block_number smallint,
trip_number smallint,
service_id varchar(8),
node_id varchar(4),
site_id int,
sched_time_h float,
rnd_time_h int,
act_arr_at_tp int,
act_dep_at_tp int,
arr_late_min float,
dep_early_min float,
dwell_min float,
rnd_dwell_min int,
board smallint,
alight smallint,
corner_description varchar(80),
p_dwell_min float,
p_hold_min float,
seg_to varchar(10),
lift_flag int)
go

create view tmp_tp as
select calendar_id, line_id, line_direction, veh_id, block_number,trip_number,service_id, node_id, site_id,
sched_time/3600.0 as sched_time_h,
round(sched_time/3600.0, 0) as rnd_time_h,
act_arr_at_tp,act_dep_at_tp,
(act_arr_at_tp-sched_time)/60.0 as arr_late_min ,
(sched_time-act_dep_at_tp)/60.0 as dep_early_min,
(act_dep_at_tp-act_arr_at_tp)/60.0 as dwell_min,
round((act_dep_at_tp-act_arr_at_tp)/60.0, 0) as rnd_dwell_min,
board, alight,
(apc_msg_time-act_arr_at_tp)/60.0 as p_dwell ,
(act_dep_at_tp-apc_msg_time)/60.0 as p_hold ,
seg_to, lift_flag
from t_APC_POC_lift
where act_arr_at_tp>0 and act_dep_at_tp>0 and sched_time>0
go

insert into tp_adherence
select a.calendar_id, a.line_id, a.line_direction, a.veh_id, a.block_number, a.trip_number, a.service_id, a.node_id, a.site_id,
a.sched_time_h, a.rnd_time_h, a.act_arr_at_tp, a.act_dep_at_tp,
a.arr_late_min, a.dep_early_min, a.dwell_min, a.rnd_dwell_min,
a.board, a.alight,
b.corner_description,
a.p_dwell,
```

```
a.p_hold,
a.seg_to,
lift_flag
from tmp_tp a
inner join stop_location b
on a.site_id=b.site_id
go

drop view tmp_tp
go

drop view t_apc_poc_lift
go
```

G.2 Link Travel Time

```
IF EXISTS(SELECT TABLE_NAME FROM INFORMATION_SCHEMA.TABLES WHERE TABLE_NAME = 'tp2tp_travel_time')
DROP TABLE tp2tp_travel_time
go
create table tp2tp_travel_time (
line_id varchar(8),
line_direction varchar(8),
veh_id int,
block_number smallint,
seg_from varchar(8),
seg_to varchar(8),
service_id varchar(8),
pat_id int,
t_dep_h float,
rnd_t_dep_h int,
t_arr_h float,
travel_time_min float,
rnd_travel_time_min int,
sched_travel_min float,
travel_speed_mph float)
go
insert into tp2tp_travel_time
select  a.line_id, a.line_direction, a.veh_id, a.block_number,
a.seg_to, b.seg_to, a.service_id, a.pat_id,
a.act_dep_at_tp/3600.0, round(a.act_dep_at_tp/3600.0,0),
b.act_arr_at_tp/3600.0,
(b.act_arr_at_tp-a.act_arr_at_tp)/60.0,
round((b.act_arr_at_tp-a.act_arr_at_tp)/60.0, 0),
(b.sched_time-a.sched_time)/60.0,
(b.odometer-a.odometer)*36.0/(b.act_arr_at_tp-a.act_arr_at_tp)
from t_apc_poc a
inner join t_apc_poc b
on a.line_id=b.line_id and a.line_direction=b.line_direction
and a.seg_from=b.seg_to and a.seg_from<>a.seg_to and b.seg_from<>b.seg_to
and a.trip_number=b.trip_number and a.veh_id=b.veh_id and a.pat_id = b.pat_id

where b.act_arr_at_tp>0 and a.act_arr_at_tp>0
and (b.act_arr_at_tp>a.act_arr_at_tp)
and b.odometer>a.odometer
go
```

APPENDIX H: ON-TIME PERFORMANCE (OTP) COMPARISONS

H.1 NB TP OTP

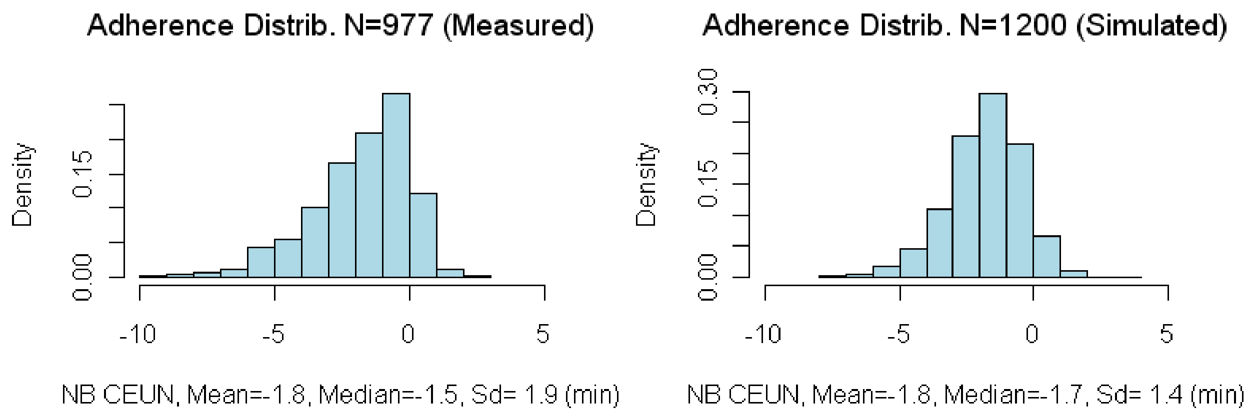


Figure H-1 Comparisons of TP Adherence (min) – NB CEUN

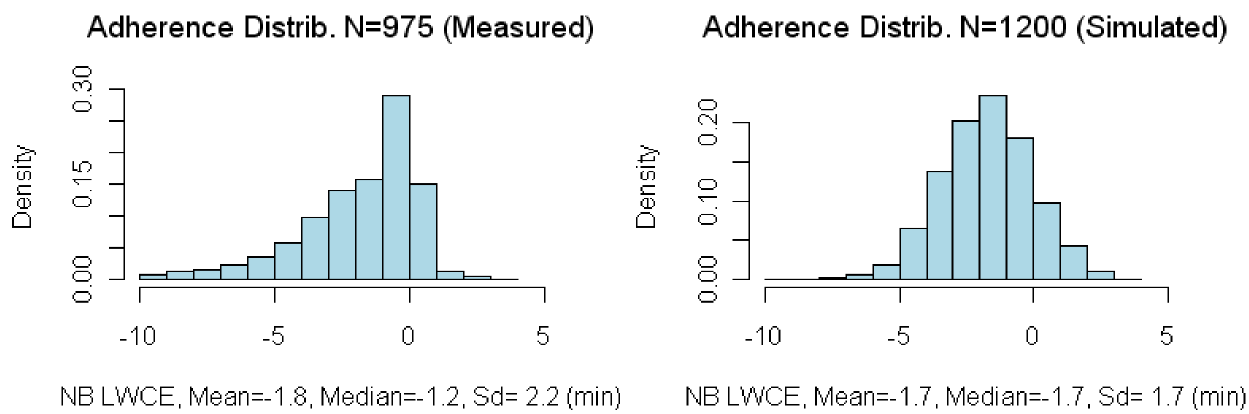


Figure H-2 Comparisons of TP Adherence (min) – NB LWCE

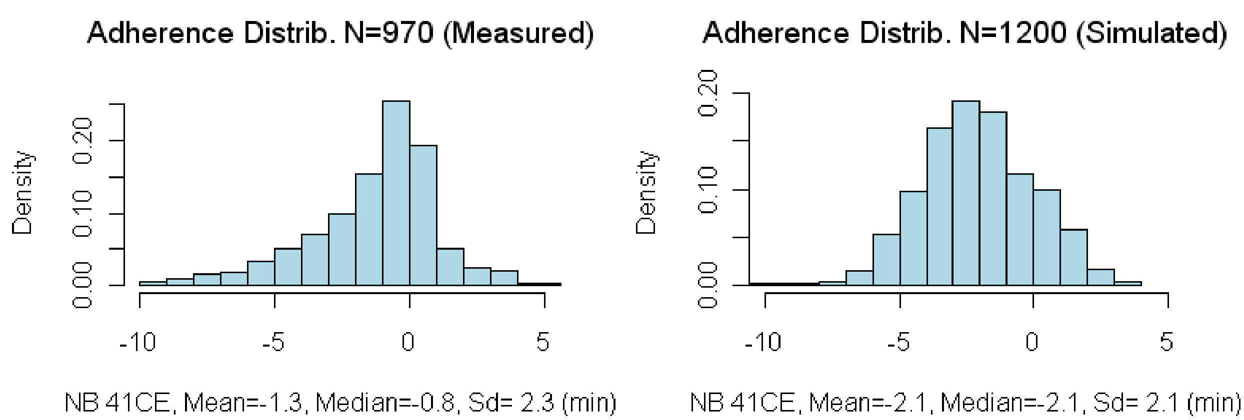


Figure H-3 Comparisons of TP Adherence (min) – NB 41CE

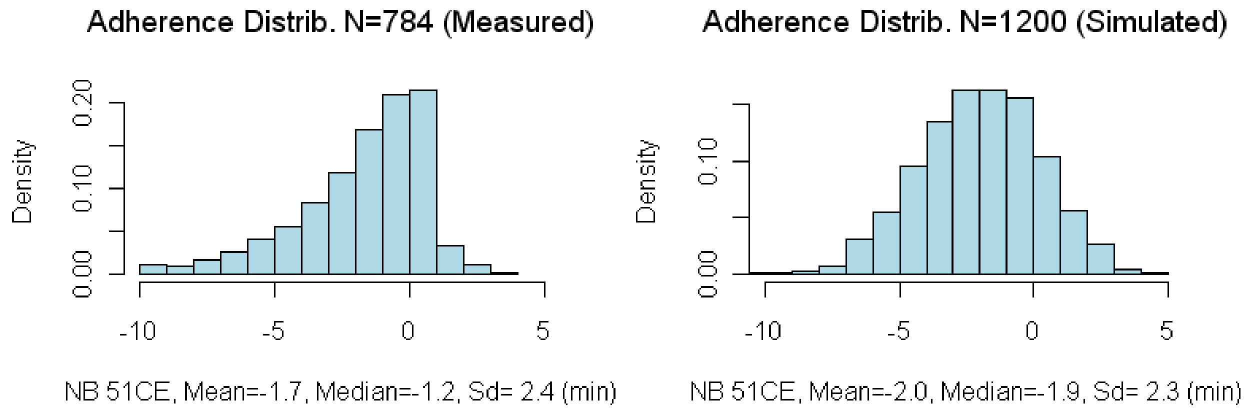


Figure H-4 Comparisons of TP Adherence (min) – NB 51CE

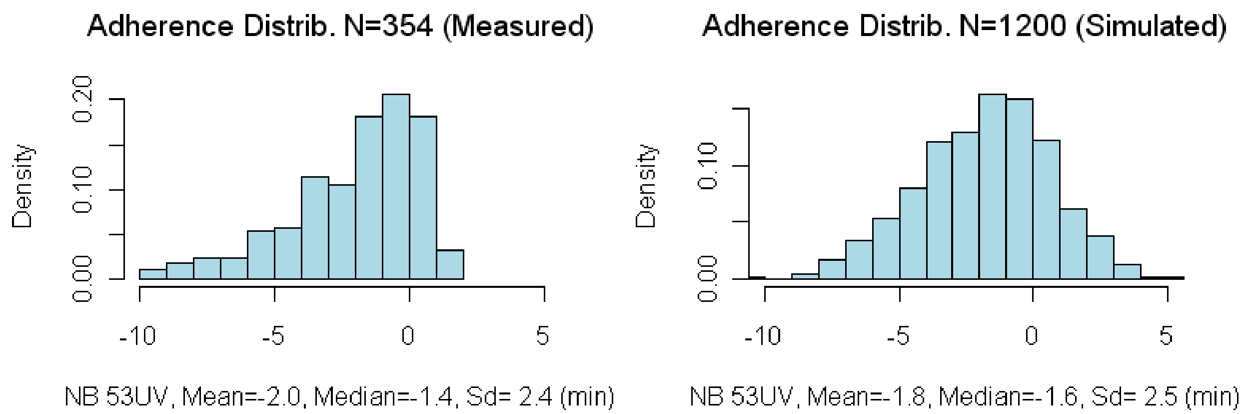


Figure H-5 Comparisons of TP Adherence (min) – NB 53UV

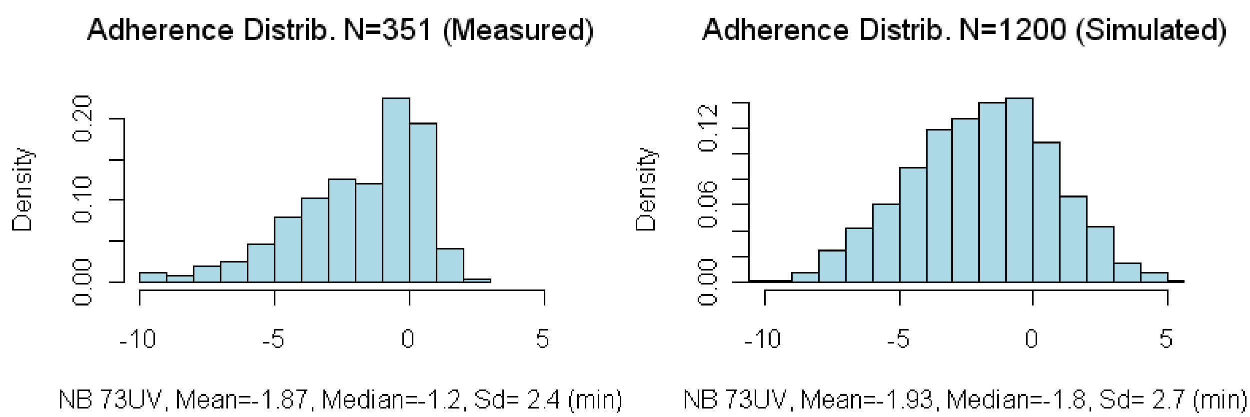


Figure H-6 Comparisons of TP Adherence (min) – NB 73UV

H.2 SB TP OTP

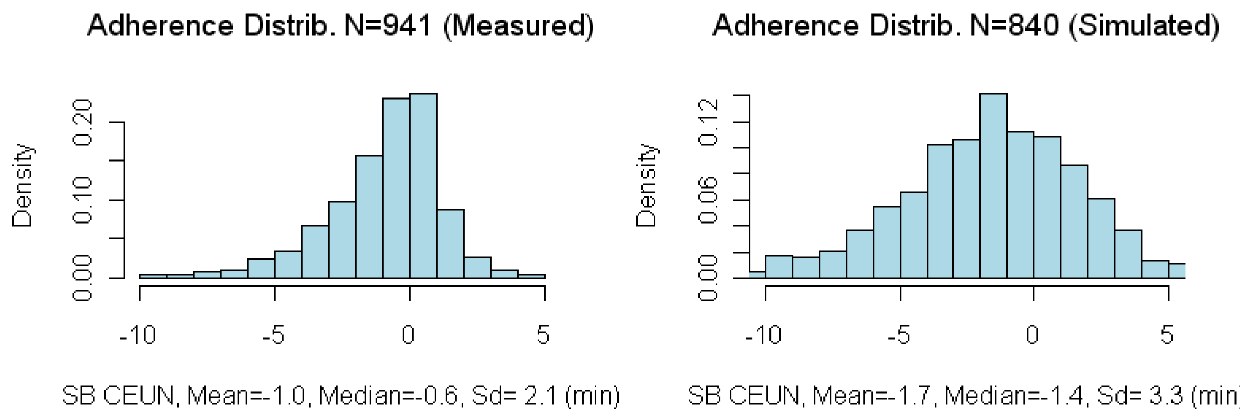


Figure H-7 Comparisons of TP Adherence (min) – SB CEUN

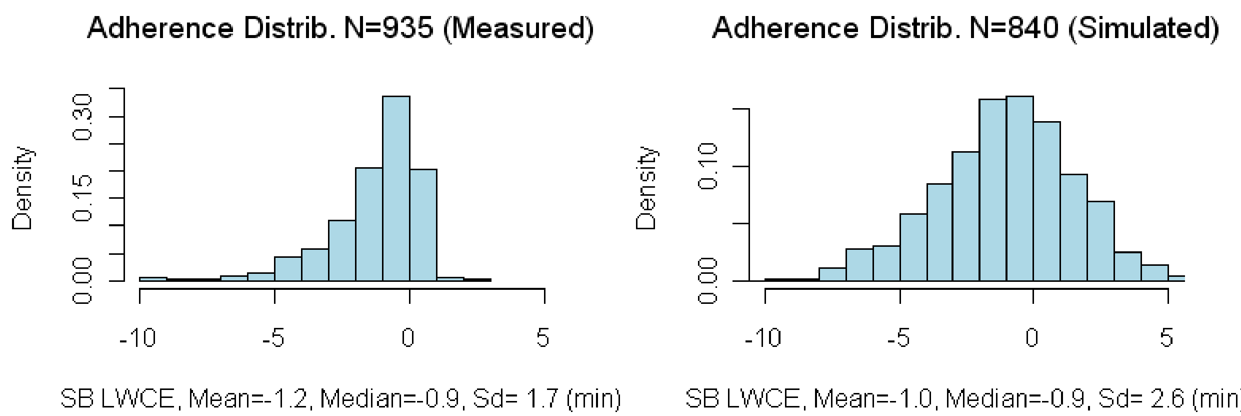


Figure H-8 Comparisons of TP Adherence (min) – SB LWCE

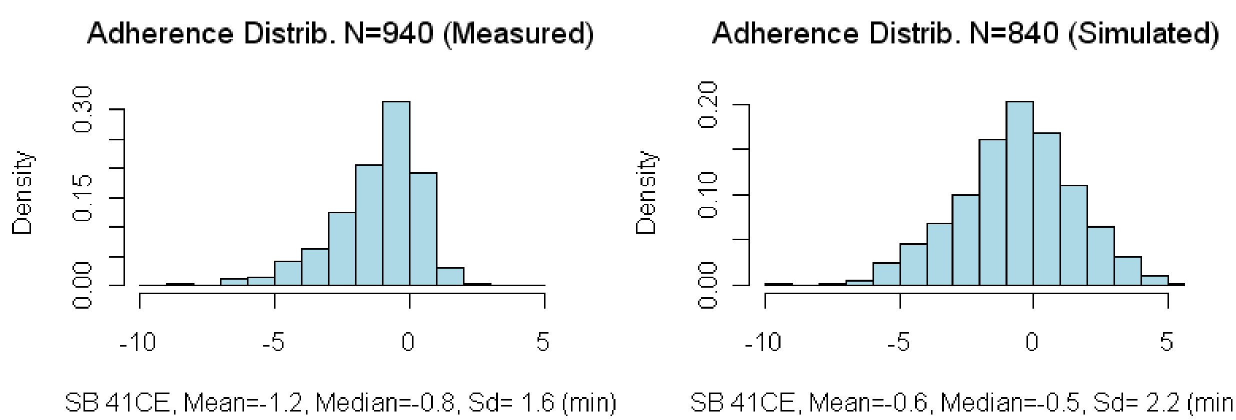


Figure H-9 Comparisons of TP Adherence (min) – SB 41CE

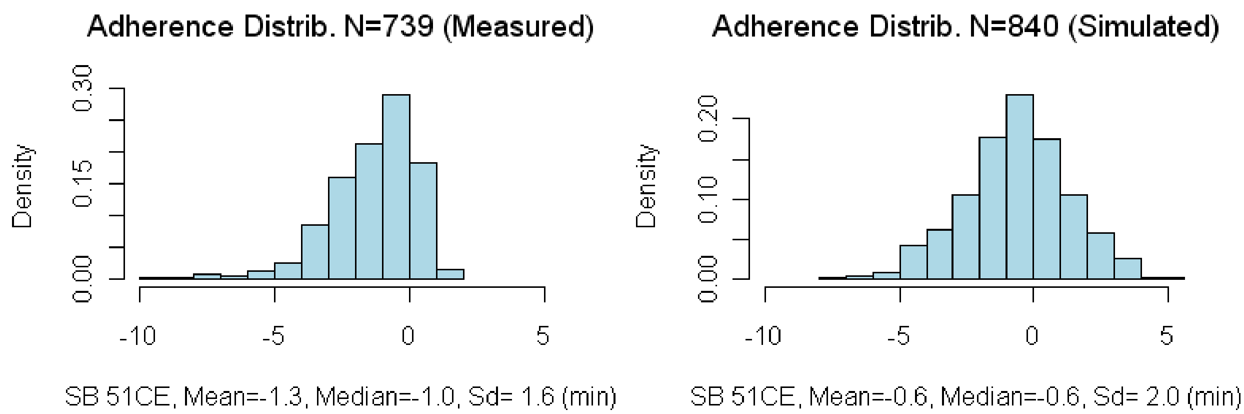


Figure H-10 Comparisons of TP Adherence (min) – SB 51CE

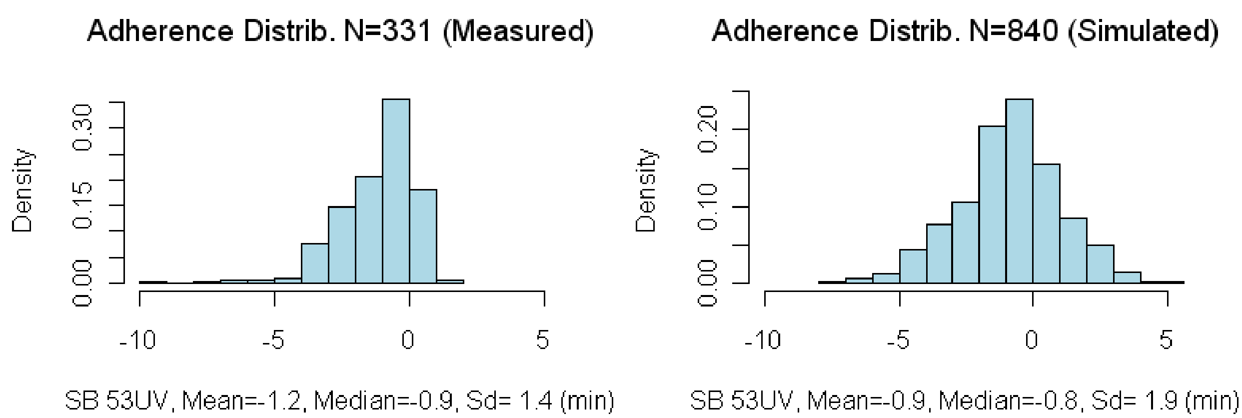


Figure H-11 Comparisons of TP Adherence (min) – SB 53UV

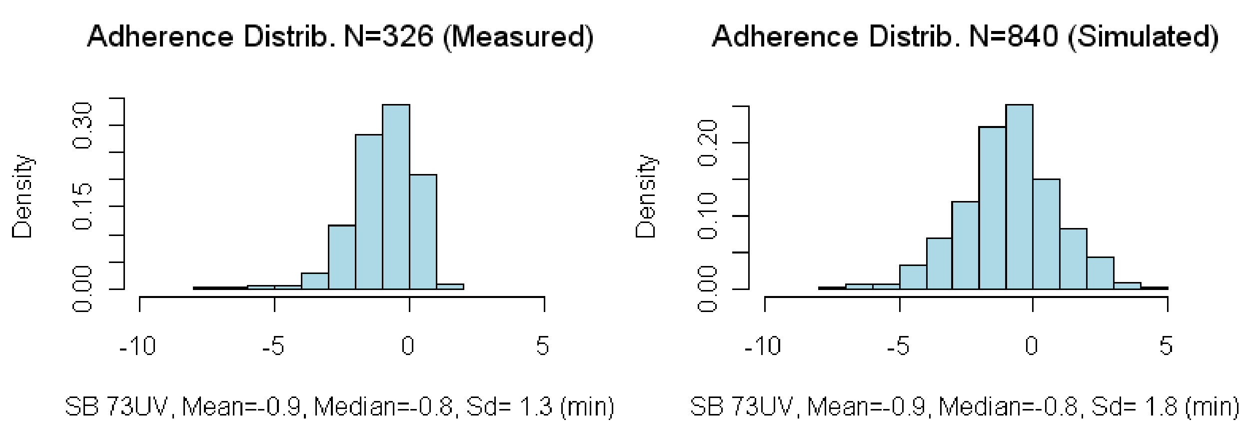


Figure H-12 Comparisons of TP Adherence (min) – SB 73UV