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A New Methodology for Evaluating the Effectiveness of Bus Rapid Transit Strategies

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A NEW METHODOLOGY FOR EVALUATING THE EFFECTIVENESS OF BUS RAPID TRANSIT STRATEGIES

by

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ABSTRACT

Over the last few years, public transportation has become more desirable as capacity of existing roadways failed to keep up with rapidly increasing traffic demand. Buses are one of the most common modes of public transportation with low impact on network capacity, especially in small and congested urban areas. However, the use of regularly scheduled buses as the main public transport mode can become useless with the presence of traffic congestion and dense construction areas. In cases like these, innovative solutions, such as bus rapid transit (BRT), can provide an increased level of service without having to resort to other, more expensive modes, such as light rail transit (LRT) and metro systems (subways). Transit signal priority (TSP), which provides priority to approaching buses at signalized intersections by extending the green or truncating the red, can also increase the performance of the bus service.

Understanding the combined impact of TSP and BRT on network traffic operations can be complex. Although TSP has been implemented worldwide, none of the previous studies have examined in depth the effects of using conditional and unconditional TSP strategies with a BRT system. The objective of this research is to evaluate the effectiveness of BRT without TSP, then with conditional or unconditional TSP strategies. The micro-simulation software VISSIM was used to compare different TSP and BRT scenarios. These simulation scenarios include the base scenario (before implementation of the TSP and BRT systems), Unconditional TSP (TSP activates for all buses), Conditional TSP 3 minutes behind (TSP only activates for buses that are 3 minutes or more behind schedule), Conditional TSP 5 minutes behind (only activates for buses 5 minutes or more behind schedule), BRT with no TSP, BRT with Unconditional TSP, BRT with Conditional TSP 3 minutes behind, and BRT with Conditional TSP 5 minutes behind.

The VISSIM simulation model was developed, calibrated and validated using a variety of data that was collected in the field. These data included geometric data, (number of lanes, intersection geometries, etc.); traffic data (average daily traffic volumes at major intersections, turning movement percentages at intersections, heavy vehicle percentages, bus passenger data, etc.); and traffic control data (signal types, timings and phasings, split history, etc.). Using this field data ensured the simulation model was sufficient for modeling the test corridor. From this model, the main performance parameters (for all vehicles and for buses only) for through movements in both directions (eastbound and westbound) along the corridor were analyzed for the various BRT/TSP scenarios. These parameters included average travel times, average speed profiles, average delays, and average number of stops. As part of a holistic approach, the effects of BRT and TSP on crossing street delay were also evaluated.

Simulation results showed that TSP and BRT scenarios were effective in reducing travel times (up to 26 %) and delays (up to 64%), as well as increasing the speed (up to 47%), compared to the base scenario. The most effective scenarios were achieved by combining BRT and TSP. Results also showed that BRT with Conditional TSP 3 minutes behind significantly improved travel times (17 – 26%), average speed (30 – 39%), and average total delay per vehicle (11 – 32%) for the main corridor through movements compared with the base scenario, with only minor effects on crossing street delays. BRT with Unconditional TSP resulted in significant crossing street delays, especially at major intersections with high traffic demand, which indicates that this scenario is impractical for implementation in the corridor. Additionally, BRT with Conditional TSP 3 minutes behind had better travel time savings than BRT with Conditional TSP 5 minutes behind for both travel directions, making this the most beneficial scenario.

This research provided an innovative approach by using nested sets (hierarchical design) of TSP and BRT combination scenarios. Coupled with microscopic simulation, nested sets in the hierarchical design are used to evaluate the effectiveness of BRT without TSP, then with conditional or unconditional TSP strategies. The robust methodology developed in this research can be applied to any corridor to understand the combined TSP and BRT effects on traffic performance. Presenting the results in an organized fashion like this can be helpful in decision making.

This research investigated the effects of BRT along I-Drive corridor (before and after conditions) at the intersection level. Intersection analysis demonstrated based on real life data for the before and after the construction of BRT using the Highway Capacity Software™ (HCS2010) that was built based on the Highway Capacity Manual (HCM 2010) procedures for urban streets and signalized intersections. The performance measure used in this analysis is the level of service (LOS) criteria which depends on the control delay (seconds per vehicle) for each approach and for the entire intersection. The results show that implementing BRT did not change the LOS. However, the control delay has improved at most of the intersections' approaches. The majority of intersections operated with an overall LOS "C" or better except for Kirkman Road intersection (T2) with LOS "E" because it has the highest traffic volumes before and after BRT construction.

This research also used regression analysis to observe the effect of the tested scenarios analyzed in VISSIM software compared to the No TSP – No BRT base model for all vehicles and for buses only. The developed regression model can predict the effect of each scenario on each studied Measures of Performance (MOE). Minitab statistical software was used to conduct this multiple regression analysis. The developed models with real life data input are able to predict how proposed enhancements change the studied MOEs. The BRT models presented in this research can be used for further sensitivity analysis on a larger regional network in the upcoming regional expansion of the transit system in Central Florida. Since this research demonstrated the operational functionality and effectiveness of BRT and TSP systems in this critical corridor in Central Florida, these systems' accomplishments can be expanded throughout the state of Florida to provide greater benefits to transit passengers. Furthermore, to demonstrate the methodology developed in this research, it is applied to a test corridor along International Drive (I-Drive) in Orlando, Florida. This corridor is key for regional economic prosperity of Central Florida and the novel approach developed in this dissertation can be expanded to other transit systems.

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CHAPTER 1 INTRODUCTION

1.1 Background

In order to reduce traffic congestion, many major cities are trying to convince drivers to switch to public transport. However, planners and transportation engineers cannot persuade roadway users to switch transportation modes without preparing a high quality and reliable public transportation network. To be competitive, the public transit system must be analyzed for all possible operational scenarios in order to provide the user/passenger with the best level of service (LOS) while servicing the most attractive destinations, especially in urban networks. Additionally, a successful transit system must be accessible to all people within the network, regardless of their income level, at a reasonable cost for both the operating agency and the user.

One major use of public transit is for commuting. Figure 1 below shows the commute patterns for major United States cities in 2008; this shows that congested cities with well-established public transit systems, such as New York City, can have up to 50%-60% public transport use by commuters, with only 20%-30% commuting by car.

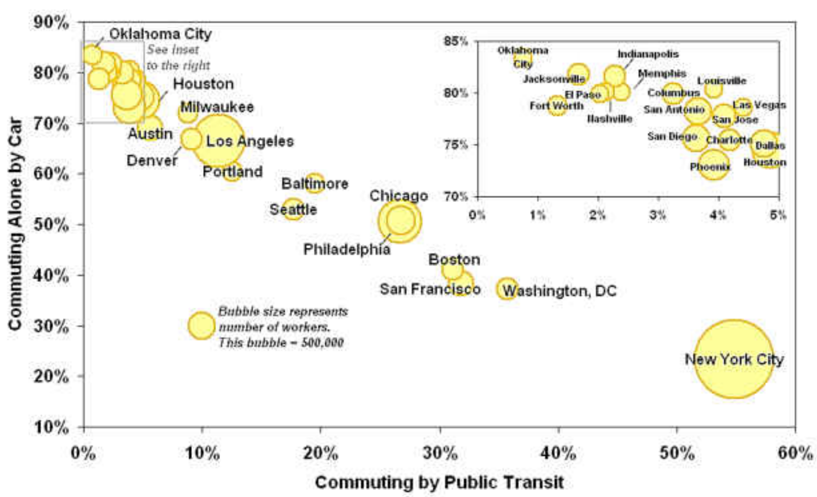


Figure 1: Major U.S. City Commute Patterns in 2008 (Wikimedia.org)

There are many types of public transit modes such as airlines, trains (including commuter and high-speed rail, tram and light rail transit (LRT), and rapid transit such as the metro/subway), and buses. On regular roadways, buses are the most common low-capacity public transit mode, especially in small areas. Since buses travel on roadways with personal cars, trucks, and other vehicles, traffic congestion and roadway construction areas are major issues that can prevent buses from reaching their scheduled destinations on time. To avoid these issues, innovative solutions are needed; one such solution is bus rapid transit (BRT). BRT can improve bus level of service (LOS) at a low cost, especially compared to other expensive public transit modes such as LRT and metro.

BRT differs from normal bus transit in that the buses have a dedicated lane. This allows the buses to avoid normal traffic congestion while also making regular drivers more comfortable, as they do not have to be interrupted by buses stopping and impeding their trips. BRT is an enhanced and customizable public transport solution intended to improve urban mobility and accessibility with its dedicated bus lanes. BRT is increasing in popularity, especially in urban areas, because of its many desirable characteristics and cost-effective installation and maintenance. With proper planning, a BRT system can provide similar services to LRT, including dedicated lanes, bus stops, quality of service, and time reliability, but for a much lower cost.

BRT can provide high capacity for a low cost, as shown in Table 1 and Figure 2. Table 1 shows the actual peak capacity for selected mass transit systems around the world; Figure 2 shows the capital cost versus passenger capacity for BRT, LRT, elevated rail, and metro. These show that the passenger capacity for BRT can be as high as 45,000 passengers per hour per direction (e.g.

BRT Bogota TransMilenio in Bogotá, Colombia) with the lowest capital cost (up to US$14 million /km) compared to LRT, elevated rail, and metro.

Table 1: Actual Peak Capacity for Selected Mass Transit Systems (Wright and Hook, 2007)

Line	Type	Ridership (Passenger/hour/direction)
Hong Kong Subway	Metro	80,000
Sao Paulo Line 1	Metro	60,000
Mexico City Line B	Metro	39,300
Santiago La Moneda	Metro	36,000
London Victoria Line	Metro	25,000
Buenos Aires Line D	Metro	20,000
Bogota TransMilenio	**BRT**	**45,000**
Sao Paulo 9 de julho	**BRT**	**34,910**
Porto Alegre Assis Brasil	**BRT**	**28,000**
Belo Horizonte Cristiano Machado	**BRT**	**21,100**
Curitiba Eixo Sul	**BRT**	**10,640**
Manila MRT-3	Elevated rail	26,000
Bangkok SkyTrain	Elevated rail	22,000
Kuala Lumpur Monorail	Monorail	3,000
Tunis	LRT	13,400

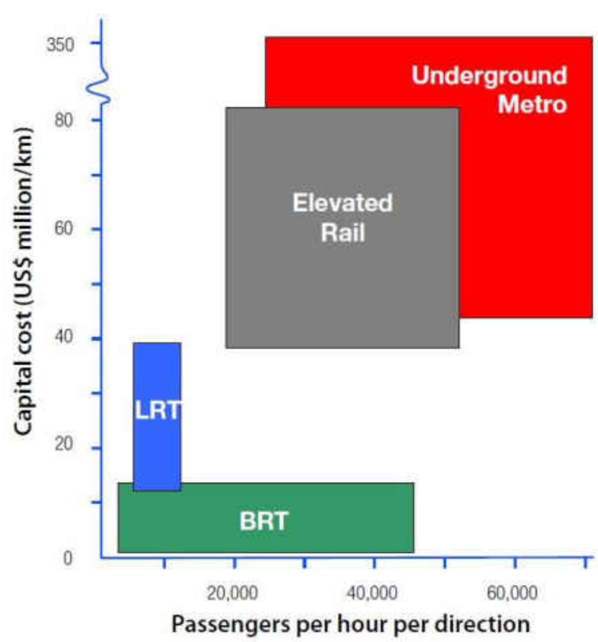


Figure 2: Passenger Capacity and Capital Cost for Mass Transit Options (Wright and Hook, 2007)

With its low capital cost, BRT can be a good starting point for transit-oriented development (TOD). TOD, which is popular in Europe, is “policy to synchronize the public transportation with cities. It is essentially about place making or designing walkable and unique places at urban scale and networking places at regional scale as enabling regional connectivity from one place” (Stojanovski, 2013). This concept is all about making city residents and visitors connected through public transportation systems while minimizing or even eliminating the need for private cars. TOD can start from homes and neighborhoods and then expand through collector streets and highways to eventually incorporate all of the attractions in a city or even connect cities to each other. The BRT system can be the beginning of this major plan, which will utilize other transit modes as well. Integration of BRT into TOD can significantly advance the development of urban life.

There are many features (options) that can be applied in accordance with BRT to improve its performance and convenience to passengers; the most common option is transit signal priority (TSP) at intersections. TSP provides priority to buses at signalized intersections by either extending the duration of the green phase or shortening the length of the red phase. In order for TSP to work correctly, the buses must be equipped with tracking equipment that can accurately detect the buses’ locations. When a bus approaches a TSP-equipped intersection, the TSP checks various parameters, including the vehicles’ phase, BRT’s phase, and pedestrians’ phase at the signal to determine if and how the bus should be given priority. TSP can improve the BRT system by increasing average travel speed, reducing travel time and delay, and enhancing bus schedule reliability without having significant negative effects on both the vehicular traffic through the BRT corridor and the crossing street traffic.

Parking management and park and ride service are other options that can enhance the BRT system. Having parking areas at the ends of the BRT corridor where passengers can park their cars free of charge and board a bus increases the convenience of passengers, especially for those who live away from the serviced corridor and network. This convenience can make BRT a more attractive choice than cars. For example, a BRT system in Los Angeles with park and ride service had 18% of its ridership come from cars and 33% of its passengers chose to use the BRT, even though they could have used their cars (Panero et. al, 2012). These percentages can be increased with more services that attract users.

In 1997, LYNX (the public transit provider for Orange, Osceola, and Seminole Counties in Florida which also provides connectivity with Lake and Polk Counties) and the City of Orlando started the free LYMMO BRT system in downtown Orlando. Figure 3 below shows a bus running on the LYNX LYMMO BRT system in downtown Orlando.

Figure 3: A Bus Running on LYMMO BRT system (LYMMO Construction Updates, 2014)

This system consists of two lines (called Orange and Grapefruit) with a total length of three miles loop and a project cost of $21 million (50% federal, 25% state, 25% local). Figure 4 below shows the LYMMO Orange and Grapefruit loop lines in downtown Orlando.

Figure 4: LYMMO Orange and Grapefruit loop lines in Downtown Orlando (LYMMO Brochure M, 2014)

The bus headways for these lines are 4 minutes during peak, 10 minutes during off-peak, and 15 minutes during off-off-peak. To improve its performance, LYMMO includes various ITS elements such as "transponders to track bus locations and time points, kiosks at stations, and signal priority" (Nashville Metropolitan Planning Organization MPO).

According to the Federal Transit Administration (FTA), LYMMO was "one of the first bus-based premium downtown circulators in the United States" (FTA Summary Report, 2013). Also, LYMMO ranked as one of the top five routes in the LYNX system and was rated highly by passengers (4.5 out of 5 customer satisfaction). Additionally, the FTA considers LYMMO to be a cost-effective service with an operational cost per passenger trip of $1.35 - $3.12, which is lower than U.S. streetcar systems, which typically have costs ranging from $3.35–$10.25 per passenger trip (FTA Summary Report, 2013).

Currently, LYMMO is using the Opticom GPS priority control system for its TSP; an overview of this system can be seen in Figure 5. Each bus has an Opticom GPS emitter that is connected to the automatic vehicle location (AVL) system. The AVL provides the bus location to the LYNX central office and allows LYNX to see if the bus is behind schedule or not. If the bus is behind schedule, the bus's Opticom GPS emitter will activate the TSP system at signalized intersections and request the traffic signal controller to provide priority to the bus by either starting the green early (early green) or extending the duration of the green phase (green extension).

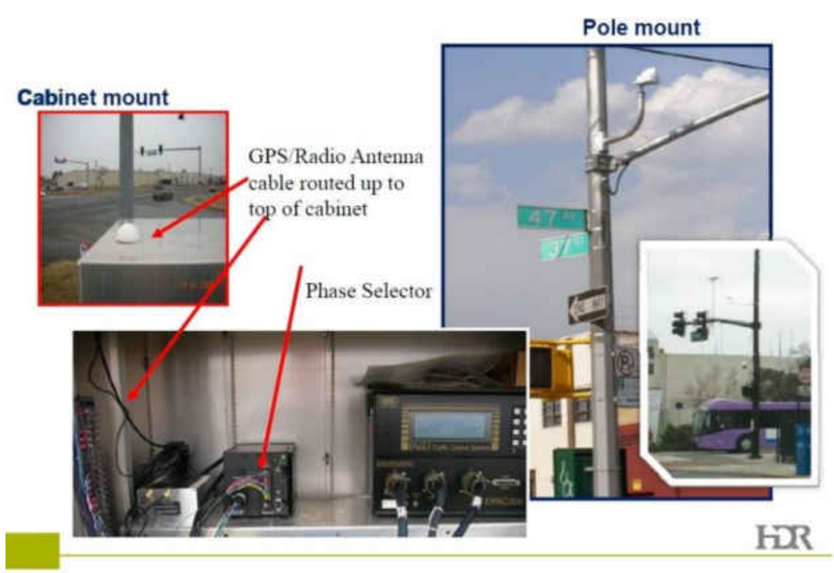


Figure 5: Opticom GPS Priority Control System Overview (HDR, 2013)

The City of Orlando has three levels of signal preemption: the highest level of priority is for railroad crossings, the second level is for emergency vehicles, and the lowest level is for transit. This means that if an emergency vehicle approaches an intersection, it will have priority over the transit vehicle.

1.2 Research Goal and Objectives

The main goal of this research is to evaluate the performance of BRT with conditional and unconditional TSP in a real life corridor (the I-Drive corridor in Orlando, FL). The existing conditions before implementing TSP and BRT systems on the corridor will be compared to the conditions after applying first TSP only and then BRT with TSP to see the impact of BRT and TSP on the system performance. It is desired to determine if these systems improve the overall transit network system level of service in the city by providing frequent and reliable service with high ridership rate in the most congested area on I-Drive. This study will include three main levels of simulation:

- **Existing Scenario** (without TSP and BRT).
- **TSP Scenarios**: TSP Unconditional, TSP Conditional with 3 minutes, and TSP Conditional with 5 minutes behind schedule.
- **BRT Scenarios**: BRT with No TSP, BRT with Unconditional TSP, BRT with Conditional TSP (3 minutes behind schedule), and BRT with Conditional TSP (5 minutes behind schedule).

The following objectives need to be accomplished to achieve the above goal:

⇨ Understand the traffic flow characteristics (e.g. travel time, delay, etc.) in the study corridor before and after implementing conditional and unconditional TSP and BRT in order to evaluate the corridor with and without these systems.

⇨ Model the overall impact of the conditional and unconditional TSP and BRT systems on the local traffic network, including side streets at signalized intersections in the corridor, to check for any possible negative effects and determine the most beneficial and practical scenario.

⇨ Conduct sensitivity analysis using a simulated environment to study the main effects of implementing conditional and unconditional TSP and BRT systems on buses and other traffic under several scenarios.

⇨ Develop a model that can evaluate and predict the performance of BRT with conditional and unconditional TSP in a real life corridor (the I-Drive corridor in Orlando, FL) as part of a wide-ranging future regional plan for the state of Florida.

⇨ Verify if BRT with TSP can create a more attractive public transportation system (compared to other modes of transportation) by increasing bus speed and reducing bus delay and travel time.

In addition to the above, this research will provide an innovative approach by using multiple linear regression and nested sets (hierarchical design) of TSP and BRT combination scenarios. Coupled with microscopic simulation, statistical analysis are used to evaluate the effectiveness of BRT without TSP, then with conditional or unconditional TSP strategies. The robust methodology that will be developed in this research can be applied to any corridor to understand the combined TSP and BRT effects on traffic performance. Presenting the results in an organized fashion like this can be helpful in decision making.

This research will use the microscopic multi-modal traffic flow simulation software VISSIM [developed by Planungsbüro Transport und Verkehr GmbH (PTV) in Karlsruhe, Germany (PTV Group, 2015)]. VISSIM has many abilities, including the modeling of arterial, freeway, public transit, and pedestrian modes; comparing junction geometries; analyzing public transport priority schemes; and accurately simulating traffic patterns. The software offers much flexibility, as the concept of links and connectors allows users to model geometries with any level of complexity and integrate them with other systems such as signal controllers, traffic management or emissions models (PTV-VISSIM).

The intersections LOS analysis will be performed using the Highway Capacity Software™ (HCS2010), which was developed based on the Highway Capacity Manual (HCM 2010) procedures for Urban Streets and Signalized Intersections (McTrans).

1.3 Case Study Network (Selected Corridor)

I-Drive is a major tourist attraction, as it is a major roadway close to six major theme parks (SeaWorld Orlando, Discovery Cove, Aquatica SeaWorld's Waterpark, Wet 'n Wild, Universal Studios Florida, and Islands of Adventure), along with many other additional attractions, including the Orlando Premium Outlets, Fun Spot Orlando, and the Orange County Convention Center. It is also only minutes away from Walt Disney World Resort. These attractions create high traffic movements and congestion throughout the year, especially during conventions, for tourists, business travelers, and workers alike.

Figure 6 below illustrates the I-Drive test corridor and indicates both the eastbound to northbound movement (eastbound direction) and the southbound to westbound movement (westbound direction). This test corridor is approximately 1.1 mile in length and stretches from Wet 'N' Wild at Universal Boulevard to Fun Spot Way (near the Orlando Premium Outlets). This corridor was chosen for TSP testing since it was the site of a demonstration project for TSP in October 2011 for the ITS World Congress held in Orlando. There are six major signalized intersections along the corridor: Universal Boulevard (T1), Kirkman Road (T2), Grand National Drive (T3), Municipal Drive (T4), Del Verde Way (T5), and Fun Spot Way (T6).

Figure 6: International Drive Test Corridor

According to the Florida Department of Transportation (FDOT), there are 39 intersections in the City of Orlando equipped with TSP systems (FDOT, July 2014). These systems are operated for LYNX (Central Florida Regional Transportation Authority). In October 2011, the City of Orlando implemented Unconditional TSP along this corridor; this provided signal priority for any GPS equipped bus serving LYNX LINK 8 (shown in Figure 7) regardless of schedule adherence or passenger load. In early 2013, the City of Orlando and LYNX converted the Unconditional TSP to a Conditional TSP system, which only provides signal priority to buses that are 3 minutes or more behind schedule.

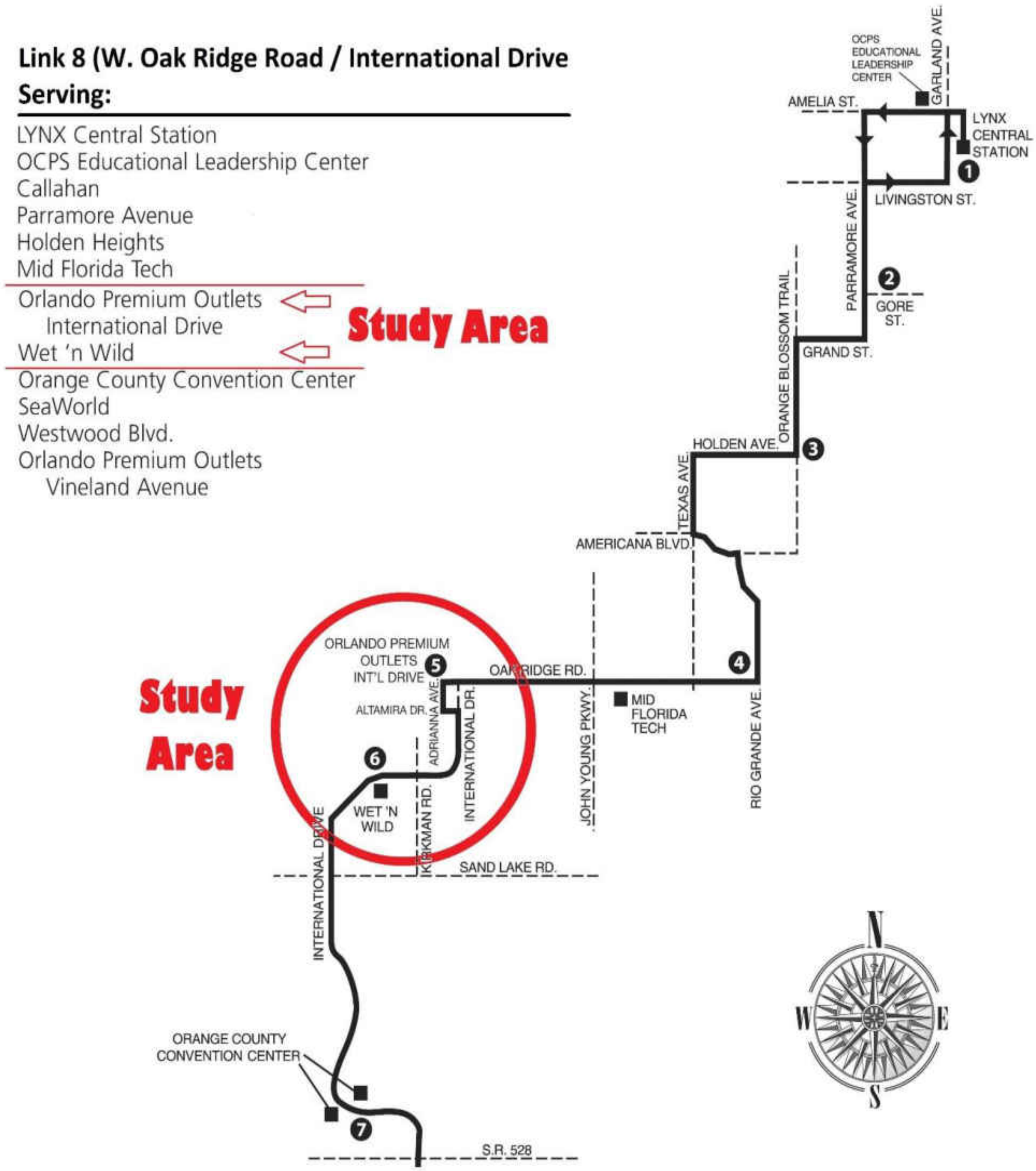


Figure 7: Part of Link 8 Route (LYNX Link 8, 2014)

BRT construction on I-Drive started in July 2013 with a budget of $9,000,000 and was completed by the end of 2014. In this corridor, there is a dedicated curb-side bus lane in each direction with the TSP system active at all of the corridor intersections. Figure 8 shows a three dimensional small section concept of the I-Drive BRT system.

Figure 8: Concept for the proposed BRT system on I-Drive, Orlando (I-Drive Master Transit and Improvement District)

As will be demonstrated under next chapter in this research (literature review), previous research addressed the impact of TSP on bus and general traffic operations. However, the impact of combining both BRT and TSP scenarios (conditional and unconditional) has not been thoroughly examined and understood. Improving traffic progression in one direction to benefit the bus and other vehicles moving in that direction can also result negative impacts on crossing traffic. Therefore, a holistic approach should be used to evaluate what scenarios are practical to implement. Due to the complicated nature of real life networks, a simulation approach with proper design of scenarios is needed. Furthermore, it is critical to demonstrate this approach using real life corridors.

CHAPTER 2 LITERATURE REVIEW

This literature review summarizes the most important research that has been performed on TSP and BRT worldwide to support the idea behind this research and shows possible ways to expand it. The first section of this literature review discusses TSP, including its definition, benefits, components, engineering approach, and examples. The second section explains BRT, including its definition, history, benefits, and components. The third section summarizes the most important BRT studies and strategies that have been applied around the world. The fourth section discusses in more detail previous studies and research that combined both BRT and TSP, along with other strategies.

2.1 Transit Signal Priority (TSP)

2.1.1 TSP definition

Transit Signal Priority (TSP) is an operational strategy that provides efficient transit operation (improved movement) by providing priority to transit vehicles at signalized intersections in one of two ways (shortening red phase or extending green phase), without negatively affecting the signal coordination, as shown in Figure 9 (Smith et al. 2005).

2.1.2 TSP major benefits

- Reduces transit signal delay (40% in Tacoma, WA), travel time (10% improvement in Tri-Met Portland, OR), and running time (about 15% in Chicago, IL), (Smith et al. 2005)
- Enhances schedule reliability (Cosgrove 2008).

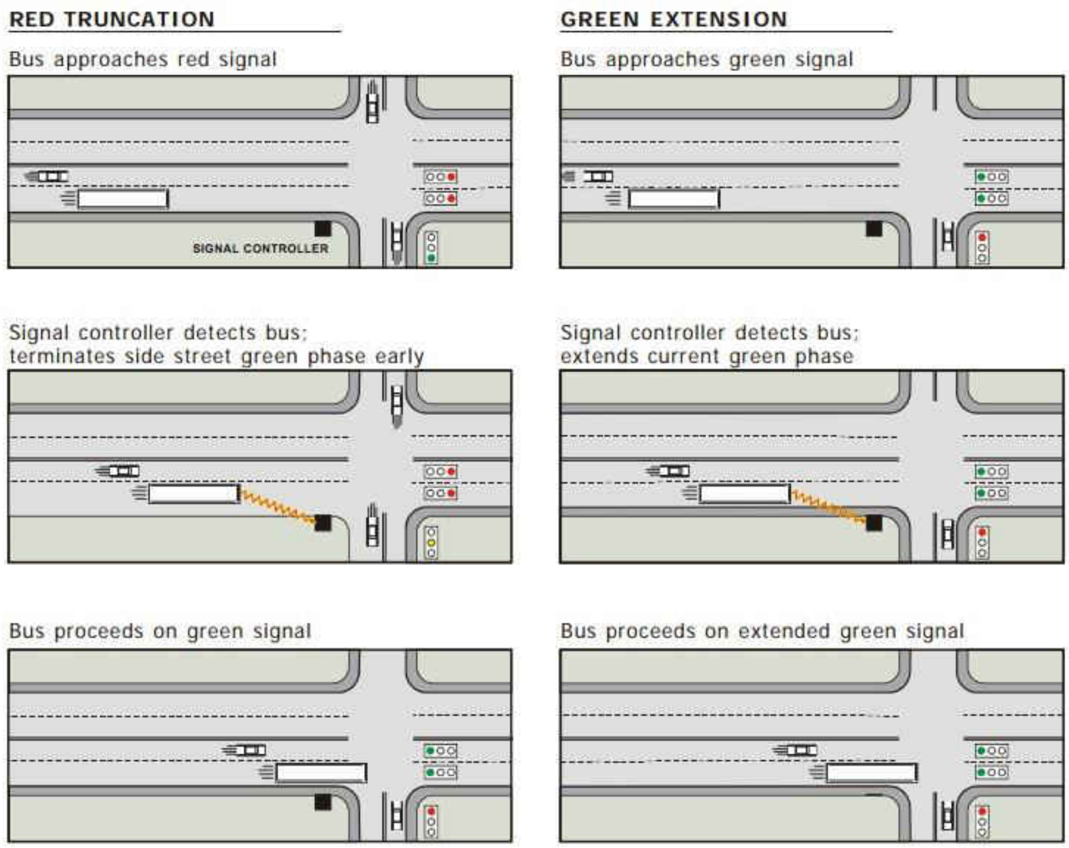


Figure 9: TSP Concept Example (TCRP Report 100, 2003)

2.1.3 TSP components

The operation of TSP consists of various components that interact with each other in a specific order. There are four main components in a typical TSP system (Smith et al. 2005):

- Detection system which collects transit vehicle data (location, arrival time, approach, etc.).
- Priority request generator which requests vehicle priority from the traffic control system.
- Priority control strategies (traffic control system software) which decide whether or not to grant priority.
- TSP system management, which is a software that manages the system, collects data, and generates reports.

Figure 10 shows the signal phasing timeline for a transit signal priority request.

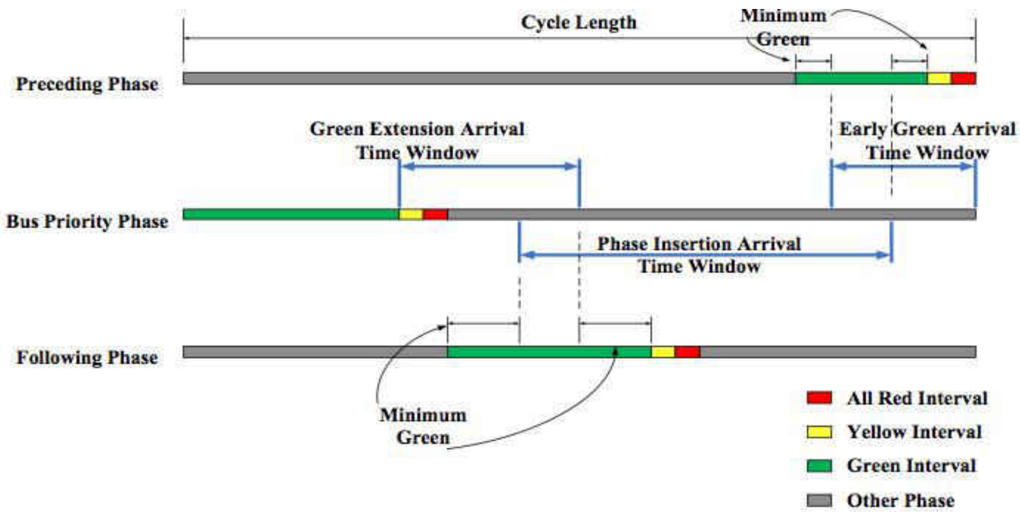


Figure 10: Transit Signal Priority Request (Zhang et al., 2012)

2.1.4 TSP engineering approach

Any successful implementation of TSP requires the following steps (Smith et al. 2005):

- Planning – This is a pro-active step to initiate a change even before any problem occurs (such as delay at intersection). Planning usually consists of goals, roles and responsibilities, locations under study, technology and system architecture.

- Design – This usually begins with detailed data collection and includes "a detailed design and engineering of each intersection and related road-side equipment; design and engineering of on-board equipment; optimization and preparation of signal timing plans; and perhaps modeling" (Smith et al. 2005). This step also includes the detailed design of the TSP system components, optimization, and timing plans with simulation model.

- Determination of appropriate TSP strategy – Some common TSP strategies are discussed below.

1) Passive signal priority: this is defined as "the use of static signal settings to reduce delay for transit vehicles" (Davol A., 2001). A passive priority strategy can be the best choice for deployment if the transit operation is very predictable based on a good understanding of routes, passenger loads, schedules, and dwell times. It can be deployed without the need for software, hardware or even transit detection. In this strategy, all the signals throughout a corridor of transit vehicles operate continuously with a fixed timing. However, the signals are coordinated for the flow of transit vehicles, which could cause unnecessary delays and stops for other vehicles. Common passive priority strategies include the use of a shorter cycle length, allocating more green time to the street with the transit route, split phasing, and signal coordination (Davol A., 2001).

2) Active signal priority: operation of this strategy requires detection devices at the intersections and advanced controllers for granting priority. The operation mechanism adjusts the signal timing in real time to minimize the delay experienced by an approaching transit vehicle. The controller type response to the detection request depends on when the vehicle will be detected in the cycle (Davol A., 2001). This response could be green extension, early green, or phase insertion (Smith et al., 2005). Active signal priority strategies can be divided into three categories (Davol A., 2001):

   - *Unconditional*: priority is given to every transit vehicle detected.
   - *Conditional*: priority is only given to transit vehicles that exceed a certain criterion; the most common criterion is amount of time behind schedule, but other criteria can include vehicle headway or passenger load.
   - *Adaptive signal priority*: the transit vehicle delay, as well as the delay faced by all

other vehicles, are analyzed and then the controller decides on the best response to achieve optimization. For this strategy, there is no need for predefinition of priority actions (green extension, early green, or phase insertion).

- Implementation and installation of TSP; operations and maintenance for the TSP; and evaluation, verification, and validation.

2.1.5 TSP Examples

Zhang et al. (2012) studied TSP (bus trend time prediction and traffic signal optimization) with connected vehicles for transit-based evacuation with a case study example on Hurricane Gustav in Gulfport (Mississippi Gulf Coast area). CORSIM (microscopic simulation software) was used in building the model, which evaluates many scenarios concerning "bus travel time prediction, traffic signal optimization, and fixed-time control at the intersections along the bus route" (Zhang et al. 2012) to find the best scenario. Four scenarios were developed with 100 simulation runs for each: existing conditions scenario, preemption scenario for transit signal (unconditional green time), priority scenario for transit without connected vehicles, and connected vehicle scenario in coordination with optimized TSP. Results showed a 12.8% bus travel time reduction and 3.8% average vehicle delay increase (still manageable) in the network if the traffic volume increased by 25%.

Pessaro (2012) measured the impacts of before and after transit signal priority results for the I-95 Express Bus service in South Florida. These measures included travel time results, on-time performance, component of delay, and average delay per intersection. The study was performed on 24 intersections equipped with TSP by synchronizing the collected travel time data from the automated passenger counters (APCs) with the observers' data. Results showed a 12% reduction in bus travel time, and a decrease in average signal delay from 24% to 20%. More importantly, on-time performance was improved from 66.7% to 75%, resulting in a 4 minute reduction in running times.

Chada and Newland (2002) studied the effectiveness of bus signal priority in a technical report. They did an evaluation of TSP's (bus signal priority) impact on traffic operations. The evaluation was done under different control strategies with different parameters, including "level of congestion, placement of bus stops, presence of express bus service, and number of transit vehicles on route required different techniques of TSP such as real-time or fixed-time based control" (Chada and Newland 2002). Case study projects in North America were discussed, including one in downtown Orlando, where TSP was implemented on LYMMO busses in 1997 by the Central Florida Transportation Authority. Signal preemption and automatic vehicle location (AVL) were used in the service operation with special phases only for LYMMO busses. Discussions showed that TSP cannot work effectively under high bus volumes or low traffic and the best solution was to use real-time control strategy.

2.2 Bus Rapid Transit (BRT)

2.2.1 BRT definition

The Bus Rapid Transit (BRT) system is defined by the U.S. Department of Transportation (USDOT), Federal Transit Administration (FTA) as an "enhanced bus system that operates on bus lanes or other transit ways in order to combine the flexibility of buses with the efficiency of rail. By doing so, BRT operates at faster speeds, provides greater service reliability and increased customer convenience. It also utilizes a combination of advanced technologies, infrastructure and operational investments that provide significantly better service than traditional bus service" (USDOT, 2015). Bus lanes are roadway lanes exclusively for buses which do not allow any other modes of transportation. Two types of bus lanes are commonly used: curbside lanes and median lanes. These types of lanes are shown in Figure 11 and discussed below.

a) ***Curbside lanes*** are BRT lanes located along the curb. Parking, standing, stopping, and right turns at intersections can affect the functionality of these lanes. Various solutions to these problems have been introduced, including having double parking beside the bus lane, allotting certain times for parking and certain times for buses only, and having a prohibited right turn at certain intersections to reduce bus delay.

b) ***Median lanes*** are BRT lanes located along the median. Typically, these lanes are installed in wide streets that can accommodate the BRT system, including typical bus stops and right-of-way, in the median. Since the bus doors are on the right of the bus, a raised curb separation from the other traffic lanes is needed in order to have bus stops on the right. Center bus stops can be used if the buses have left-side doors. Unlike the curbside lanes, median lanes usually do not have much conflicts with other traffic, such as parking or right turns; however, median lanes can cause conflicts with left turners (can be solved with permitted or separated left turn phase) and cause bus passengers issues regarding their safety while crossing the street to reach the outer sidewalk (can be solved with bridges or tunnels).

Figure 11: Curbside Lanes (Left) and Median Lanes (Right) (Grid Chicago blog, 2014)

2.2.2 BRT history

The first BRT system in the world established in Curitiba, Brazil, in 1974 by the architect and urban planner Jaime Lerner, former Mayor of Curitiba, Brazil, for three terms, (Weinstock et al., 2011). Figure 12 below shows the evolution of using public transit in the United States. It can be seen that the first exclusive bus lane in the United States was established in 1939 in Chicago. In 1973, Los Angeles built its exclusive bus lanes then expand it to carpools in 1976. Also, Pittsburgh, Pennsylvania opened its exclusive bus lanes in 1977.

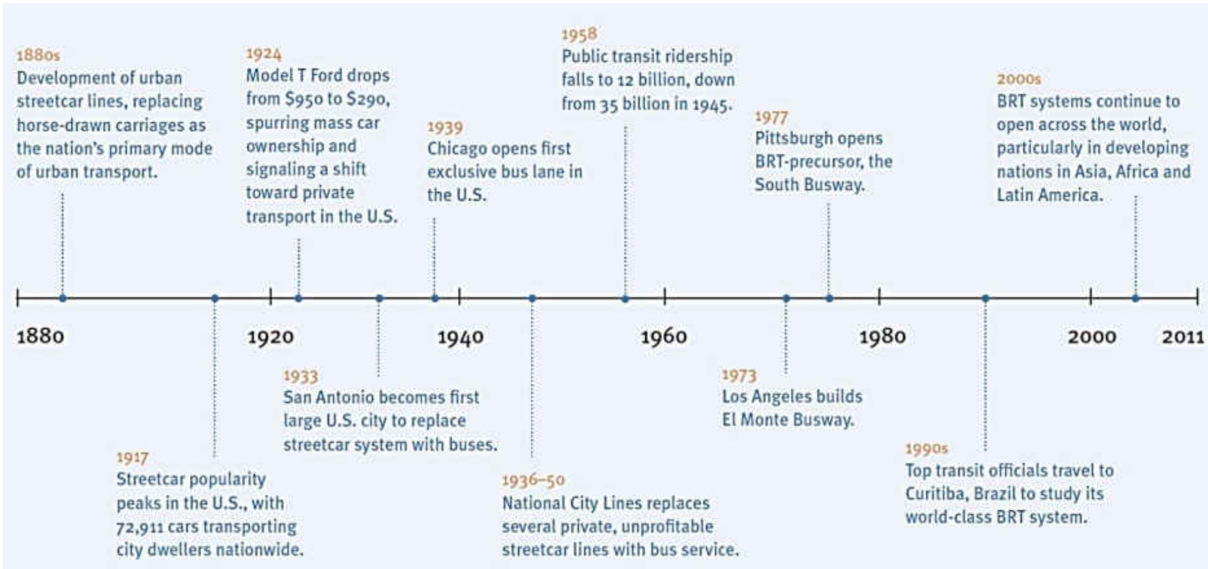


Figure 12 Public Transit milestones in the United States (Weinstock et al., 2011)

In 1969, the first high speed busway opened in Washington DC with a length of 6.5 km and a 16 m right-of-way (Peter Midgley, 2005). After the 1973 oil crises in Europe and the U.S., there was increased interest in public transport; by the year 1980, there were 27 BRT system established worldwide:

- U.S. (10 systems): Boston, Chicago, Dallas, Dayton, Los Angeles, Milwaukee, New York, Pittsburgh, San Francisco, and Washington DC.
- Europe (7 systems): Belgium (Liege), France (Evry, Paris, and Saint-Quentin-en-Yvelines), and United Kingdom (Redditch, Runcorn, and London).
- Latin America (7 systems): Brazil (Curitiba, Belo Horizonte, Goiania, Porto Alegre, Recife, and Sao Paulo), and Trinidad (Port-of-Spain).
- Middle East (2 systems): Turkey (Istanbul, and Ankara).
- Africa (1 system): Ivory Coast (Abidjan).

Nowadays, the BRT system is a popular mode of transportation in more than 160 cities worldwide and can carry nearly 30 million daily passenger trips (Carrigan et al., 2013). Table 2 below shows the BRT growth since the 1970s.

Table 2: Evolution of BRT Systems around the World (Wirasinghe et al., 2013)

2001-Present	**More than 104 cities have implemented BRT in this era.** Ahmedabad, Amsterdam, Auckland, Bangkok, Barranquilla, Beijing, Blumenau, Boston, Bradford, Brampton, Brasília, Brescia, Brisbane, Bucaramanga, Buenos Aires, Caen, Cali, Cambridge, Cape Town, Changzhou, Chongqing, Cleveland, Crawley, Dalian, Diadema São Paulo, Douai, Ecatepec, Edinburgh, Eindhoven, Eugene, Gothenburg, Guadalajara, Guangzhou, Guatemala, Guayaquil, Halifax, Hamburg, Hangzhou, Hefei, Istanbul, Jaboatão dos Guararapes, Jaipur, Jakarta, Jinan, João Pessoa, Johannesburg, Kansas City, Kent, La Rochelle, Lagos, Las Vegas, León de los Aldama, Lille, Lima, London, Londrina, Lorient, Los Angeles, Luton, Lyon, Maceió, Maubeuge, Medellín, Melbourne, Merida, Mexico City, Monterrey, Nagoya, Nancy, Nantes, Natal, New Delhi, New York, Niteroi, Oakland, Olinda, Panama, Pereira, Phoenix, Prato, Pune, Rio de Janeiro, Rouen, Santiago, Santos, Seoul, Snohomish County Snohomish, County, Stockton, Sumaré, Swansea, Sydney Parramatta/Rouse Hill, Sydney, Blacktown/Rouse , Hill, Sydney, Liverpool /Parramatta, Tehran, Toulouse, Uberlândia, Utrecht, Winnipeg, Xiamen, Yancheng, York, York Regional Municipality, Zaozhuang, Zhengzhou
1981-2000	2000:Bogotá, Colombia; Twente, Netherlands 1998: Taipei, Taiwan; Juiz de Fora, Brazil; 1999:Kunming, China; Joinville, Brazil 1996: Vancouver, Canada; 1997: Dublin, Ireland; Miami & Orlando, US 1995:Leeds, UK; Quito,Ecuador; 1996:Oberhausen, Germany; Jonkoping, Sweden 1988:Mauá -Diadema, Brazil; 1993:Paris, France; 1994:Ipswich, UK 1983:Ottawa, Canada; 1985: Nagoya, Japan; 1986:Adelaide, Australia
Before 1980	1980: São Paulo, Brazil; Essen, Germany 1977: Pittsburgh, US; Porto Alegre, Brazil 1976: Goiania, Brazil 1974: Curitiba, Brazil 1971: Runcorn, UK 1969: Virginia, US

2.2.3 BRT benefits

The main goal of establishing BRT system is to improve the level of service across the serviced corridor and the entire surrounding network. This has positive benefit-cost implications, as well as many other practical effects, including the following:

1. Reduction in travel time and delay. This is the key improvement area of BRT due to system wide reductions in delay while passengers are waiting for and boarding the bus, delay due to general congestion, delay due to traffic signals, and delay due to right turns. For example, the Istanbul BRT system can save a typical passenger nearly 52 minutes per day (Carrigan et al., 2013).

2. Improvement in speed and reliability. Roadway users will not switch to BRT unless it has schedule reliability, as that will affect the quality of service and arrival time accuracy. This can be enhanced by having a frequent service with appropriately distributed stations to reduce the number of stops and stopping time and to use TSP to improve average speed.

3. Reduction in environmental impacts. By convincing roadway users to switch to public transport, BRT will reduce the vehicle miles travelled (VMT) and consequently vehicle emissions, which will reduce the amount of greenhouse gases and air pollutants. For example, the Istanbul BRT system can "reduce CO_2 emissions by 167 tons/day and cut daily fuel consumption by more than 240 ton-liters" (Carrigan et al., 2013).

4. Increased safety. A BRT system can reduce the amount of fatalities, injuries, and property damage due to crashes. The safety impacts on five major cities before and after implementing BRT systems are shown in Table 3 below.

Table 3: Safety Impacts of Selected BRT Systems (Carrigan et al., 2013)

City	Type of transit service		Corridor and length (km)	Safety impacts with BRT, per year, per km (percent change in parenthesis		
	Before	After		Property Damage Only Crashes	Injuries	Fatalities
Mexico City	Informal transit	Single lane BRT	Metrobus Line 3 (17 km)	+7.5 (+11%)	-6.7 (-38%)	- 0.3 (-38%)
Guadalajara, Mexico	Bus priority lane	BRT with overtaking lane	Macrobus (16 km)	-83.19 (-56%)	-4.1 (-69%)	-0.2 (-68%)
Bogota, Colombia	Busway	Multi-lane BRT	Av. Caracas (28 km)	n/a	-12.1 (-39%)	-0.9 (-48%)
Ahmedabad, India	Informal transit	Single lane BRT	Janmarg system (49 km)	-2.8 (-32%)	-1.5 (-28%)	-1.3 (-55%)
Melbourne, AU	Conventional bus	Queue jumpers, signal priority	SmartBus Routes 900, 903 (88.5 km)	-0.09 (-11%)	-0.1 (-25%)	-0.03 (-100%)

5. Improved urban and land development. Investigations have shown that land values (residential and businesses) near BRT network and station increase and that the "construction, operation and maintenance of BRT systems can create jobs" (Carrigan et al., 2013).

2.2.4 BRT components

Bayle et al. (2012) and Galicia et al., (2009) mentioned the following main components and characteristics of a BRT system:

1. Running ways (BRT lanes as shown in Figure 11) are the paths exclusively used by buses without the participation of any other mode of transportation to ensure that buses are not delayed by other mixed traffic. Running ways can be at-grade mixed with traffic, at-grade

separated by guardrail/curbstone or sidewalks, or grade-separated (which is rare due to the extra cost, similar to LRT).

2. BRT stations (see Figure 13 below) can be simple, enhanced (more convenient for passengers who are waiting for buses), or terminals (bus centers or connection hubs).

Figure 13: Enhanced BRT Station in Curitiba, Brazil (left) and LYNX Central Florida Regional Transportation Authority Station in Orlando, Florida (right) (Left: Wikipedia. Right: fabral.com)

3. BRT vehicles that operate on the running ways.

4. Fare collection, which can be either in-bus (on-board), off-board, or at terminals/stations. The collection strategies can be either manual (by inspector/supervisor) or automated using machines, cash payment, smart cards, and/or credit cards.

5. Intelligent Transportation Systems (ITS) technologies that can enhance the level and quality of service. TSP is one of the most commonly used ITS technologies in many BRT systems around the world. Other ITS applications that can be used with BRT include

"automatic vehicle location, lane-assist system, automatic speed and spacing control system, and voice and video monitoring" (Galicia et al., 2009).

6. Service and operation plans in order to introduce more "frequent, rapid, efficient, reliable, comfortable, and easy and quick to understand" service for the passengers (Galicia et al., 2009). These can include "marketing identity, feeders system, and on-time performance monitoring" (Galicia et al., 2009).

7. Other physical and operational components which can vary from one BRT system to another depending on the cost budget and the need for it. These features include "guideway, park-and ride facilities, and surrounding land use (known as transit oriented development)" (Galicia et al., 2009). These can also include adequate marketing strategies and customer service accessibility via online, in-bus (on-board), bus stations, smartphones, or other media.

2.3 Bus Rapid Transit Studies and Strategies around the World

In a report prepared for FDOT by **Polzin et al. (2013)**, a new tool called *Transit Boarding Estimation and Simulation Tool (TBEST)* was tested and calibrated for light rail transit (LRT) and bus rapid transit (BRT) planning forecasts in order to enhance these public transportation services. This tool was designed specifically for application in Florida. For BRT, this tool used empirical and experimental data to evaluate the BRT system and score its ridership based on many BRT options and specifications that affect ridership, including "BRT vehicles (floor height, fuel, and guided technology), BRT stations (physical architecture, shelter, real-time information, fare vending, and off-vehicle fare collection), travel way (exclusively, signal preemption, and visual clearness of travel way), and marketing" (Polzin et al., 2013). Results suggested that a recalibration process (in accordance with the Federal Transit Administration) and travel behavior revision is highly needed in order to enhance the forecasting process and not to depend only on the empirical and experimental data.

Sharma and Swami (2013) studied how to reduce the congestion at a signalized intersection on a BRT corridor, especially concerning conflicts with the exclusive bus lane and traffic right of way. This study suggested to have an appropriate distance before the intersection where the exclusive bus lane ends and other traffic can access BRT lanes. Roadway conditions, such as traffic, geometry, and control devices, were taken into consideration and the intersection was modeled using VISSIM. Results showed that providing space before the intersection for all traffic to use the BRT lanes reduced congestion, delay, and emissions, and increased the speed for all vehicles.

Du et al. (2013) studied the effectiveness of a BRT system on an expressway in Beijing, China using both simulation data (VISSIM) and field data (before and after BRT implementation). Results showed a positive enhancement in BRT services with good improvements in travel time, speed, and capacity for buses and some undesirable influences on private vehicles.

Lindau et al. (2013) focused on the capacity and speed behavior of buses on a single-lane per direction BRT system. Trial experiments were used with a multi-linear regression model by varying many factors including "demand levels, boarding and alighting rates, spacing of stations, vehicle loadings, quantity of berths per station, and traffic signal positioning in relation to stations" (Lindau et al., 2013). Results showed that this system can have capacity up to 15,000 passengers/hour/direction with an operating speed of 20 km/hour. Also, this paper showed the importance of using simulation models in BRT performance sensitivity analysis.

Dawson et al. (2011) suggested to use Two Way Left Turn Lanes (TWLTL) in the center of local urban streets for BRT during the peak hours (since there is usually a lack of space in the right-of-way). Due to the limitation of this idea, this scenario can only be applied if there is an existing TWLTL available. Another scenario discussed was to use curb lanes in local streets for BRT only during peak hours. A real life study location was chosen in Austin, Texas. Different characteristics of the simulation results were discussed, including the following:

- Street right-of-ways and how to manage the limited available space for both BRT and other traffic vehicles, especially at intersections.
- Pedestrian safety issues that cannot be addressed in a simulation environment.
- BRT major conflict points including left and right turners at signalized intersections, and entering vehicles from side streets.
- Station locations for both median and curb BRT lanes. It was noticed that mid-block and far-side stations are very dangerous for pedestrians in the median BRT lanes (crossing issues) unlike for the curb BRT lanes. Additionally, if there is a lack of space, it is hard to provide a passenger station in the middle of the street. Near-sided station problems concerned the bus waiting time for loading and unloading passengers, especially if the green phase is active at the nearest signalized intersection.

Jiang & Murga (2010) focused in their research on how to evaluate and improve the BRT system's Level of Service (LOS) in the city of Chicago using simulation software before implementation. They used three simulation outputs to evaluate the BRT system's bus travel speed, personal vehicles' travel speed, and bus travel time and reliability. Three scenarios were addressed: lengthening bus stops, changing from curbside bus stops to bus stop bays, and installing BRT lanes with bus bays. Results showed that all three scenarios enhanced the corridor's LOS; using BRT lanes with bus stop bays resulted in a +21% change in bus travel speed and -12% change in automobile travel speed. This shows that dedicating lanes from the existing roadway for exclusive bus use will reduce roadway capacity. Therefore, it is recommended to add additional lanes for BRT instead of converting existing traffic lanes to BRT only lanes (if there is enough space available for this strategy).

Li et al (2009) studied the single BRT dedicated lane concept using the micro-simulation software VISSIM. This concept addresses the lack of space (right of way) scenario and/or low funds case where there is no ability to have two dedicated lanes for BRT system. In this case, the opposite direction buses can overtake and pass each other only at bus stops. This research took into consideration the following factors: travel time, dwell time, headway, delay at intersections, and speed. Results showed that large headways (low bus frequency) can produce the same amount of travel time for single lane BRT systems as for double lane BRT systems with small headway (high bus frequency). Also, the results showed that bus "speed control" is the key factor in controlling bus delay at intersections, which affects the bus travel time but does not affect the other traffic vehicles.

Yagi and Mohammadian (2008) used the "Opinion Survey" method with almost 1000 respondents to evaluate a new BRT system and its ridership and compare it to the existing modes of transportations in Jakarta, Indonesia. Many factors were taken into consideration for modelling (using logit model) including readiness of using BRT; socioeconomic information; origindestination trips (from home to work, school, and Central Business District or CBD); travel cost; and time. They found that the following variables affect the choice of BRT for mode of travel including “cost, time, distance, income, vehicle ownership, gender/age, vehicle availability, driver’s license, work/school location, and allowance provided by the employer” (Yagi and Mohammadian, 2008).

Chen et al. (2007) aimed to reduce the travel times on a BRT system corridor in Beijing by studying the traffic controllers on both isolated and coordinated intersections using VISSIM. Many factors were taken into account, including “BRT schedules, BRT headways, Buses offsets, signal cycles and green times” (Chen et al., 2007). Results showed that coordinated intersections provided better BRT performance with shorter travel times than isolated intersections did.

Siddique and Khan (2006) used capacity analysis in their research to compare three scenarios for BRT corridor: base case 2001, future case 2021, and future case 2021 with additional green time for transit streets. The studied BRT corridor is located in the CBD of Ottawa (Canada) and NETSIM simulation software was used. Results showed that adding more green time to the transit streets was not sufficient (on the corridor level) to enhance the corridor level of service and more factors needed to be taken into account including speed, travel time, and delay.

Hidalgo (2006) compared several scenarios for public transit based on capacity, ridership, and financial and socio-economic factors in Latin America. Results showed that BRT is more cost effective than the Metro based on capacity (20K – 40K passengers) and socio-economic factors, especially in developing countries.

Satiennam et al. (2006) studied several enhancement scenarios for BRT system based on "demand management and forecasting and emission models" in Bangkok, Thailand. Recommended enhancements included installation of parking spots and paratransit facilities at BRT stations, reduction of the number of regular buses that serve in the same BRT corridor, installation of TSP system, and studying the effects of media in encouraging the public to use the BRT system.

Sarasota County Area Transit (SCAT) in Florida (2006) prepared a brochure about the BRT system and how well it will work in their area, especially with the existing traffic congestion and expected growth. They mentioned that BRT will "attract housing development around stations, create more housing options for the region's residents, and cut down the automobile trips" (SCAT, 2006).

Alvinsyah and Zulkati (2005) discussed the impact of applying new public transport on the existing BRT systems in Jakarta, Indonesia, using simulation. Results showed that in order to enhance the overall network level of service, special improvements needed to be taken into account, such as integrated fare collection and provided feeder services.

Bayle et al. (2012) conducted an experimental simulation study to test six major components of a BRT system in Sydney, Australia, to determine the most significant ones. The studied components were "running ways, the stations, the vehicles, the fare collection, the ITS technologies, and the service and operating plans" (Bayle et al., 2012). Results showed that "the frequency of the services, the number of bus stops within the network, the presence of bus lanes and the demand applied on the network" were the most statistically significant components in the BRT system.

Minnesota Department of Transportation MnDOT (2005) prepared a report study about applying BRT on I-35W Corridor between Minneapolis and Lakeville. This proposed BRT system will run on separated lanes, will pass ramp metering areas with High Occupancy Vehicles (HOVs) using special lanes, and will have traffic signal priority at certain locations. Findings indicated that "buses will be able to operate at posted speed during peak hours, corridor will experience significant growth in employment and population, BRT system will serve more people in the future without adding more lanes on the freeway" (MnDOT, 2005).

Papageorgiou et al. (2009) presented some scenarios for BRT with priority system on the island of Cyprus using simulation modelling in order to enhance the transit system level of service. These scenarios included "two dedicated bus lanes one at each side of the road, and single dedicated bus lane scenario in the middle of the road with bus advance" (See Figure 14 below).

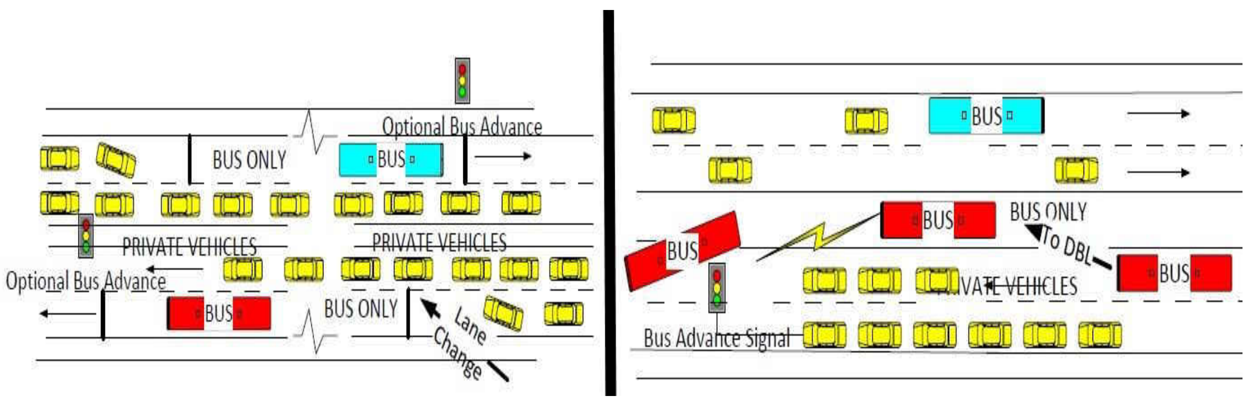


Figure 14: Proposed Scenarios: Two Dedicated Bus Lanes (Left) and Single Dedicated Bus Lane (Right) (Papageorgiou et al., 2009)

Simulation results (Table 4) showed that the "Two Dedicated Bus Lanes" scenario decreased performance since the two dedicated bus lanes were constructed by taking one lane in each direction from the original traffic lanes (due to lack of space), which led to a capacity reduction.

The other scenario (Single Dedicated Bus Lane) showed positive results with an enhanced level of service.

Table 4: Simulation Results (Papageorgiou et al., 2009)

Scenario	Total Travel Time	Delay Time	Average Speed
Two Dedicated Bus Lanes One at Each Side of The Road	Increased by 36%	Increased by 58%	Decreased by 43%
Single Dedicated Bus Lane Scenario in The Middle of the Road with Bus Advance	Reduced by 21%	Decreased by 18%	Increased by 27%

Canales et al. (2006) summarized various BRT implementations in many cities around the world, starting from the first city in the world that implemented BRT, Curitiba (Brazil), to Porto Alegre (Brazil), Bogota (Colombia), Quito (Ecuador), Ottawa (Canada), Brisbane (Australia), Adelaide (Australia), Paris (France), Leeds (UK), Dublin (Ireland), Stockholm (Sweden), Barcelona (Spain), and Madrid (Spain). It was concluded that it is hard to implement BRT in old dense cities, such as ones in Europe. Recommendations for BRT systems was to have them in corridors with high bus-car conflict, low speed areas, and "aggregated time-headway less than seven minutes" (Canales et al., 2006).

Iubel (2012) compared BRT and subway in terms of "cost-efficiency" in the city of Curitiba, Brazil using simulation software. Three scenarios were studied: BRT only, BRT with subway, and subway only. Results showed that, in the long term, the subway would be the most cost-effective scenario.

Chen et al. (2013) evaluated the interactions between BRT and general traffic in terms of lane changing and vehicle counts on an urban BRT corridor. This paper used empirical methods to obtain the conclusions and results. It showed that reducing the amount of lane-changing can positively affect the traffic behavior downstream of BRT bus station, especially concerning the amount of queue discharging. It was discovered that "16% saturation rate reduction of general traffic and 17% increase in bus travel time are induced by lane violations" (Chen et al., 2013).

2.4 BRT with TSP

Zlatkovic et al. (2013) studied the effects of queue jumpers (QJ) (a type of roadway geometry that use specific lanes to provide priority for transit at intersections) and TSP on BRT using four VISSIM models:

- Existing scenario (no QJ and no TSP).
- QJ only.
- TSP only.
- Combination of QJ & TSP.

The studied BRT corridor had 13 signalized intersections, 15 minutes scheduled headway, 29 stops (14 westbound and 15 eastbound), and 10 seconds time for TSP green extension/red truncation along 10.8 miles of 3500 S in West Valley City, Utah. Results showed that the combination of QJ and TSP situation had the greatest benefits with "13-22% reduction in BRT travel times, better corridor progression, lower intersection delays and number of stops, increased speed (22%), and better travel time reliability and headway adherence" (Zlatkovic et al., 2013). Also, the different transit scenarios did not negatively affect the passenger cars along the corridor, but caused some negative results for the crossing streets (primarily a 15% increase in average delay).

Xu and Zheng (2012) studied the effect of the location of bus-only lanes (curb lanes or median lanes) on the TSP logic rules. This study compared the curb bus-only lanes with the median bus-only lanes arrangement using VISSIM under heavy load scenarios. Results indicated that TSP is a major development for BRT to improve the transit program system using a different signal phasing scheme. It also indicated that median lanes had more restrictions and less flexibility in the phase combinations and sequences. The through-vehicle phase is the key to "better moderate the negative effect of signal priority treatments on general traffic and pedestrians" (Xu and Zheng, 2012). There was no proof in the results that any of the two scenarios was better than the other in reducing the delay for prioritized vehicles at traffic signals. The overall intersection performance results were better for the curb bus-only lanes arrangement if the "green extension and early green were provided to TSP-enabled intersections" (Xu and Zheng, 2012).

Using the micro-simulation software VISSIM, **Yang et al. (2012)** evaluated strategies aimed to improve the BRT level of service. The BRT study area was in Yingtan City, China. Four main scenarios were tested in this study and compared with the base case: exclusive bus lane, conventional active signal priority, active signal priority using advanced detection, and transit speed guidance. The signal priority using advanced detection can detect the bus one cycle before it arrives at the intersection and give it the priority it needs at the arrival moment. Transit speed guidance monitors the bus's travel speed before it arrives at the intersection to predict the arrival time at each intersection in the study area and gives the bus the appropriate priority. One major disadvantage of the signal priority using advanced detection was that it could not handle conflicting priority requests; because of this, it was analyzed only for the eastbound direction. Results showed that active signal priority using advanced detection and transit speed guidance provided the best improvements. These scenarios produced some negative impacts on the private cars, with a negligible impact from the advanced detection strategy.

Zlatkovic et al. (2012) evaluated TSP options for a BRT corridor in West Valley City, Utah, using VISSIM and ASC/3 software. Four scenarios were tested to find the optimal one: No TSP, TSP, TSP with phase rotation, and custom TSP. Results showed that the last two scenarios had the best outputs in terms of travel times, delays, number of stops, intersection performance, and network performance. TSP with phase rotation produced a "9 – 12% reduction in travel times, and over 60% reduction in delays at some intersections" with little impact on vehicular traffic. Custom TSP was the best for BRT, with "9 – 14% reduction in travel times, over 60% reduction in delays at some intersections, major reductions in intersection stopping percentage and waiting time;" however, it had a significant impact (more than TSP with phase rotation) on vehicular traffic, Zlatkovic et al. (2012). In terms of progression, both TSP with phase rotation and custom TSP had good progression improvement with acceptable running time reliability.

Xu et al. (2010) compared two cases using VISSIM micro-simulation software: unconditional and conditional signal priority at isolated signalized intersections with median bus-only lanes in terms of intersection performance. This study discussed the phase insertion, green-extension and early-green management, and technical framework and logic rules in TSP for BRT. Results from the simulation showed that it is desirable to move from unconditional to conditional priority. The major reason to use conditional priority is to improve service reliability for transit vehicles at low cost, but there was no clear output to conclude that conditional signal priority with lateness adjustments can improve intersection performance. Results also showed that there was a significant improvement in schedule lateness correction using phase insertion, especially in conditional priority (more than unconditional priority).

Martin and Zlatkovic (2010) discussed the efficiency of BRT supported with TSP and its future impact on other vehicles in the year 2030 for a real life case study on 5600 West Street in Salt Lake County, Utah using VISSIM. This case study consists of a 5-mile corridor with center running BRT lanes, 6 BRT stations in each direction, and 7 signalized intersections. They defined BRT as a "flexible, high performance rapid transit mode that uses buses or specialized rubber tired-based vehicles operating on pavement, and combines a variety of physical, operating, and system elements into a permanently integrated system" (Martin and Zlatkovic, 2010). Various scenarios (some design changes, TSP Green Extension/Early Green and Phase Rotation strategies, and other BRT cases) were analyzed for general traffic travel time, transit travel time, and performance of each intersection and the overall system. Results showed that the worst case scenario was when there was no action taken to adjust the existing real life conditions. Some improvements occurred when small changes were performed, such as "prohibited mid-block left turns, longer left and right turn lanes at intersections, and signal optimization" (Martin and Zlatkovic, 2010). The most beneficial results for future/planned adjustments on BRT came from the TSP Green Extension/Early Green strategy with 7% lower BRT travel time, a significant reduction in intersection delay, and minor/negligible impact on general traffic.

Lahon (2011) analyzed a 2-mile BRT corridor (10 minutes headway) with 6 signalized intersections in the City of Pleasanton, California. This study used micro-simulation software (VISSIM) and vehicle actuated programming (VAP) to simulate TSP and queue jumpers (with green extension, and early green) for BRT. Two models were applied on the system: TSP with queue jumpers using the right turn lane only, and TSP with queue jumpers using both right and left turn lanes. A maximum of 10% of the cycle length was used for TSP to provide the proper treatment, reduce delay, and minimize the negative effects on other traffic vehicles. Additionally, an exclusive 10 seconds phase was added to the system. Results showed that TSP and queue jumpers can be effective when there is high congestion, and therefore high volume-capacity ratio, at intersections. In these cases, bus travel time was reduced by 30% with no negative effects on the other traffic vehicles. However, this study did not evaluate effect on crossing street traffic.

Chen et al. (2008) studied the effectiveness of TSP for Southern Axis BRT line one in Beijing, China. Six different scenarios (based on different strategies like green extension, red truncation, phase insertion, and signal coordination) were introduced and analyzed using VISSIM micro-simulation software for no priority vs. priority based on field data collection. These scenarios included the base condition, increased demand of non-motorized traffic at intersections, sensitivity analysis of the BRT headway, various congestion levels, various levels of cross-street volume, and presence of signal coordination. There is a need to balance the priority and reliability offered by TSP for BRT with the impacts on other traffic. Therefore, the engineer needs to pay attention to corridor conditions including "roadway characteristics, travel demand, traffic composition, frequency of BRT service, and cycle characteristics" (Chen et al., 2008). Results of BRT with TSP strategies showed that TSP can reduce average travel time and delay, increase schedule adherence, decrease average waiting time by up to 10%, and improve service reliability by up to 35%. However, there are negative effects on the other corridor traffic. More study is needed on the non-motorized traffic (such as bicyclists and pedestrians) which can be affected by TSP and BRT implementations and the fluctuation of their travel times, speeds, delays, and headways.

Wang and Weng (2010) evaluated the effects of signal priority on a BRT intersection case study in Beijing using VISSIM micro-simulation software. This study showed the positive improvements on the intersection behavior by using actuated traffic signal control over fixed (pre-timed) control.

A new concept called Bus Lane with Intermittent Priority (BLIMP) was studied by **Carey et al. (2009)** using VISSIM software. This concept was only applied in two places worldwide and it "utilizes dynamic lane assignment to designate an exclusive bus lane on a temporary, bus-actuated basis. The BLIMP concept priority is assigned only when needed; however, as the amount of priority is increased the concept starts to exhibit the characteristics of an exclusive lane" (Carey et al., 2009). A BRT corridor case study was chosen in Eugene, Oregon and PTV America (creators of VISSIM) helped in developing special tools in VISSIM in order to simulate this concept in their software. Results showed that this concept can provide significant enhancements in bus travel time and reliability during peak hours with minimal impact on general intersection traffic.

Dai (2011) evaluated a BRT system and its influence on other traffic in the city network of Guangzhou, China. This study modelled several scenarios, including the BRT with signal preemption. The model results indicated that BRT with preemption helped minimize some of the disturbances, especially at intersections, but it was recommended to be careful regarding priority time and duration in order to not negatively affect other traffic and signal phases.

Yang et al. (2013) studied two main strategies for BRT using VISSIM in Yingtan, China: TSP using advanced bus detection for one cycle before the bus arrives the intersection and transit speed control by controlling the bus's speed in order to be able to predict its arrival rate to give priority at an appropriate time. Results showed that both strategies improved the level of service for both general traffic and transit vehicles.

Toma et al. (2012) analyzed a planned BRT corridor with TSP system for Khon Kaen City, Thailand, using VISSIM. Simulation results and sensitivity analysis outcomes (by varying some factors such as bus headway and traffic volumes) showed that travel time was reduced after applying the signal priority with detection system on the BRT corridor.

2.5 Summary and Significance of Research

The above literature review proves that understanding the separate and combined effects of TSP and BRT on network operations performance can be challenging. Due to the complicated nature of real life networks which often leads to conflicting and sometimes misleading results, a new simplified approach is needed. Presenting the simulation results in an easy and well organized manner is crucial for decision makers who have limited budget and time to make decisions. None of the previous studies examined in depth the holistic effects of implementing conditional and unconditional TSP strategies with a BRT system and their impact on crossing street traffic.

Many studies in this chapter discussed TSP, BRT, and the combined effects of BRT with TSP. This review of past literature showed that there are many features (options) that can be used with a BRT system, with the most common one being TSP at intersections. This feature can improve the

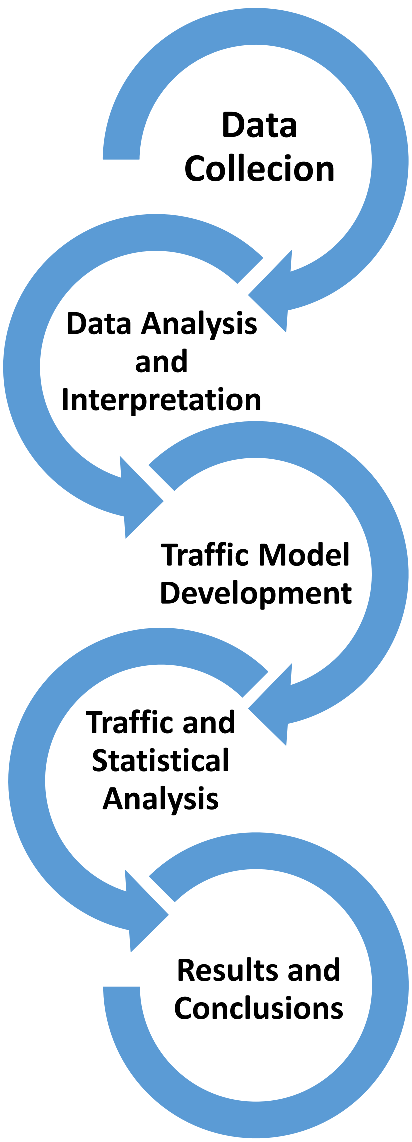
BRT system by increasing its speed, reducing travel time and delay, and enhancing bus schedule reliability without negatively affecting the general traffic through the corridor and on crossing streets. This research will analyze in details the use of conditional and unconditional TSP strategies with a BRT system and then compare them with each other in order to better understand the effects of these strategies on the network performance measures using the microscopic traffic simulation software VISSIM.

In the following sections, a new approach presented that utilizes hierarchical design and multiple linear regression to analyze simulation results for various strategies (scenarios) and present them in an organized manner that is easy for decision makers to understand. The robust methodology developed in this research will be applied on I-Drive corridor for the sake of demonstrating the new approach. However, this methodology can be easily applied and extended elsewhere.

CHAPTER 3 METHODOLOGY

3.1 Research Methodology

The methodology to achieve the identified research goal and objectives is shown in Figure 15.



- **Demand data:** entry volumes, turning movements, and vehicle mix (classification).
- **Geometric data:** node coordinates, link length, number of lanes, length of turn bays, lane drop locations, lane add locations, lane connection information, lane channelization, grade, lane widths, curvature data, and bus stop data.
- **Traffic control data:** sign data, signal control data, posted speeds, movement permissions (e.g. RTOR), and stop bar location.
- **Calibration and validation data:** capacity data, speed data, and travel time data.

- **Data preparation:** transform the data collected by organizing, describing, and interpreting the data to be ready for analysis.

- **VISSIM:** corridor simulation modelling of eight (8) scenarios: No TSP - No BRT scenario (the before), Unconditional TSP, Conditional TSP 3 minutes, Conditional TSP 5 minutes, BRT with No-TSP, BRT with Unconditional TSP, BRT with Conditional TSP 3 minutes, BRT with Conditional TSP 5 minutes.
- **HCS**: intersections Level of Service (LOS) & Delay Analysis before and after BRT.

- Comparison of the eight modeled scenarios across various performance measure parameters.
- Nested Sets Analysis.
- Multiple Linear Regression.
- Comparison of the Intersection LOS & Delay before and after BRT.

- Performance assessment using various parameters on the study intersections and corridor before and after BRT.
- Recommendations and Findings

Figure 15: Developed Research Methodology

This research will use the International Drive as a test corridor before and after the implementation of Conditional and Unconditional TSP with and without BRT. Several scenarios developed and modeled in VISSIM; these scenarios consist of three main levels (No-TSP and No-BRT, TSP only without BRT, and BRT with and without TSP) as shown in Figure 16.

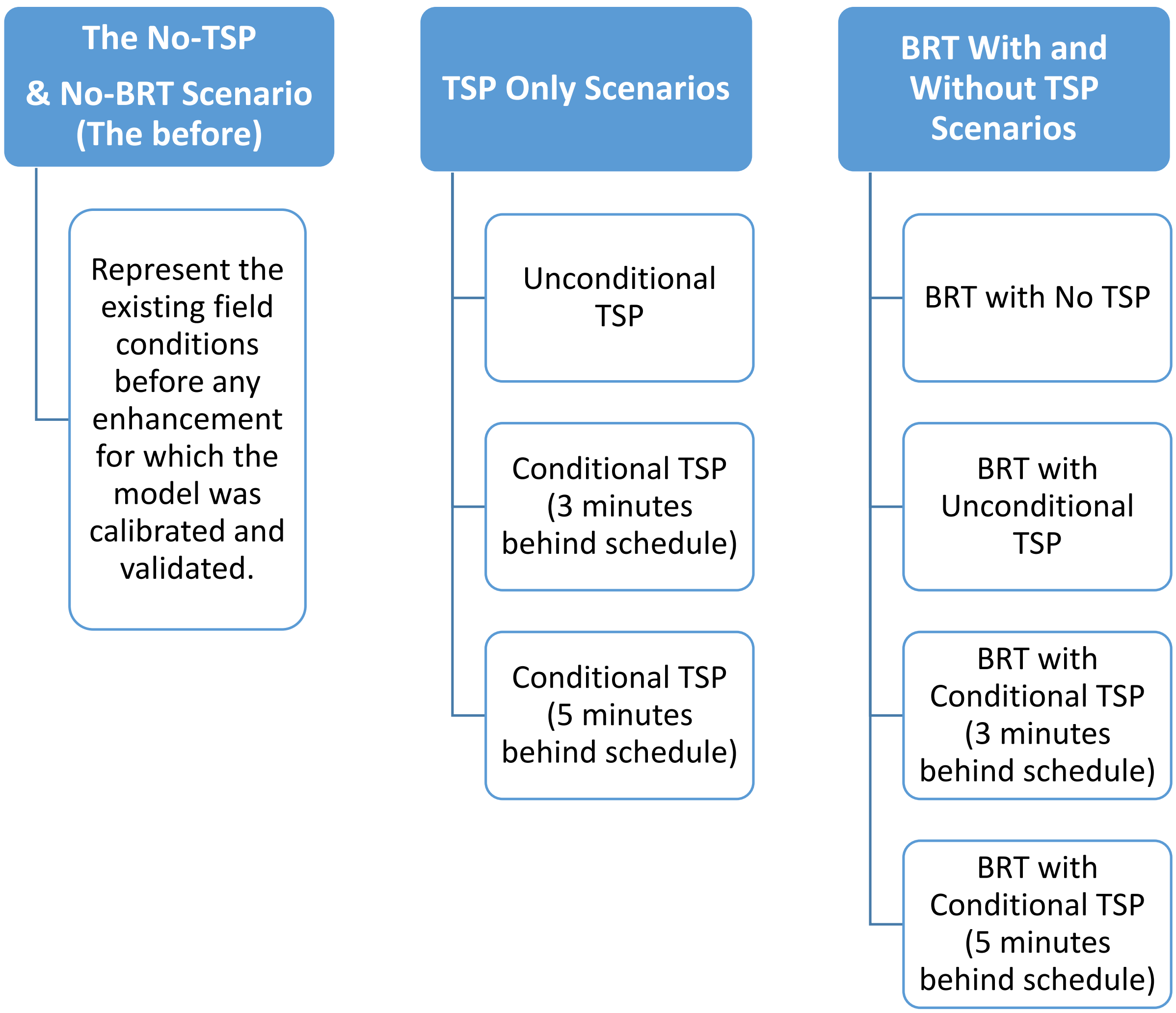


Figure 16: Developed Scenarios for the Present Research

The different Conditional TSP scenarios (3 minutes and 5 minutes behind schedule) indicate that the TSP only activated for buses that were at least either 3 or 5 minutes behind schedule. In the field, the TSP system was programmed to activate the TSP emitter only if the bus was 3 minutes or more behind schedule (Conditional TSP 3 minutes behind schedule). Since this behind schedule time is lower than the industry standard of 5 minutes behind schedule, it was decided to use VISSIM to simulate the corridor with 5 minutes behind schedule TSP (Conditional TSP 5 minutes behind scchedule) and compare this with the other scenarios (Kloos, 2002).

Field traffic data were collected, as discussed in Al-Deek et al. (2014) and Consoli et al. (2015) on the implementation of TSP on I-Drive. The Kittleson study (Freeman and Tsoi, 2013) was also used to obtain input data for VISSIM. Additionally, passenger data for Link 8 was provided by LYNX. Several field visits were also made, during which they rode the bus for several hours and collected passenger boarding and delay data in an effort to confirm the bus travel times and delay. These data were reviewed to determine peak passenger volumes.

Based on these field data, a base VISSIM model was developed, calibrated, and validated. This VISSIM calibration and validation process was performed using turning movement counts at the signalized intersections, average speed profiles, and average travel times.

The developed methodology uses the microscopic simulation and statistical analysis to evaluate the effectiveness of BRT without TSP and with conditional or unconditional TSP strategies. This methodology can be applied to any corridor to understand the combined TSP and BRT effects on traffic performance.

3.2 Limitations of the Study

Since this research is focused on the effects of BRT and TSP on vehicular traffic, the following topics were not considered in this research:

- Pedestrian data to evaluate pedestrian performance.
- Bicycle data to evaluate bicycle performance.
- Traffic safety issues.
- Economic evaluations [cost-effectiveness analysis (CEA) that compares the relative costs and outcomes (effects) of each scenario].
- Environmental impacts.

Another limitation of the study is the reliability of the collected field data. Field bus reliability was an issue in this corridor, as buses were often not spaced properly, which affected the accuracy of the passenger counts. For instance, Link 8 sometimes had more than an hour headway between buses, but at other times, especially during the PM peak period, two and sometimes three Link 8 buses were running at the same time in the same direction. Other issues that affected the data collection included bad weather (e.g., afternoon thunderstorms and heavy rain), buses being full, buses sometimes not stopping at all bus stops, and the limited time frame of data collection for Unconditional TSP and Conditional TSP due to the start date of the BRT construction project.

CHAPTER 4 DATA COLLECTION AND REDUCTION

4.1 General Information

Data collection is one of the major tasks in this research. This chapter introduces the different types of collected data that were used in this research, including geometric data (number of lanes, lane width, etc.), traffic data (average daily traffic (ADT) at major road links, peak hour volume (PHV) at major intersections, % of heavy vehicles (HV), etc.), and traffic control data (signal types, timings, and phasing).

As previously discussed, the selected test corridor consists of an approximately 1.1 mile stretch of International Drive (I-Drive) from Wet 'N' Wild located at Universal Boulevard to Fun Spot Way near the Orlando Premium Outlets. The test corridor contains the six following major signalized intersections (Figure 17):

1) Universal Boulevard (T1),
2) Kirkman Road (T2),
3) Grand National Drive (T3),
4) Municipal Drive (T4),
5) Del Verde Way (T5), and
6) Fun Spot Way (T6).

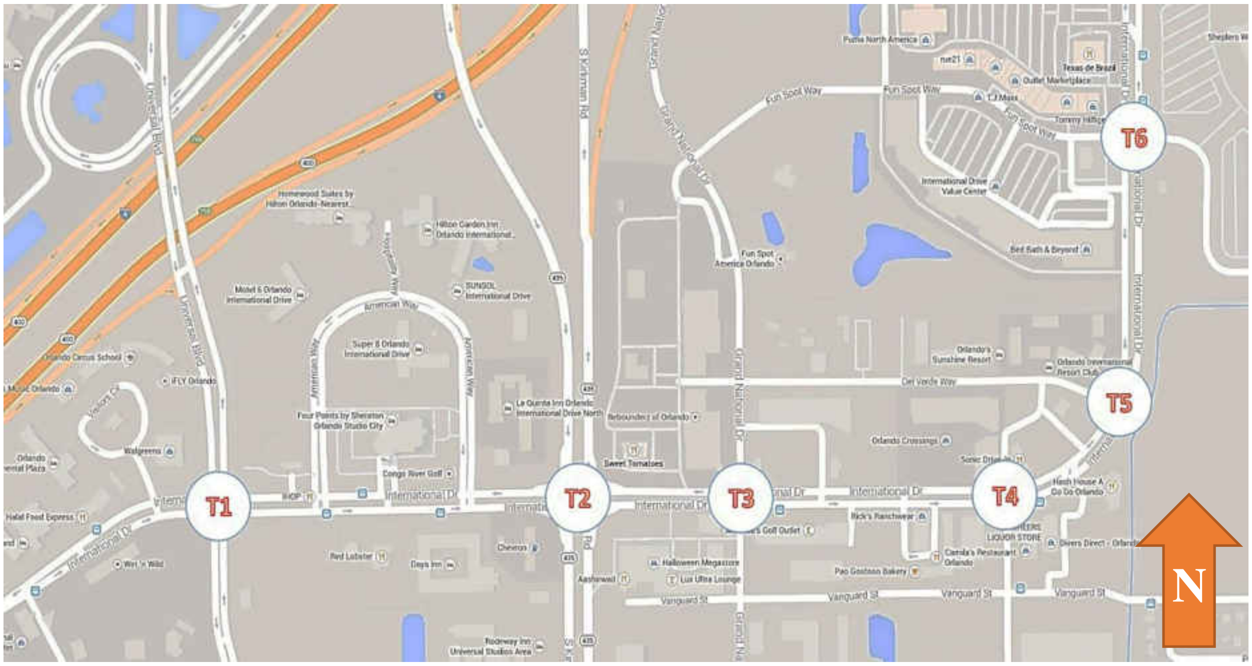


Figure 17: International Drive Corridor

(The Original Photo "before editing" is credited to Google Maps, 2014)

Detailed aerial photos for each of these intersections (before the construction of BRT) are shown in Figures 18-23 below.

Figure 18: Intersection (T1) – Universal Boulevard

(The Original Photo "before editing" is credited to Google Maps, 2014)

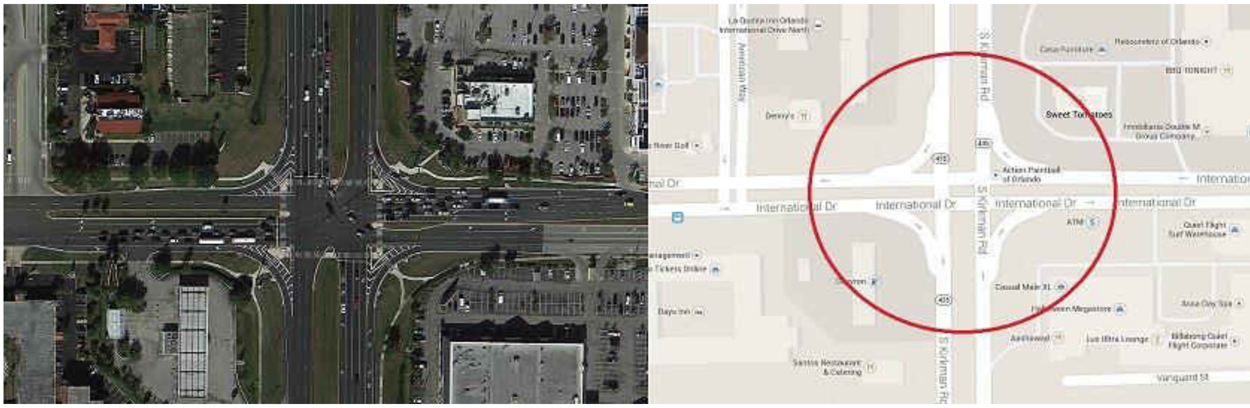


Figure 19: Intersection (T2) – Kirkman Road

(The Original Photo "before editing" is credited to Google Maps, 2014)

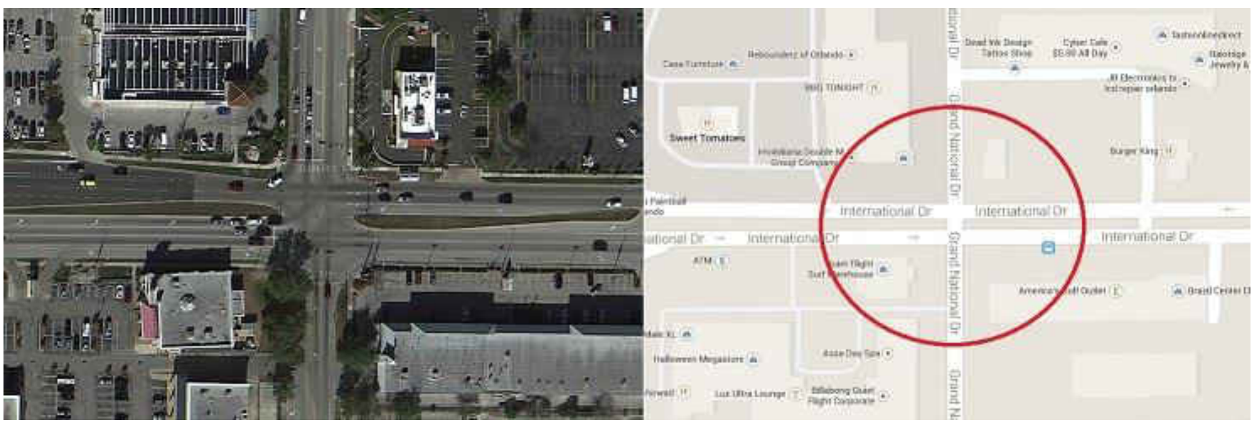


Figure 20: Intersection (T3) – Grand National Drive

(The Original Photo "before editing" is credited to Google Maps, 2014)

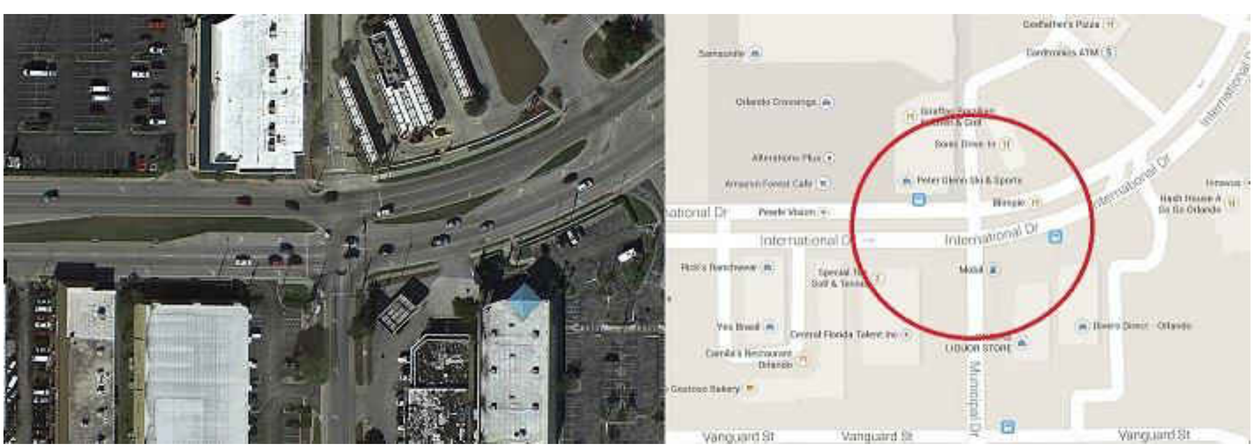


Figure 21: Intersection (T4) - Municipal Drive

(The Original Photo "before editing" is credited to Google Maps, 2014)

Figure 22: Intersection (T5) – Del Verde Way

(The Original Photo "before editing" is credited to Google Maps, 2014)

Figure 23: Intersection (T6) – Fun Spot Way

(The Original Photo "before editing" is credited to Google Maps, 2014)

4.2 Geometric and Control Data

Google maps, engineering drawings, and field visits were utilized to obtain accurate geometric data for the corridor. These geometric data include information on the intersections and links within the corridor, such as the number of lanes per approach and lane widths, as well as "node coordinates, link length, number of lanes, length of turn bays, lane drop locations, lane add locations, lane connection information, lane channelization, grade, lane widths, curvature data, and bus stop data" (Holm et al., FHWA 2007).

Table 5 shows the main geometric data collected from the field for each intersection on the corridor before the BRT construction.

Table 5. Intersections Characteristics before the BRT Construction

Intersection	Control Type	Number of lanes				Lane Width (ft)				Number of Approaches
		EB	WB	NB	SB	EB	WB	NB	SB	
T1	Traffic Signal	4	5	3	6	11	11	11	11	4
T2		4	4	5	6	11	11	11	11	4
T3		4	3	2	3	11	11	11	11	4
T4		4	3	2	2	11	11	11	11	4
T5		2	-	3	2	11	-	11	11	3
T6		2	3	4	3	11	11	11	11	4

Figure 24 shows a sample of the geometric, signing, and pavement marking plan for Intersection T5 (Del Verde Way with International Drive) after completion of the BRT lanes. Additional detailed plans are shown in **Appendix C**.

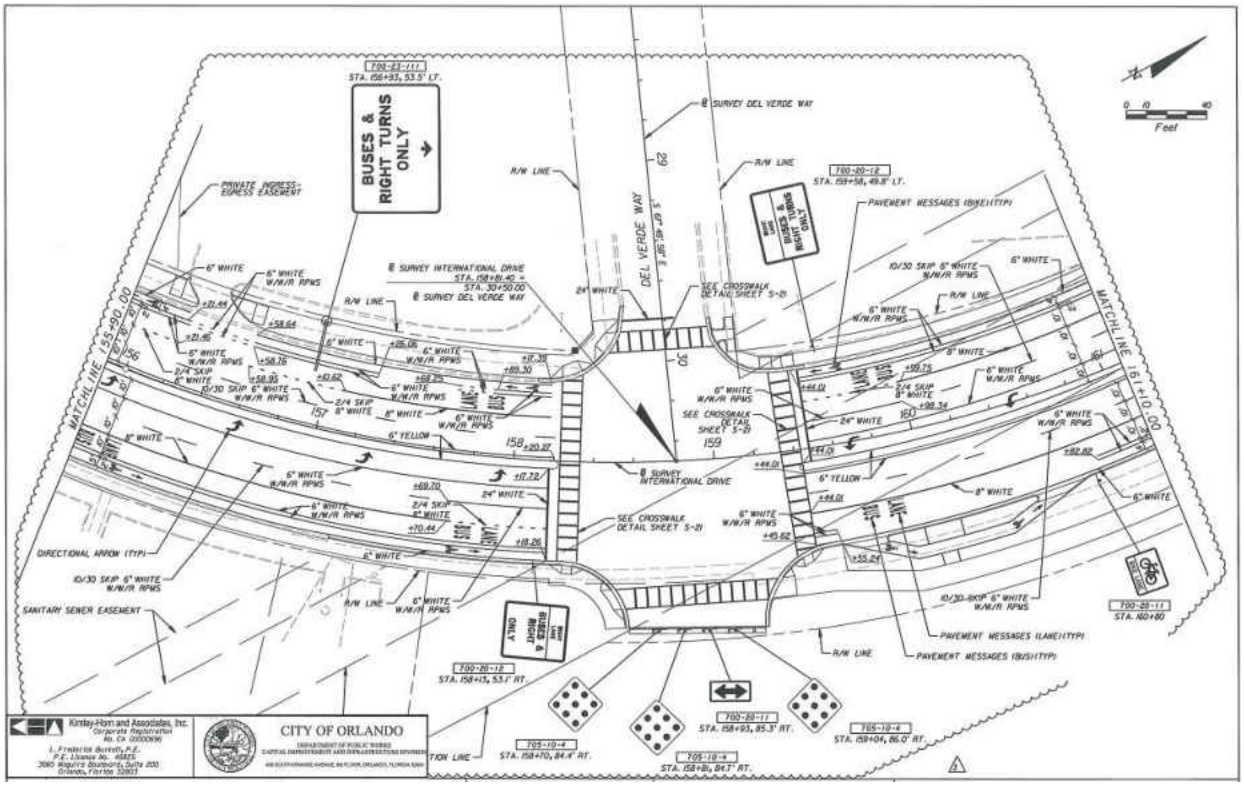


Figure 24: Sample of Geometric, Signing, and Pavement Marking Plan for BRT - Intersection (T5) Del Verde Way with International Drive (City of Orlando)

Signal control data are also very important to develop an accurate VISSIM model. Split histories for each of the traffic signals in the test corridor were provided by the City of Orlando Traffic Management Center (TMC). These split histories show the split of green time amongst the major and minor traffic movements.

Figure 25 shows a sample of the split history data between 15:00 and 15:20 for intersection T5 (Del Verde Way and International Drive); more detailed signal control data are shown in **Appendix D**.

Split History

ID: 369

Name: Del Verde Wy & International Dr

Begin Date/Time: 03/06/2013 3:00 pm **End Date/Time:** 03/06/2013

DateTime		Pattern	Cycle	SP1	SP2	SP3	SP4	SP5	SP6
3/6/2013	15:00:09 PM	14	75	0	62	0	13	0	59
3/6/2013	15:01:24 PM	14	75	0	75	0	0	0	75
3/6/2013	15:02:39 PM	14	75	0	75	0	0	0	75
3/6/2013	15:03:54 PM	14	75	0	62	0	13	0	59
3/6/2013	15:05:09 PM	14	75	0	75	0	0	0	75
3/6/2013	15:06:24 PM	14	75	0	62	0	13	0	59
3/6/2013	15:07:39 PM	14	75	0	64	0	11	0	61
3/6/2013	15:08:54 PM	14	75	0	64	0	11	0	60
3/6/2013	15:10:09 PM	14	75	0	75	0	0	0	75
3/6/2013	15:11:24 PM	14	75	0	63	0	12	0	60
3/6/2013	15:12:39 PM	14	75	0	61	0	14	0	58
3/6/2013	15:13:54 PM	14	75	0	75	0	0	0	75
3/6/2013	15:15:09 PM	14	75	0	75	0	0	0	75
3/6/2013	15:15:09 PM	14	75	0	75	0	0	0	75
3/6/2013	15:16:24 PM	14	75	0	75	0	0	0	75
3/6/2013	15:17:39 PM	14	75	0	75	0	0	0	75
3/6/2013	15:18:54 PM	14	75	0	63	0	12	0	60
3/6/2013	15:20:09 PM	14	75	0	64	0	11	0	60

Figure 25: Split History Sample for Intersection T5 (City of Orlando)

4.3 Traffic Data

Two main types of traffic counts were obtained to develop the VISSIM model: automatic counts and manual counts.

4.3.1 Automatic Traffic Counts (ATC) (Tube Counts)

Tube counters are one of the most commonly used devices worldwide to count traffic. Pneumatic tube counters were used to collect traffic volumes throughout the corridor for two working days in September 2012 and June 2013; these counters are shown in Figure 26.

Figure 26: Pneumatic Tube Counter (Rodrigue, J., 2011)

Figure 27 shows the ATC locations along the corridor.

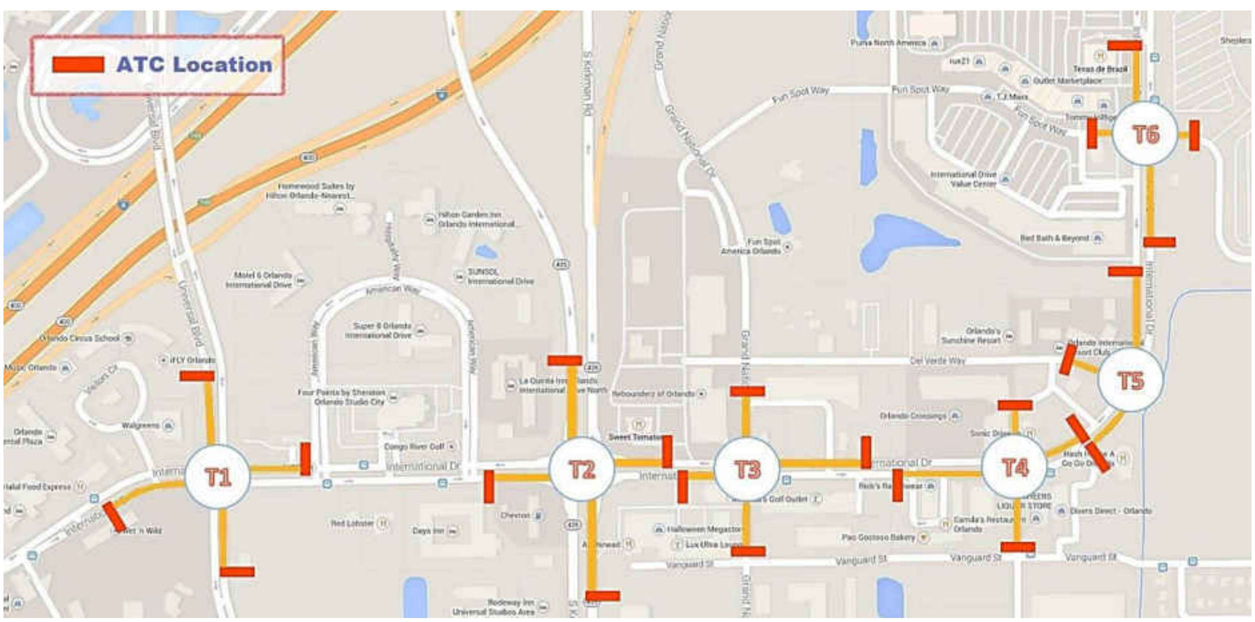


Figure 27: ATC Locations on International Drive Corridor

(The Original Photo "before editing" is credited to Google Maps, 2014)

These counts showed that the peak volumes were concentrated in the PM period 15:00 and 19:00 (3:00 PM – 7:00 PM). Figure 28 shows a sample of daily traffic volumes on Intersection T1 (Universal Boulevard with International Drive). More details about the peaks for each direction are shown in **Appendix A**.

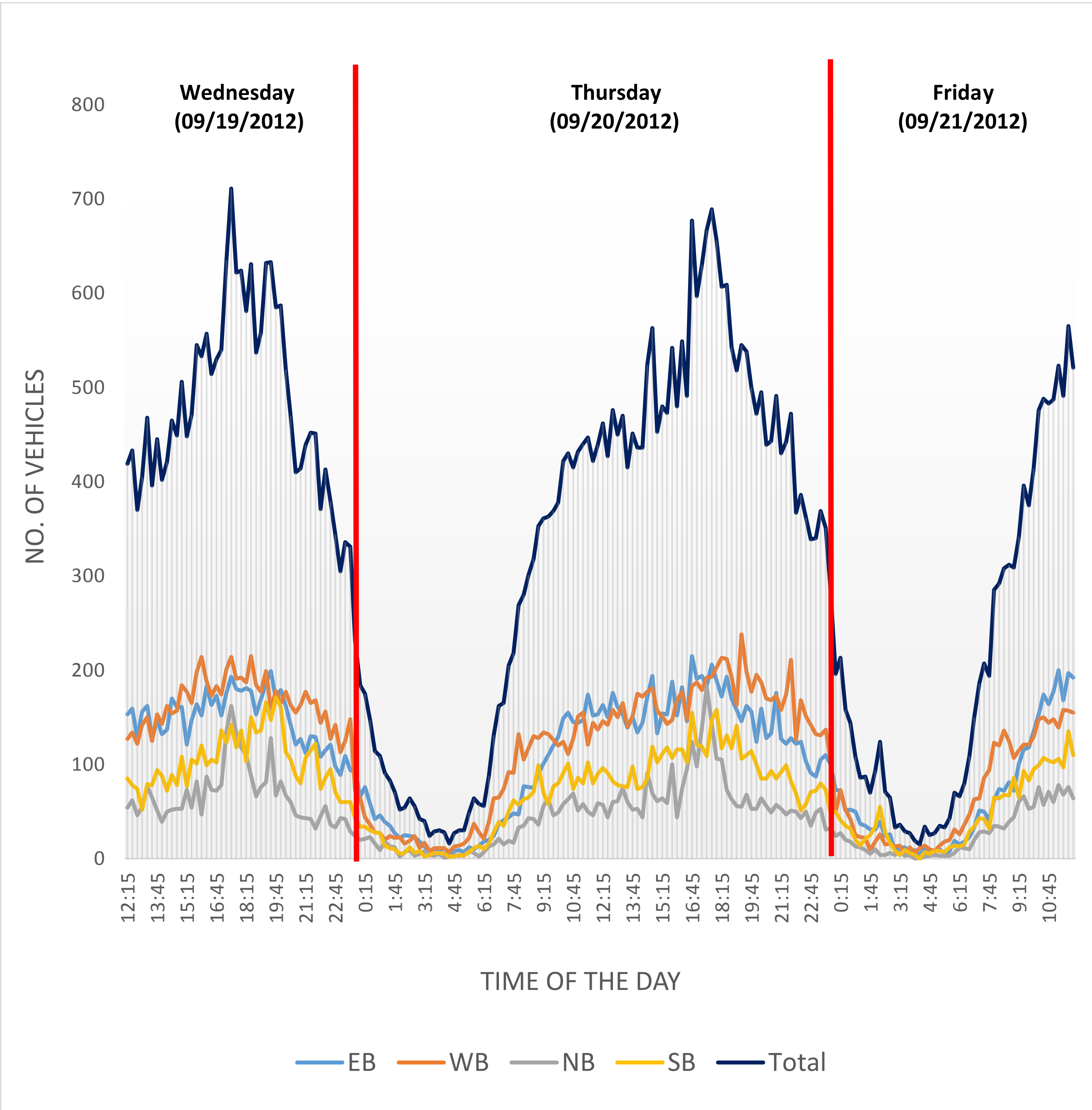


Figure 28: Sample of Daily Traffic Volumes on Intersection (T1)

4.3.2 Manual Traffic Counts (MTC)

Manual traffic counts (MTC) were conducted to obtain entering traffic volumes, turning movements, and vehicle classifications at the intersection locations shown in Figure 29. These data were captured using Jamar data collectors (Figure 30) and digital camera recorders (Figure 31) during the peak PM periods 15:00 and 19:00 (3:00 PM – 7:00 PM) on working days in fall 2012.

The digital cameras were located to observe as much of the whole intersection subject approach as possible. Video recording required less manpower than the Jamar data collection and provided a permanent record that can be used in the future if needed. A field technician operated the Jamar data collector and later uploaded the collected data into a computer program for analysis.

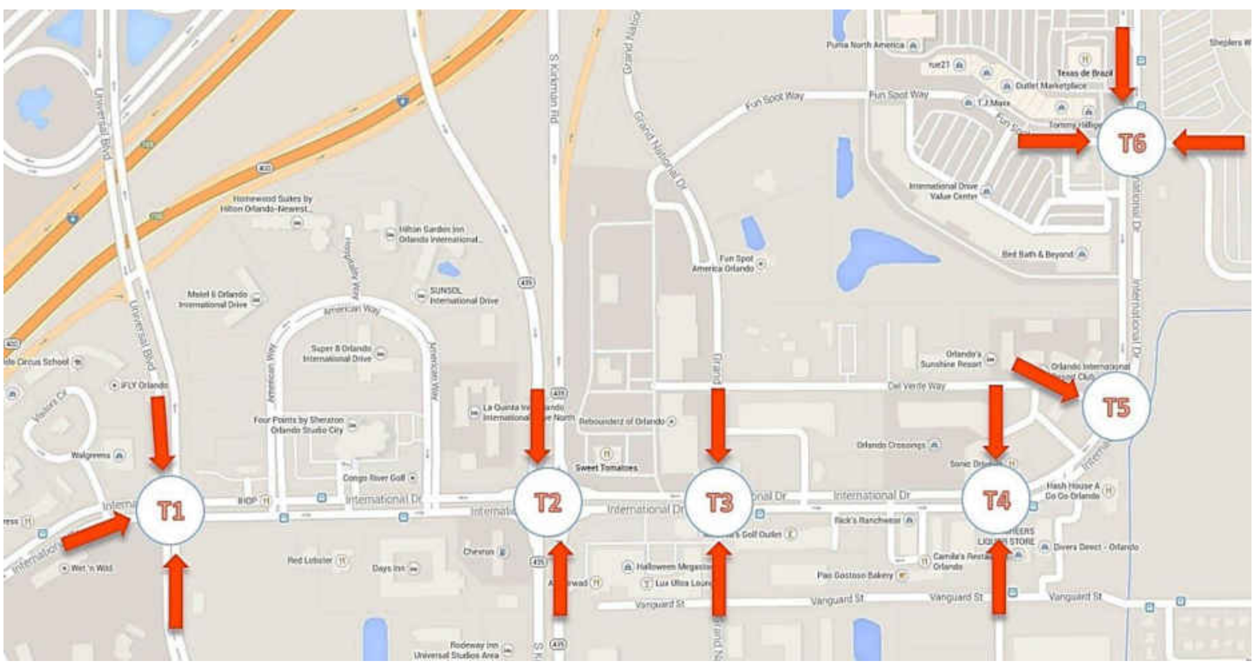


Figure 29: Entering Traffic Volume Locations

(The Original Photo "before editing" is credited to Google Maps, 2014)

Figure 30: JAMAR Data Collector for Turning Movements (Jamar Inc., 2014)

Figure 31: Videotaping Turning Movements (Camera Sample on T3 - Grand National with I-Drive Intersection)

There were three main turning movements (Left, Through, and Right) for the main types of vehicles: passenger vehicles (PC), heavy vehicles (HV), and buses. Vehicles with 6 or more tires touching the roadway were considered heavy vehicle, per the Highway Capacity Manual (HCM2010). Figure 32 shows the vehicle movements data sheet and a sample summary of vehicle movements data sheet. Detailed information on the turning movements is shown in **Appendix B**.

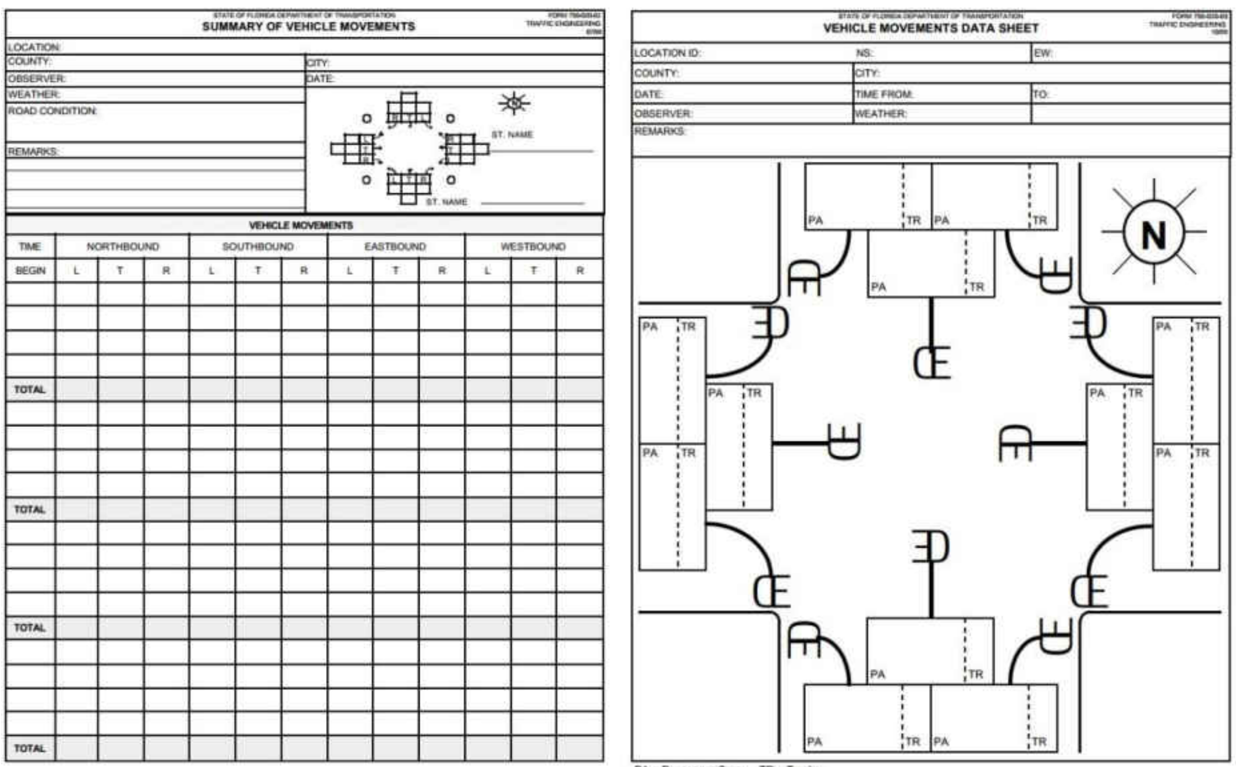


Figure 32: Summary of Vehicle Movements and Vehicle Movement Data Sheet Samples (MUTS, 2000)

From the MTC, the peak hour factor (PHF) was calculated for each intersection. The PHF is "*the ratio of total hourly volume to the peak flow rate within the hour*" and was calculated based on the Highway Capacity Manual (HCM) Equation 1 shown below (HCM, 2010).

$$\text{PHF} = \frac{\text{Hourly Volume}}{\text{Peal Flow Rate (within the hour)}} \quad \textbf{(1)}$$

Since the MTC data were collected for 15-minute periods, the PHF was computed using the following Equation 2:

$$\text{PHF} = \frac{V}{15 * V_{15}} \tag{2}$$

Where:

- PHF: peak hour factor,
- V: hourly volume (vehicle / hour), and
- V_{15}: volume during the peak 15 min of the analysis hour (vehicle / 15 min).

Tables 6 through 11 show the peak hour volume [in vehicles/hour (VPH)], peak hour factor, and heavy vehicle (HV) and bus percentages for each intersection on the corridor. Also, Figures 33 through 38 show the traffic volumes for the corridor intersections during the PM peak hour.

Table 6. Peak Hour Volume Calculation Results for Intersection T1

Peak Hour Volume (VPH)		EB			WB			NB			SB		
		643			879			641			489		
18:00 - 19:00	TOTAL	126	457	60	61	633	185	50	478	113	236	173	80
Total	PHF	0.93	0.87	0.71	0.90	0.73	0.81	0.78	0.84	0.66	0.73	0.70	0.69
2652	HV & BUS %	4%	2%	3%	3%	2%	2%	0%	2%	3%	2%	1%	0%

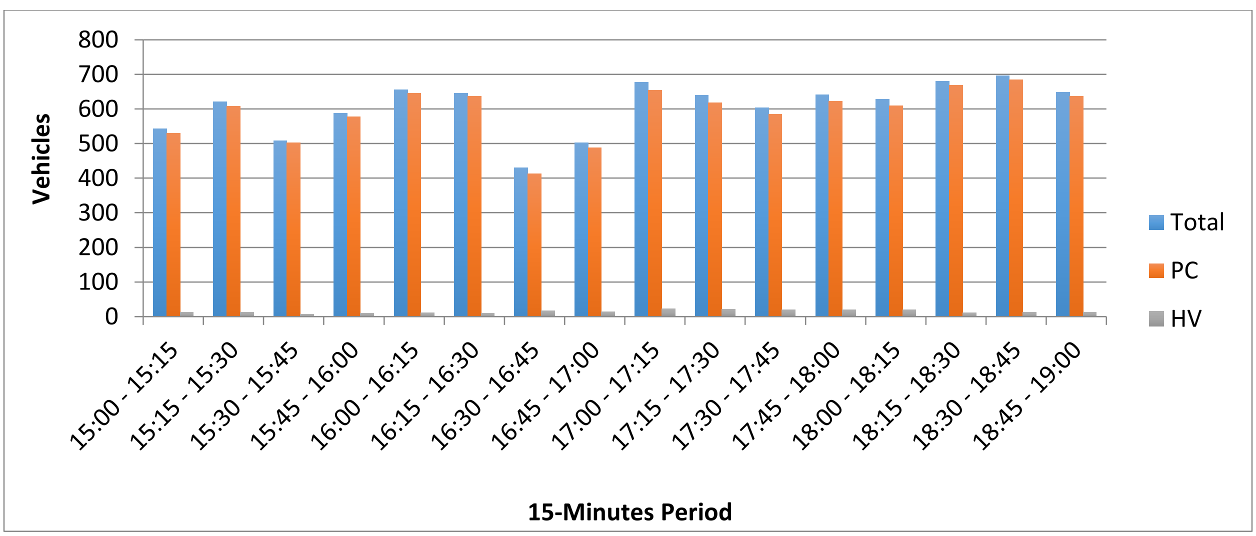


Figure 33: 15-Minutes Period Turning Movements on Intersection T1

Table 7. Peak Hour Volume Calculation Results for Intersection T2

Peak Hour Volume (VPH)		EB			WB			NB			SB		
		947			1403			1974			1353		
17:15 – 18:15	TOTAL	194	674	79	188	494	721	65	1667	242	354	710	289
Total 5677	PHF	0.93	0.89	0.82	0.98	0.86	0.65	0.77	0.92	0.81	0.80	0.88	0.88
	HV & BUS %	3%	2%	1%	3%	3%	1%	2%	1%	1%	2%	2%	1%

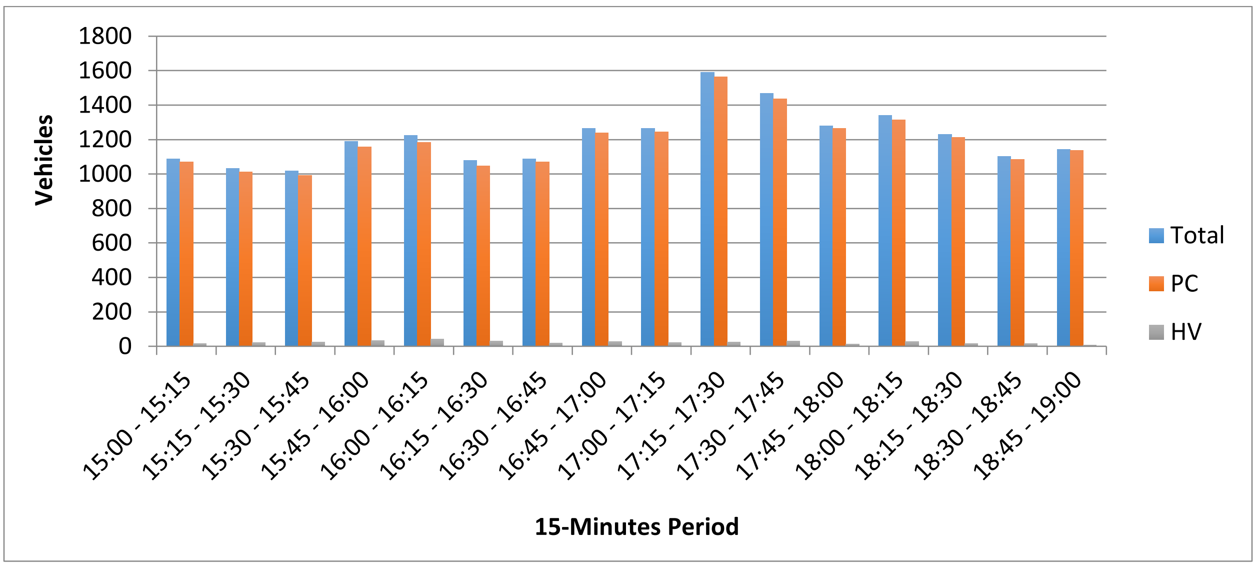


Figure 34: 15-Minutes Period Turning Movements on Intersection T2

Table 8. Peak Hour Volume Calculation Results for Intersection T3

Peak Hour Volume (VPH)		EB			WB			NB			SB		
		967			849			592			661		
16:15 - 17:15	TOTAL	218	744	5	23	821	5	327	214	51	79	170	412
Total 3069	PHF	0.81	0.93	0.31	0.72	0.94	0.63	0.90	0.84	0.75	0.66	0.87	0.83
	HV & BUS %	2%	2%	0%	0%	2%	0%	0%	2%	0%	0%	1%	3%

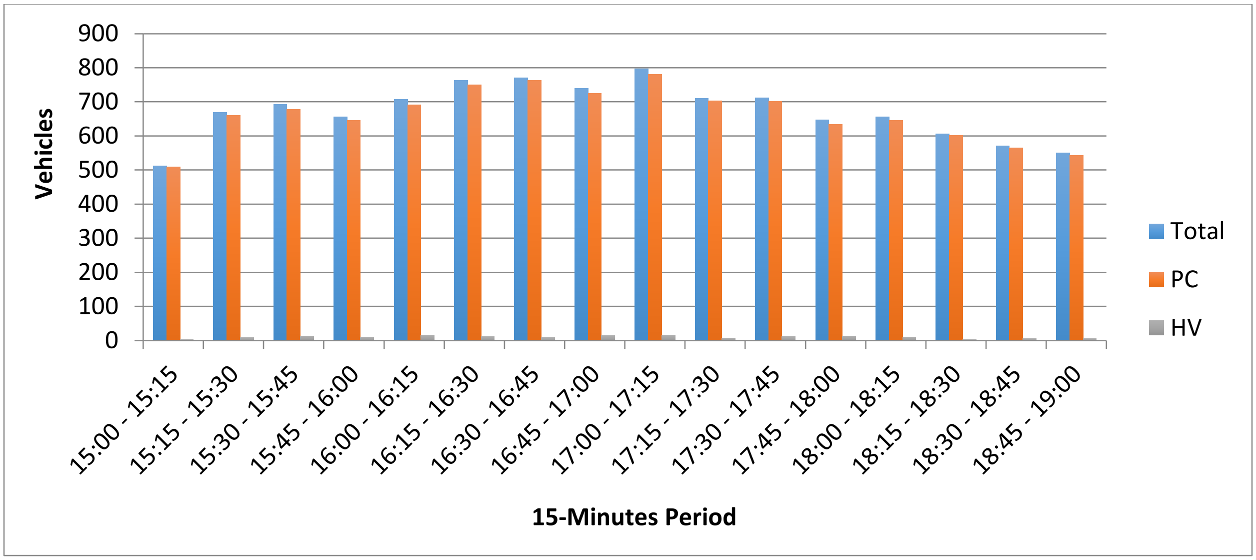


Figure 35: 15-Minutes Period Turning Movements on Intersection T3

Table 9. Peak Hour Volume Calculation Results for Intersection T4

Peak Hour Volume (VPH)		EB			WB			NB			SB		
		741			823			318			0		
16:15 - 17:15	TOTAL	26	651	64	133	685	5	131	0	187	-	-	-
Total 1882	PHF	0.81	0.91	0.80	0.77	0.91	0.42	0.66	-	0.81	-	-	-
	HV & BUS %	0%	2%	3%	0%	1%	0%	2%	-	1%	-	-	-

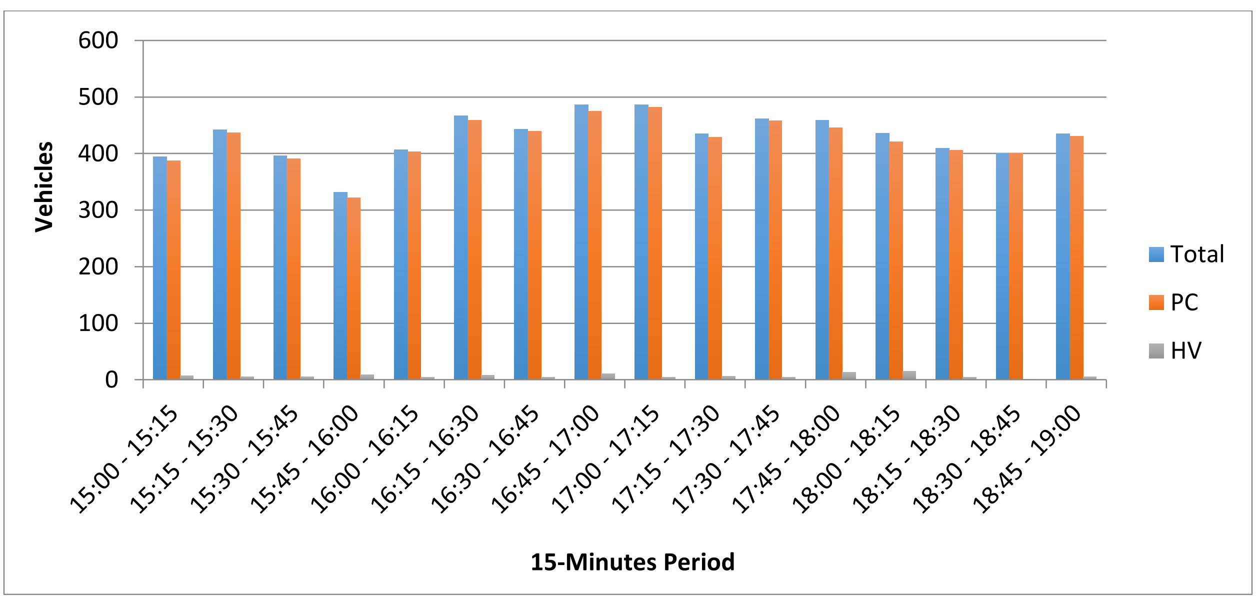


Figure 36: 15-Minutes Period Turning Movements on Intersection T4

Table 10. Peak Hour Volume Calculation Results for Intersection T5

Peak Hour Volume (VPH)		EB			WB			NB			SB		
		31			0			839			741		
17:15 - 18:15	TOTAL	-	-	31	-	-	-	-	839	-	-	738	3
Total 1611	PHF	-	-	0.65	-	-	-	-	0.90	-	-	0.97	0.38
	HV & BUS %	-	-	0%	-	-	-	-	1%	-	-	1%	33%

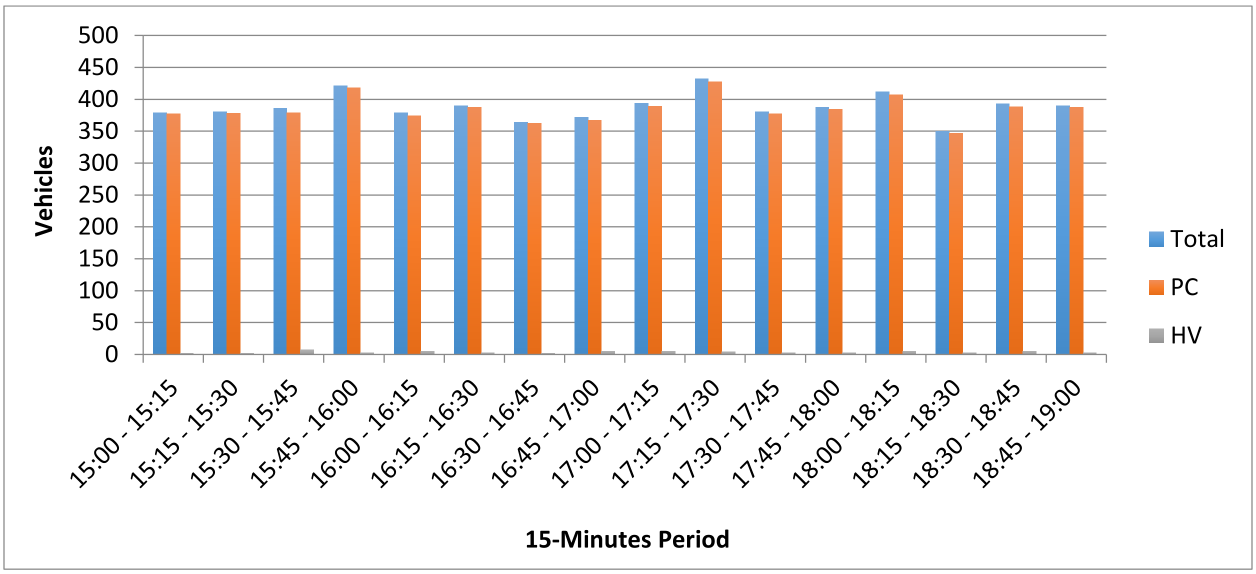


Figure 37: 15-Minutes Period Turning Movements on Intersection T5

Table 11. Peak Hour Volume Calculation Results for Intersection T6

Peak Hour Volume (VPH)		EB			WB			NB			SB		
		143			39			1206			1092		
16:30 - 17:30	TOTAL	73	13	57	27	7	5	104	1049	53	20	1005	67
Total 2480	PHF	0.63	0.33	0.71	0.61	0.29	0.42	0.93	0.97	0.70	0.63	0.97	0.80
	HV & BUS %	1%	0%	0%	0%	0%	0%	0%	1%	0%	0%	2%	0%

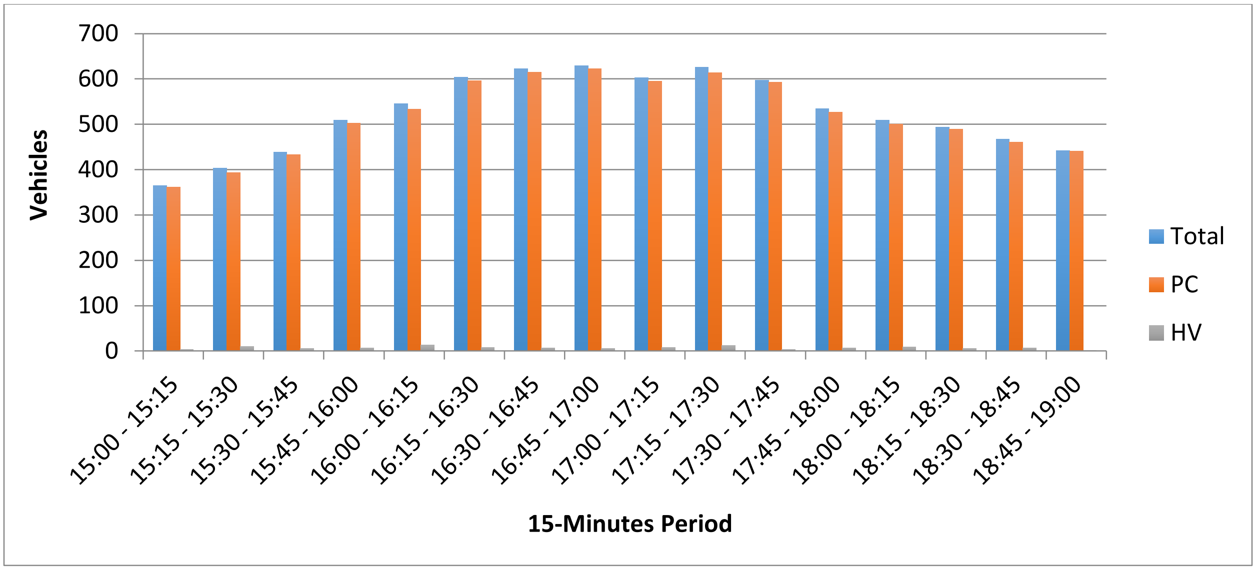


Figure 38: 15-Minutes Period Turning Movements on Intersection T6

Figure 39 summarizes the peak hour volumes (in VPH) on the corridor. Kirkman Intersection (T2) had the highest peak hour volume with 5677 VPH and then the Grand National Intersection (T3) with 3069 VPH.

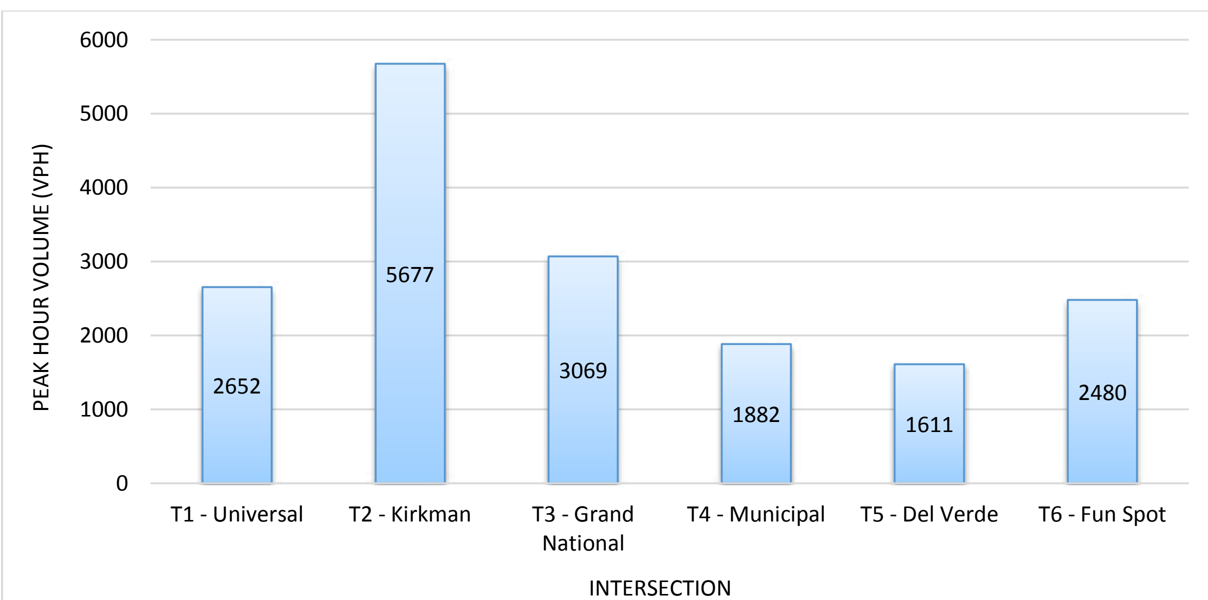


Figure 39: Summary of the Peak Hour Volume on the Corridor

4.4 Passenger Data

To assist in this research, LYNK provided automatic passenger counts for the study period from October 2011 to February 2012. The peak bus hours were determined by plotting bus load versus time, as shown in Figure 40. This figure indicates that the peak bus hour was between 4:00 PM and 5:00 PM (16:00 and 17:00).

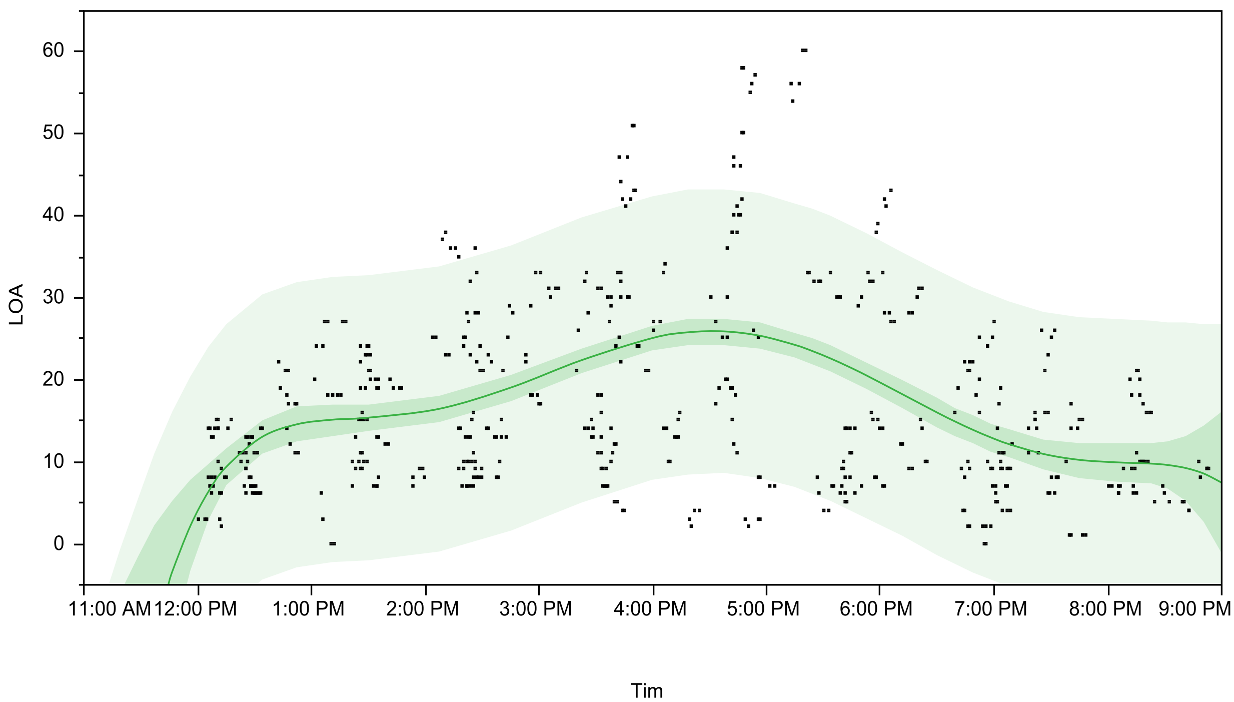


Figure 40: LYNX Passenger Counts - Route 8 Passenger Load vs Time (Monday through Friday)

Additionally, more data were obtained from the **Freeman & Tsoi (2013)** report which concerned a before-and-after study to evaluate the performance of the TSP system on International Drive. They collected data from bus runs (7 runs each direction along the corridor) during peaks and used travel times, speeds, and passengers' activity while boarding and exiting the bus to perform the evaluation.

In addition to the LYNX passenger counts, field visits were performed to collect additional bus data during the PM peak period (15:00 – 19:00) during working days. These collected data included bus travel time, bus delay time, traffic signal delay, passenger delay at stops, arrival time and departure time at stops, and the number of passengers boarding and alighting. Figure 41 shows a sample data sheet that was used in the field.

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Wednesday - April 10. 2013		-	Temp	72	Weather	Sunny	Traffic Signal Delay (Sec)			Run #	
Stop #	Stop Name	SIGNALs	Arrival Time	Doors Open	Doors Closed	Bus Leaves	RED	Green	Passengers Boarding	Passengers Alighting	Staying On Board
	Wet 'N Wild										
1	6200 International Dr and Universal Blvd		15:20:00	2.0	5.0	3.0			0	0	15
		Universal					-	-			
2			15:20:22	2.0	89.0	3.0			3	0	15
		Kirkman					17.0	-			
		Grand National					7.7	-			
3	5500 International Dr and Grand National Dr		No Stop	-	-	-			0	0	15
		Municipal					-	-			
4			No Stop	-	-	-			0	0	15
		Del Verde Way					-	-			
5	5300 International Dr and Municipal Dr		No Stop	-	-	-			0	0	15
		Fun Spot					-	-			
6	5200 International Dr and Fun Spot Dr		No Stop	-	-	-			0	0	15
		Altamira					110.2	-			
7			15:27:00	2.0	8.6	2.0			4	2	17
8			15:28:09	2.0	2.5	3.0			0	1	16
		Oak Ridge					72.0	-			
9	5200 Oak Ridge Rd and International Dr		15:30:14	3.0	9.4	2.0			0	0	16
	Outlet										
10	Oak Ridge Rd and International Dr		15:52:00	2.0	41.9	2.0			1	0	13

Figure 41: Sample of Passenger Count Data Sheet

Figure 42 illustrates the I-Drive test corridor with the bus stops labeled for both directions (eastbound and westbound). This research was concerned with stops 1 through 6 in the eastbound (EB) direction and stops 13 through 17 in the westbound (WB) direction.

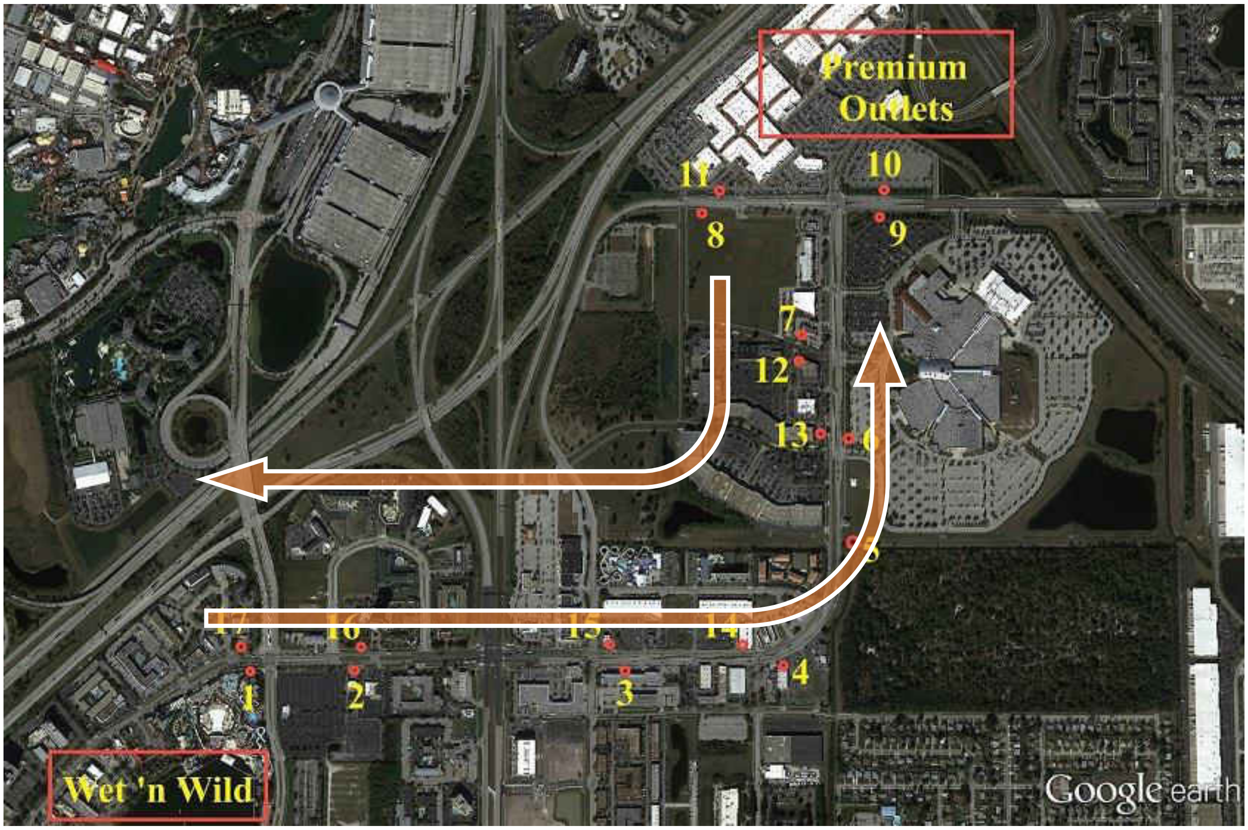


Figure 42: LYNX Link 8 Bus Stops along I-Drive Test Corridor

Tables 12 and 13 summarize the collected field data for both directions (EB and WB), including route duration, passenger delay, signal delay, total passengers boarding, total passengers alighting, average passengers on board, time and day of the week. These data were used to determine the passengers' and buses' behavior along the corridor during the peak hour.

Table 12. Bus Data Collection - Eastbound Field Summary Results

Start	End	Route Duration (sec)	Passenger Delay	Signal Delay	Total Boarding	Total Alighting	Average on Board	Route Start
Stop 1	Stop 6	0:07:33 (453)	30.0	65.0	9.0	4.0	25.4	18:42:00
Stop 1	Stop 6	0:07:51 (471)	98.0	96.0	8.0	2.0	46.6	17:33:21
Stop 1	Stop 6	0:07:42 (462)	70.0	127.0	8.0	3.0	40.2	18:25:21
Stop 1	Stop 6	0:08:56 (536)	25.0	89.0	5.0	0.0	46.4	18:11:21
Stop 1	Stop 6	0:07:38 (458)	77.0	84.0	13.0	3.0	46.4	17:32:10

Table 13. Bus Data Collection - Westbound Field Summary Results

Start	End	Route Duration (sec)	Passenger Delay	Signal Delay	Total Boarding	Total Alighting	Average on Board	Route Start
Stop 13	Stop 17	0:08:18 (498)	48.0	125.0	3	8	17.3	16:45:02
Stop 13	Stop 17	0:07:38 (398)	42.0	111.0	11	3	33.3	18:44:32
Stop 13	Stop 17	0:07:47 (467)	43.0	124.0	1	9	12.5	14:55:14
Stop 13	Stop 17	0:08:07 (487)	30.0	273.0	4	0	19.8	16:02:21
Stop 13	Stop 17	0:08:10 (490)	64.0	274.0	10	1	12.3	17:51:48

4.5 Field Bus Trajectories

Based on the collected field data, bus trajectories were developed; these are illustrated in Figures 43 and 44. The horizontal axis shows the cumulative distance along the corridor (in feet) and the vertical axis shows the cumulative time (in seconds). These trajectories were developed based on the average field bus speeds, average signal delays, and average stop delays. Trajectories were only developed for the three scenarios that field data was collected for (No TSP, Unconditional TSP, and Conditional TSP 3 minutes behind); BRT conditions were not included since the BRT construction is not yet complete. These trajectories show that both Conditional TSP and Unconditional TSP reduced travel time in both directions, with Unconditional TSP providing a greater reduction. This is expected, since Unconditional TSP provides priority to all buses, whereas Conditional TSP only provides priority to buses that are 3 minutes or more behind schedule.

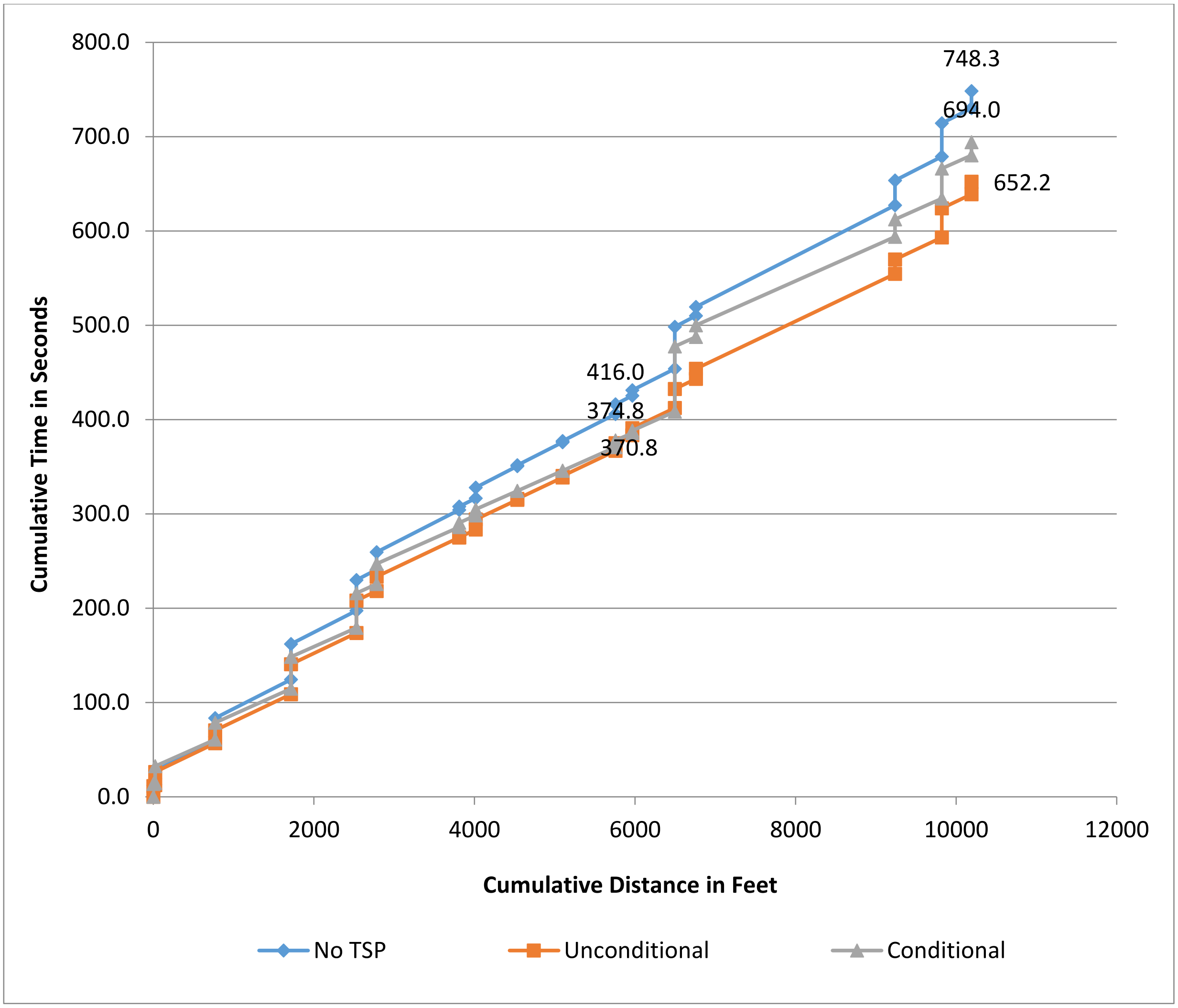


Figure 43: EB Cumulative Corridor Time vs. Distance

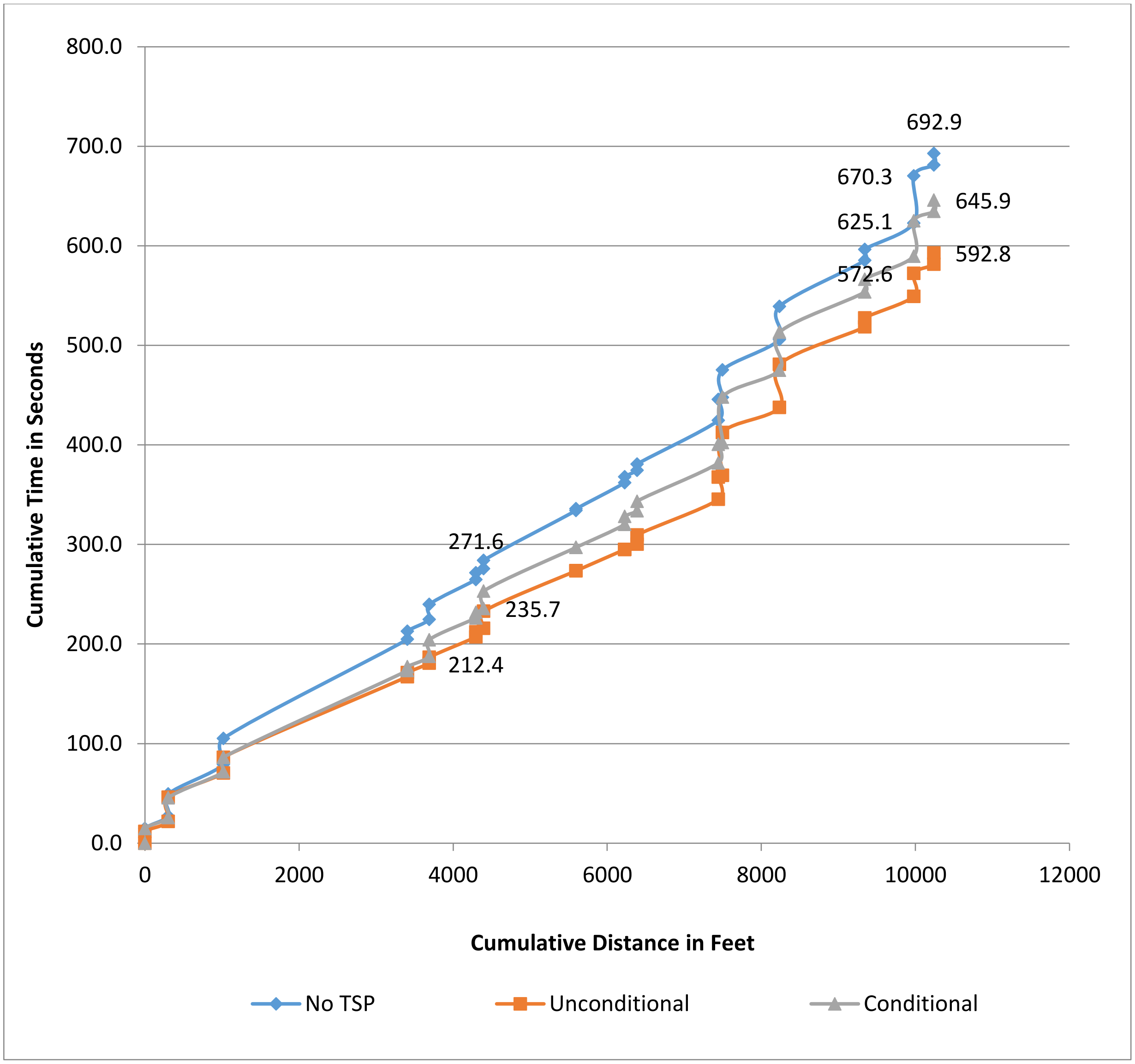


Figure 44: WB Cumulative Corridor Time vs. Distance

CHAPTER 5 VISSIM MODELING & NETWORK ANALYSIS

5.1 Introduction

This chapter describes the network analysis performed on the test corridor, including the building of the simulation model based on the existing field conditions before any enhancement (No TSP and No BRT) and the development of different scenarios to simulate various operational strategies of TSP and BRT. The simulation model was developed using the microscopic traffic flow simulation software VISSIM developed by PTV (Planung Transport Verkehr AG) from Karlsruhe, Germany. This highly complex software allows the user to simulate the effects of different elements in the corridor network, especially during the peak period of congestion, and see how these elements affect the corridor's performance.

Extensive input data were used for the microsimuation modelling, including geometry data (lengths, lanes, and curvature), control data (signal timing and signs), demand data (traffic volumes and turning movements), calibration data (capacities and travel time), and transit data (bus schedules and number of passengers alighting /boarding) (Dowling et al., FHWA 2004).

Traffic simulation modeling in VISSIM involves two main driving behavior models: lane change model and car following model. Both models require many parameters that are stored with default values to reflect the typical traffic conditions; these parameters should only be changed by experienced users. The lane change model controls the overtaking process of the vehicles while traveling. Figure 45 shows the default general driving behavior parameters for the lane change model that were used in this research.

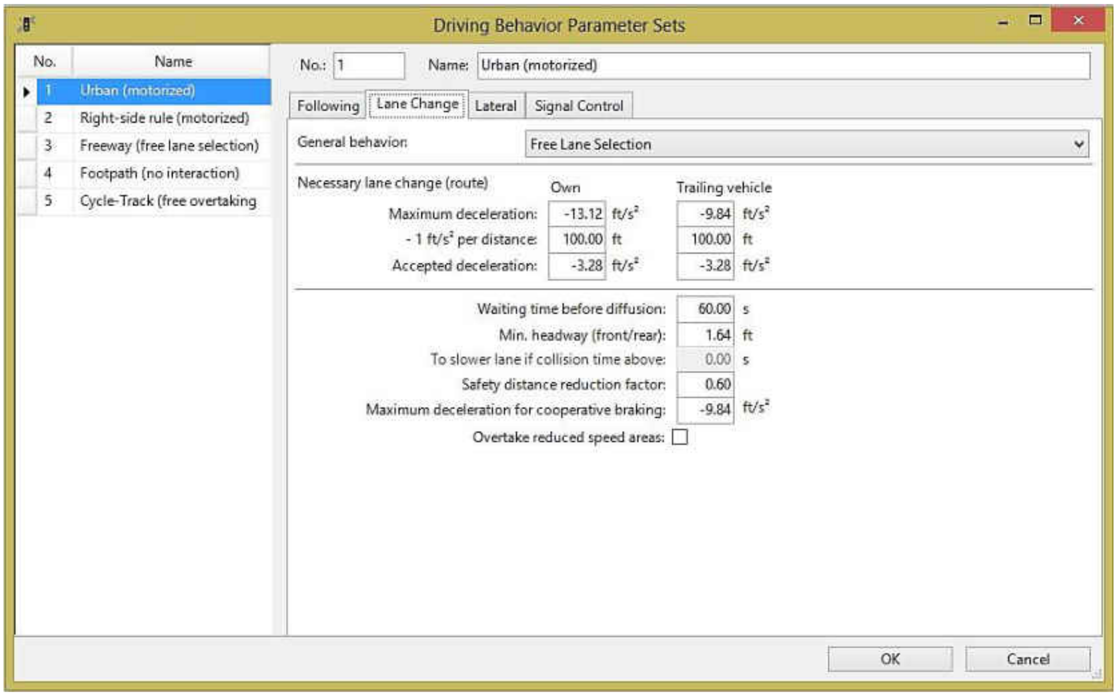


Figure 45: Driving Behavior – Lane Change Default Parameters

The car following model is explained in Figure 46. This model was introduced by Wiedemann in 1974 for arterials and urban traffic.

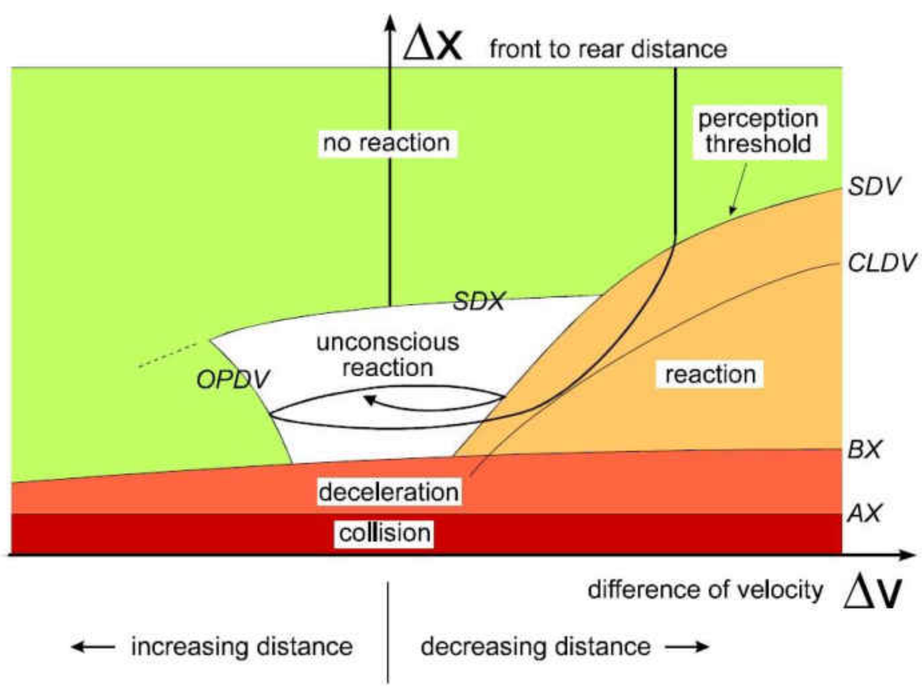


Figure 46: Car Following Logic by Wiedemann 1974 (VISSIM User Manual, 2011)

In Figure 46, the variables are defined as shown below (Olstam and Tapani, 2004):

- **AX** is "the desired distance between stationary vehicles. This threshold consists of the length of the front vehicle and the desired front-to-rear distance."
- **BX** is "the desired minimum following distance at low speed differences."
- **SDV** is "the approaching point. This threshold is used to describe the point where the driver notices that he or she approaches a slower vehicle."
- **CLDV** is "the decreasing speed difference."
- **OPDV** is "the increasing speed difference."
- **SDX** is "the maximum following distance."

The car following model describes the moving vehicle as "the driver's behavior of a faster moving vehicle starts to decelerate as he reaches his individual perception threshold to a slower moving vehicle. Also, his speed will fall below that vehicle's speed until he starts to slightly accelerate again after reaching another perception threshold. This results in an iterative process of acceleration and deceleration" (VISSIM User Manual, 2011). Figure 47 shows the default general parameters for the car following model that were used in this research.

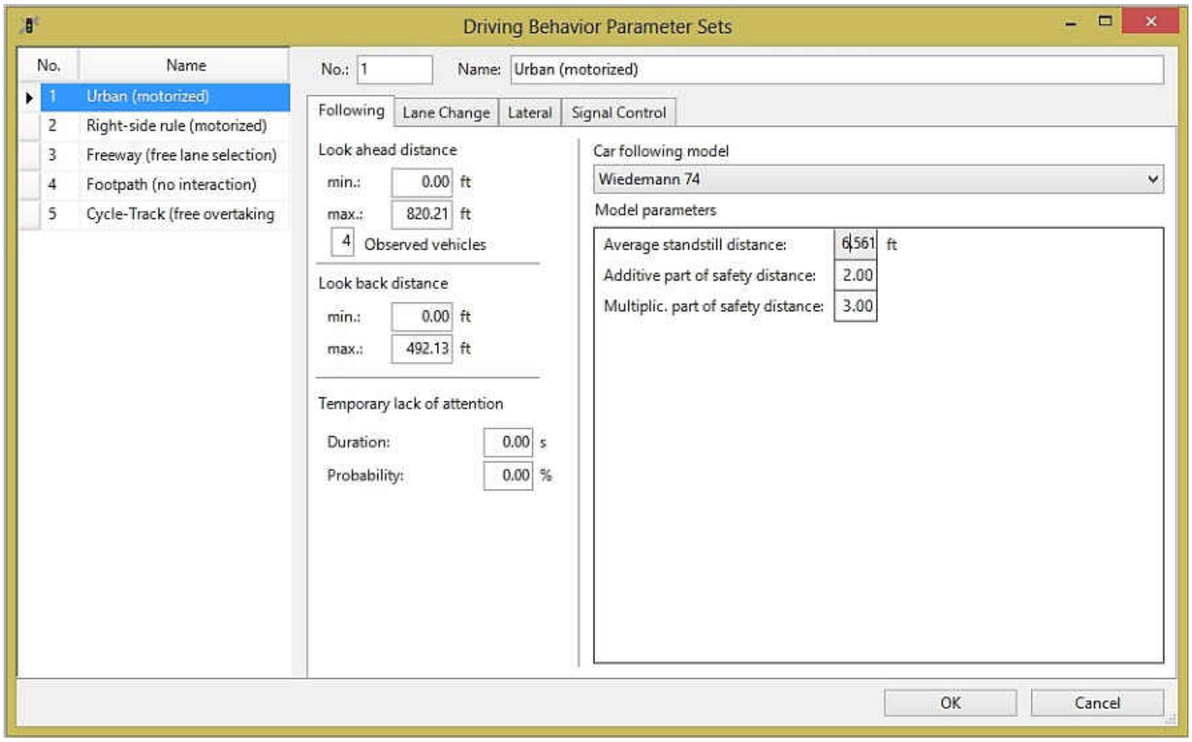
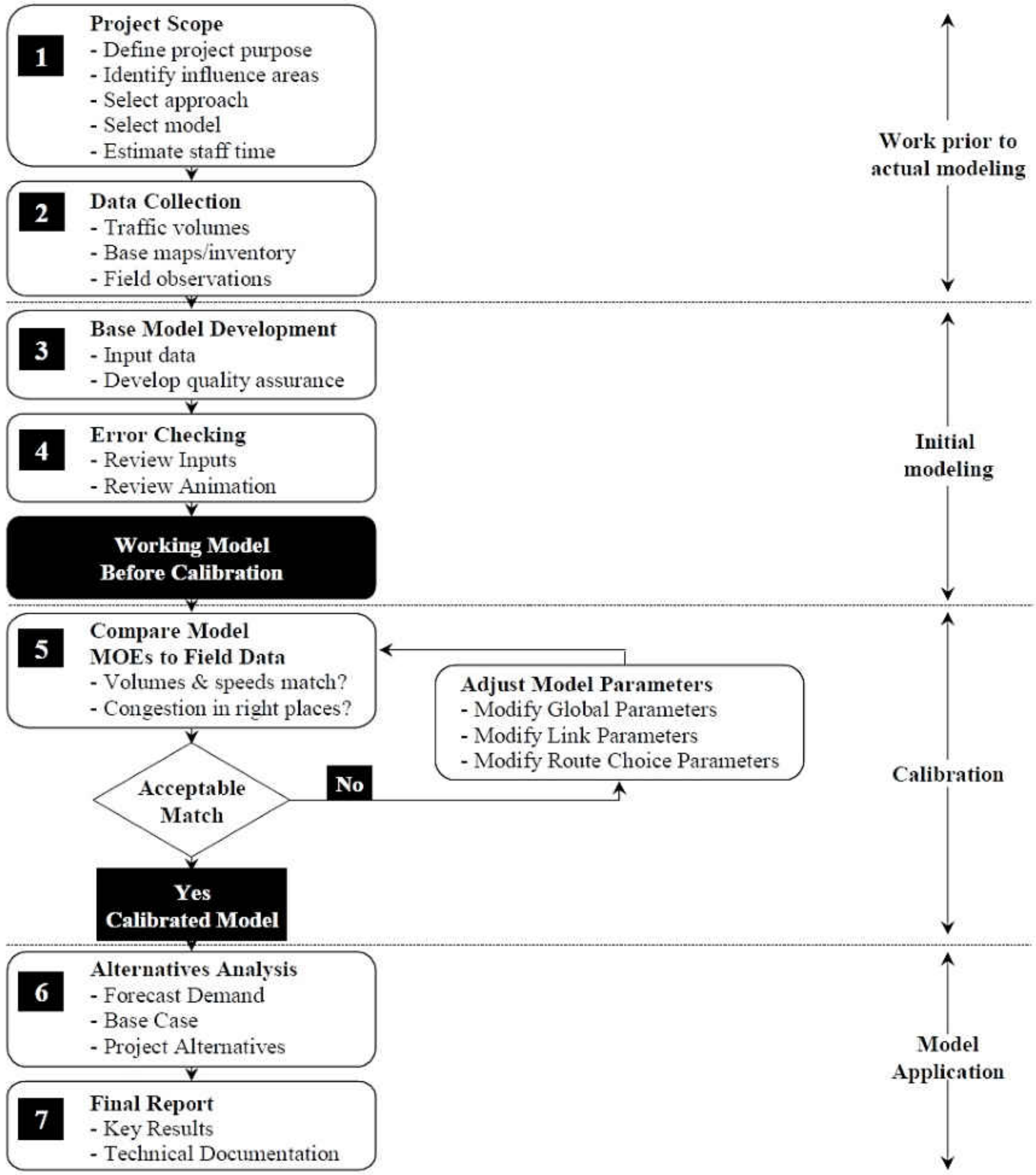


Figure 47: Driving Behavior – Car Following Default Parameters

5.2 Base Model Development

The model development process is outlined in Figure 48. This process has been developed by FHWA based on the best practices of simulation modeling from across the United States. The major tasks are "identification of study purpose, scope, and approach, data collection and preparation, base model development, error checking, calibration and validation, alternatives analysis, final report and technical documentation" (Dowling et al., FHWA 2004).



Developed by the FHWA Traffic Analysis Tools Team and later adapted from *Advanced Corsim Training Manual*, Short, Elliott, Hendrickson, Inc., Minnesota Department of Transportation, September 2003.

Figure 48: Microsimulation Model Development and Application Process (Dowling et al., FHWA 2004)

This process shows that building the base model (which is No TSP and No BRT in this research) for the existing conditions is necessary to ensure the model is reliable, accurate, and verifiable before testing any enhancements.

Coding the model started with importing a reliable scale image (aerial photo or CAD file) in order to code the network accurately. Then, the links (streets), connectors, and nodes (intersections) were created using accurate geometric inputs based on the field data. After these were created, the traffic control data (stop and yield signs, and signals) were added, as well as the intersections and link operations (speed limits, lane use, detectors, etc.). Then, the travel demand data (vehicle types, entry volumes, turning movements, bus routes, etc.) were input and the default traveler behavior parameters were checked. Finally, before moving to the calibration and validation process, the model was checked for errors by reviewing the inputs, performing a visual monitoring (animation) check, and analyzing all numerical and analytical errors. Figure 49 shows a simulation screenshot for the existing (T2) and (T3) intersections taken from the VISSIM software.

Figure 49: Kirkman (T2) and Grand National (T3) Intersections on I-Drive Corridor coded in VISSIM

5.3 Calibration and Validation

Figure 48 shows that model calibration and validation are important steps during the model development process. These steps ensure that the model is accurate and valid by checking that it reflects the traffic conditions in the field as much as possible. Many types of field data were used to accomplish this process. The calibration and validation results were developed using the average of several simulation runs with different random number of seeds. Each run had a running period of 4 hours to allow the model to reach equilibrium even before the peak hour.

5.3.1 Visual Verification

Visual verification of the model was performed to ensure the entire network links (roadways) and nodes (intersection), as well as the traffic movements along the corridor, were accurate and to verify that the model simulated the field conditions as close as possible.

5.3.2 Multiple Runs

Initially, all VISSIM models should start with a minimum of 10 simulation runs with different random number of seeds (Oregon DOT, 2011). The randomly generated seed number is "used to make decisions for the simulation, such as the timing of vehicle loading, the type of vehicle that will be loaded, and the path for each vehicle" (Park and Won, 2006). These ten runs provided an initial data set to help find the required minimum number of simulation runs using the following Equation 3 (Oregon DOT, 2011) for a 95 percent confidence interval:

$$N = (2\ t_{0.025,N-1}\ \frac{S}{R})^2 \quad \textbf{(3)}$$

The variables in this equation are defined as shown below (Oregon DOT, 2011):

- R is the 95% confidence interval for the true mean (widely used value).
- $(t_{0.025,N-1})$ is the student's t-statistic for two-sided error of 2.5 percent (total error of 5 percent) with N-1 degrees of freedom. Based on the data set of 10 runs, t = 2.3.
- N is the number of required simulation runs.
- S is the standard deviation about the mean as calculated in the following Equation 4:

$$S^2 = \frac{\sum(x - \bar{x})^2}{N-1} \quad \textbf{(4)}$$

- x is the output value for each repetition.
- $\bar{x}$ is the average value of all repetitions.
- $(x - \bar{x})$ Indicates how far away from the mean each output value is.

Sample calculation for the initial 10 data set of travel time results for the eastbound direction (EB) is shown below.

Data: 391.25, 396.8, 406.35, 369.65, 381.575, 375.4, 397.1, 402.825, 396.175, and 379.975.

- $\bar{x} = \frac{391.25+396.8+406.35+369.65+ 381.575+375.4+397.1+402.825+396.175+379.975}{10} = 389.71$
- $S^2 = \frac{\sum(x - \bar{x})^2}{N-1} = 12.32$
- R = 7.64
- t = 2.3
- $\mathbf{N} = (2\, t_{0.025,N-1}\, \frac{S}{R})^2 \approx \mathbf{55}$ ← **Minimum Number of Simulation Runs**

A minimum of 55 simulation runs with different random number of seeds were required for a 95 percent confidence interval (57 simulation runs were used).

5.3.3 Volume/Density Check (Turning Movements & GEH)

The most commonly used criteria for traffic volume comparisons (comparing the simulation traffic volumes with the real-world traffic volumes) is the GEH formula, as shown in Equation 5 (WisDOT, 2014).

$$\text{GEH} = \sqrt{\frac{2 * (m-c)^2}{m+c}} \qquad \textbf{(5)}$$

Where:

- ***m*** is the traffic volume from the traffic model (vehicles per hour)
- ***c*** is the real-world traffic count (vehicles per hour)

The GEH formula was established by the transportation planner Geoffrey E. Havers from London, England, in the 1970s (WisDOT, 2014). Table 14 shows the GEH statistics criteria for individual traffic flows in the model and for the model as a whole. This shows that a GEH less than 5 is considered an acceptable fit (WisDOT, 2014).

Table 14: GEH Statistics Criteria for Individual Traffic Flows (WisDOT, 2014)

GEH FOR INDIVIDUAL TRAFFIC FLOWS	
GEH LESS THAN 5	Acceptable fit, probably OK.
GEH BETWEEN 5 AND 10	Caution: possible model error or bad data.
GEH GREATER THAN 10	Warning: high probability of modeling error or bad data.
GEH FOR THE MODEL AS A WHOLE	
GEH LESS THAN 5	At least 75% of intersection turn volumes.

The GEH results for the model, which are shown in Figures 50 and 51, satisfied the criteria shown in Table 14. The acceptance criterion for the model as a whole was to have GEH < 5.0 for at least 75% of intersections' turning volumes (WisDOT, 2014). Also, the acceptance criterion for the individual traffic flows was for GEH < 10.0 (WisDOT, 2014). The developed VISSIM model had GEH < 5.0 for 88% of the intersections and all of the individual traffic flows had GEH less than 10.0. More details on the GEH values are shown in **Appendix E**.

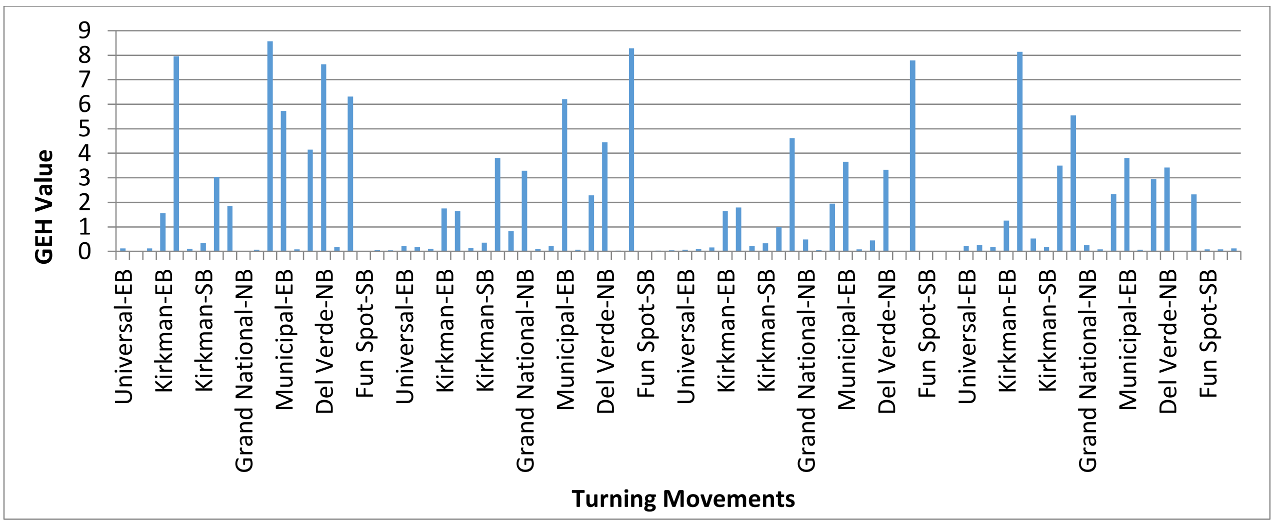


Figure 50: GEH Results

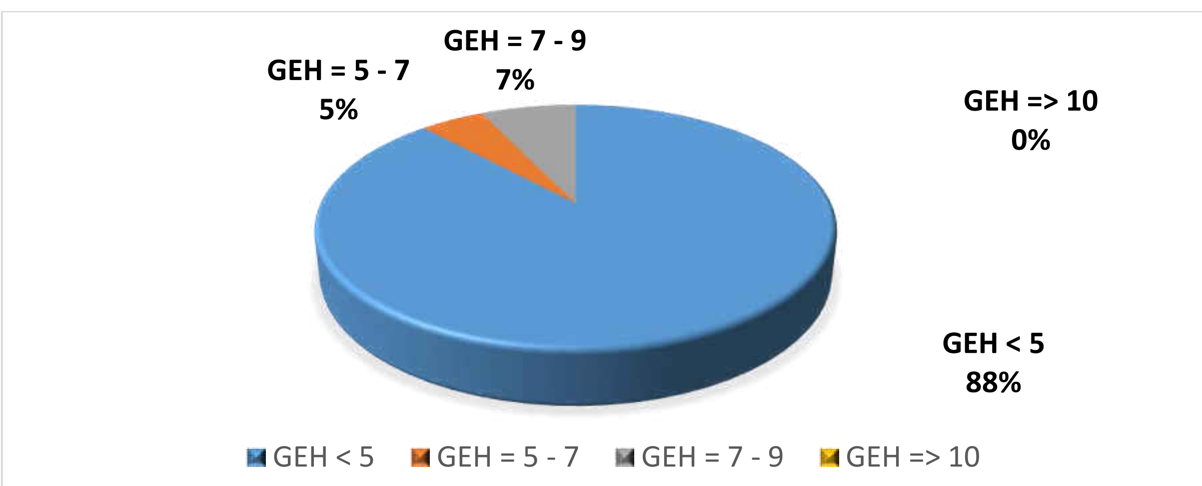


Figure 51: GEH Percentages Summary

Figure 52 compares the turning movement traffic volumes between the "No TSP No BRT" VISSIM model and the "observed" field data for the 4-hour period from 3:00PM to 7:00 PM. The (R^2) is equal to 0.967, representing a good fit. Details for each individual hour are shown in **Appendix E**.

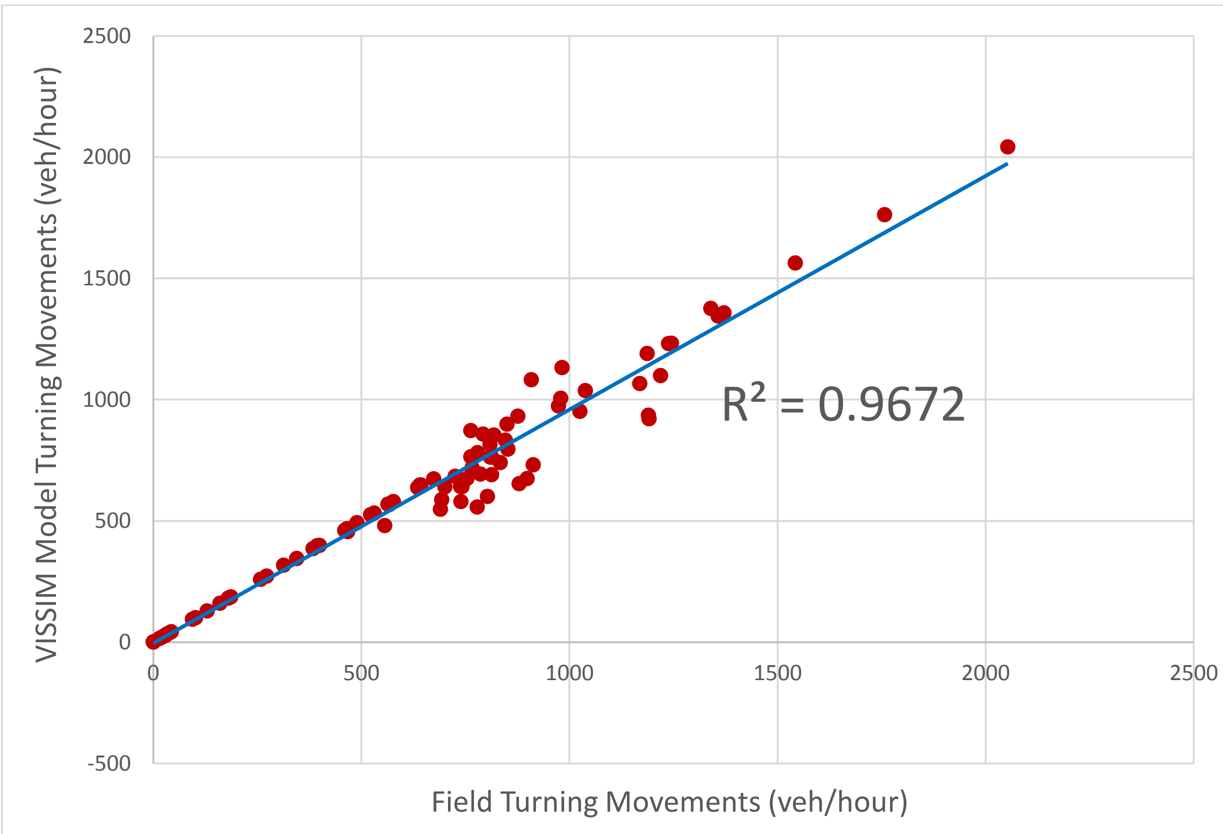


Figure 52: Turning Movement Counts (VISSIM versus Field)

5.3.4 Average Speed Distribution

The average speed profile along the corridor was also tested and compared for the "No TSP No BRT" VISSIM model and the average "observed" field data for the 4-hour period from 3:00 PM to 7:00 PM. Figures 53 and 54 show the speed profiles along the corridor for both directions; these figures show that the VISSIM model accurately reflects the real-world conditions.

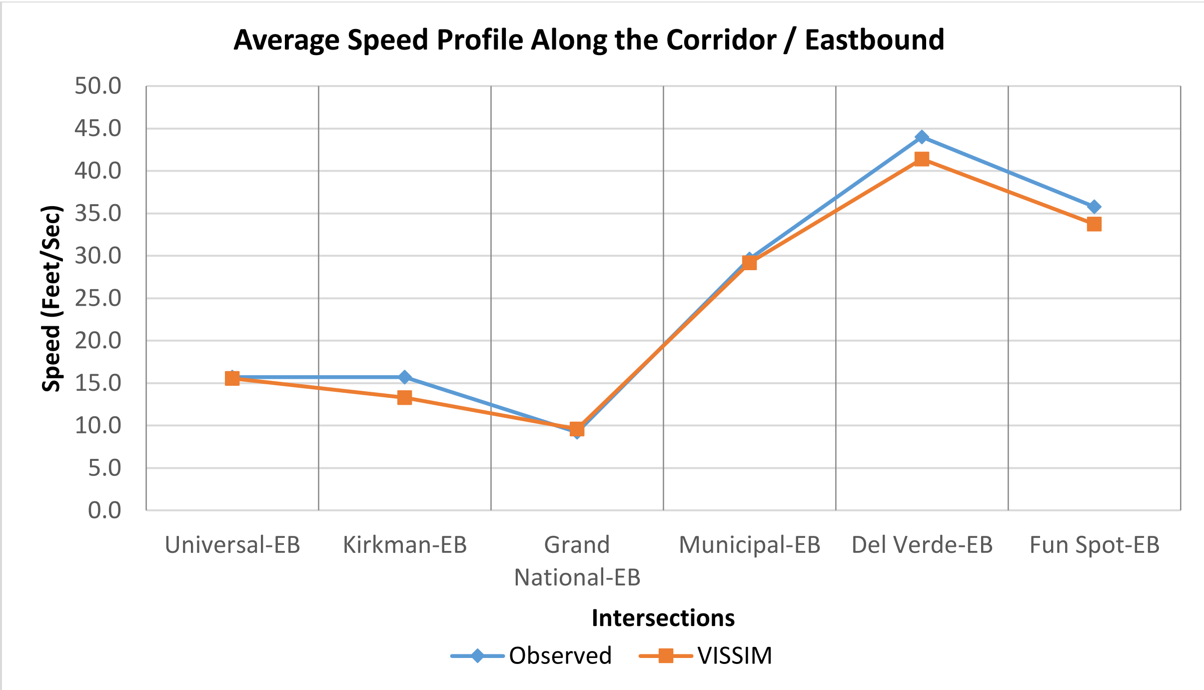


Figure 53: Average Speed Profile along the Corridor / Eastbound

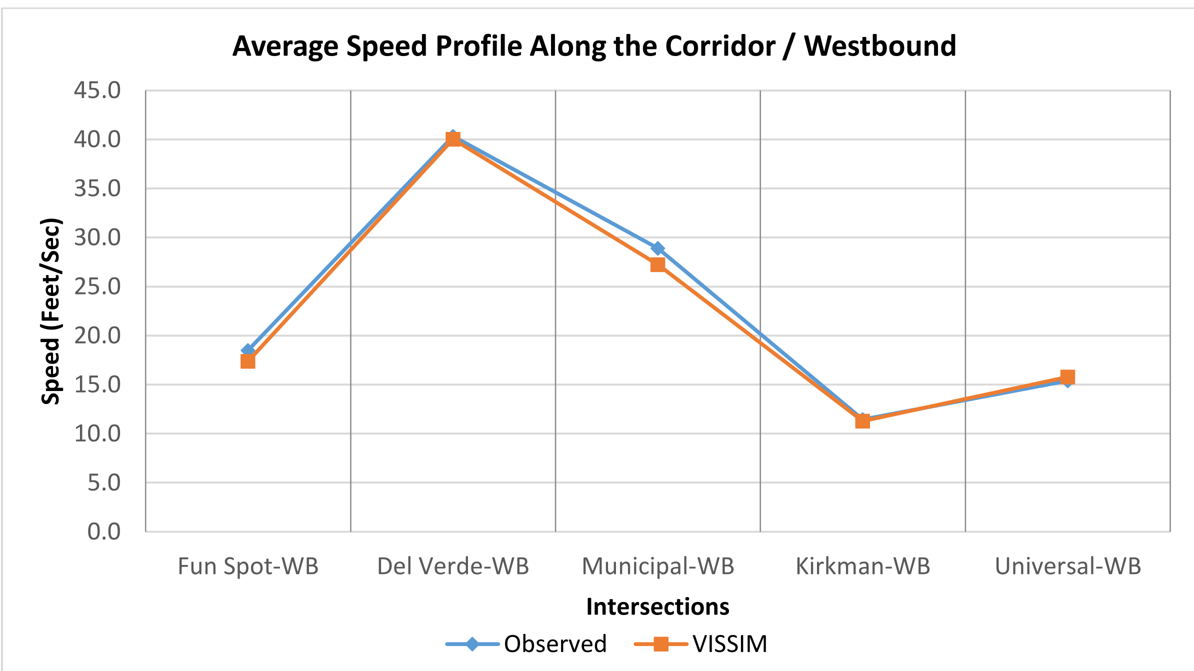


Figure 54: Average Speed Profile along the Corridor / Westbound

5.3.5 Average Travel time

The average travel times from the field data were also used to validate the VISSIM model results, as shown in Table 15. Average travel times were compared for the No TSP No BRT VISSIM model and the average field data for the 4-hour time period from 3:00 PM to 07:00 PM; the results showed that the model is accurate, with the largest difference less than 7%.

Table 15: Average Travel Times VISSIM vs. Field

Travel time section	VISSIM	Field	Difference
	Travel time (sec)	Travel time (sec)	
EB – All Vehicles	391.4	404.3	-3.29%
WB – All Vehicles	378.2	403.7	-6.74%

5.3.6 Bus Travel Time Feasibility Test

The main purpose of this step was to check the feasibility of some random bus travel time data that was collected in the field during the peak travel hours and compare this field data to VISSIM travel time outputs. Figures 55 and 56 show the feasibility of the field bus travel time data during the peak hour compared to VISSIM travel time outputs. The VISSIM travel time output is shown as the bars creating the distribution.

Field data points (shown as arrows with 490, 467, and 498 second values in Figure 56) fit inside the distribution shown by the histogram. For both directions (eastbound and westbound) the field data points fit inside the distribution shown by the histogram. As a result, it can be concluded that the parameter set is feasible because the field travel time data can be expressed (captured) by the current parameter settings.

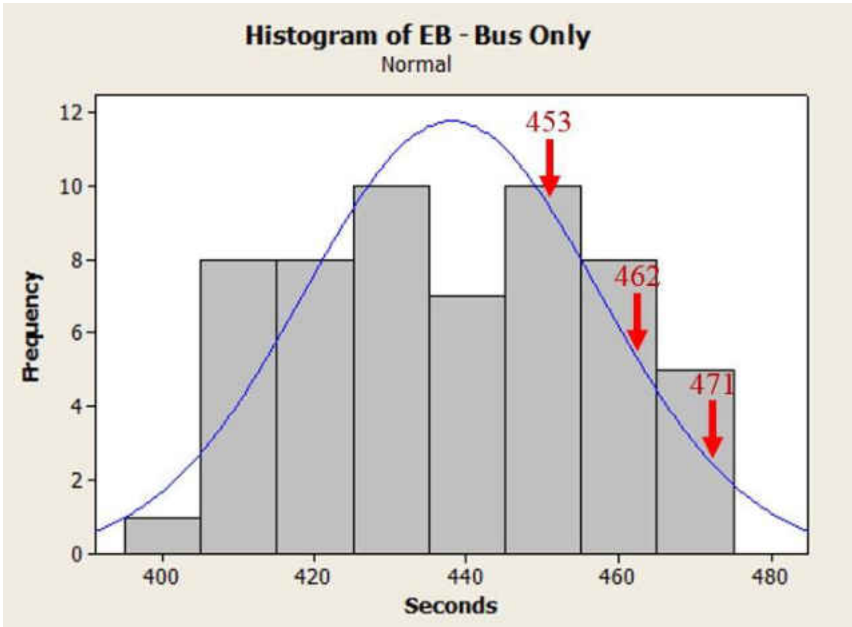


Figure 55: VISSIM Travel Time Outputs for Buses – Eastbound

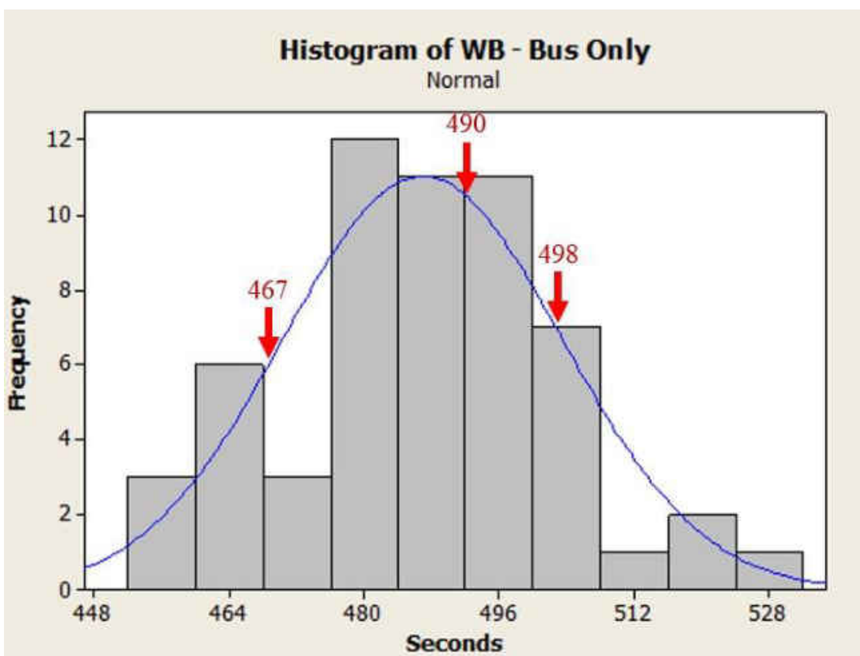


Figure 56: VISSIM Travel Time Outputs for Buses - Westbound

5.4 Development of Scenarios

Once the model was successfully validated, the various test scenarios were developed in VISSIM. These scenarios include the three main levels shown below and illustrated in Figure 16:

- EXISTING SCENARIO (Without TSP and BRT): This scenario represents the existing field conditions before any enhancement. This is the scenario for which the model was calibrated and validated.
- TSP SCENARIOS: These scenarios have TSP only and have three main levels:
  - TSP Unconditional,
  - TSP Conditional with 3 minutes behind schedule, and
  - TSP Conditional with 5 minutes behind schedule.
- BRT SCENARIOS: These scenarios contain BRT and have three main levels:
  - BRT with NO TSP: this scenario assumes an exclusive BRT curb-lane on the sides in both directions along the corridor in addition to the other traffic with no TSP.
  - BRT with Unconditional TSP: this scenario has the same exclusive BRT curb-lane assumption but with active unconditional TSP at all signalized intersections.
  - BRT with Conditional TSP (3 minutes behind schedule): this scenario has the same exclusive BRT curb-lane assumption, but with active conditional TSP (3 minutes behind schedule) at all signalized intersections.
  - BRT with Conditional TSP (5 minutes behind schedule): this scenario has the same exclusive BRT curb-lane assumption, but with active conditional TSP (5 minutes behind schedule) at all signalized intersections.

CHAPTER 6 SIMULATION RESULTS AND ITS EVALUATION

Travel time and speed are important to passengers as well as transit operators, since "the more competitive that transit travel time is with competing modes, in particular the automobile, the more attractive transit service is to potential passengers" (TCRP Report 165, 2013). Therefore, these parameters were investigated using the VISSIM model to determine the most effective and reliable transit system that can compete with the regular (automobile) traffic on the I-Drive corridor.

Figure 57 shows the factors influencing transit speed. These factors contain three main components: travel time, delay, and number of stops. Travel time includes both running time and passenger service time. This figure also shows that number of stops affects both delay and travel time, as more stops increase delay and travel time.

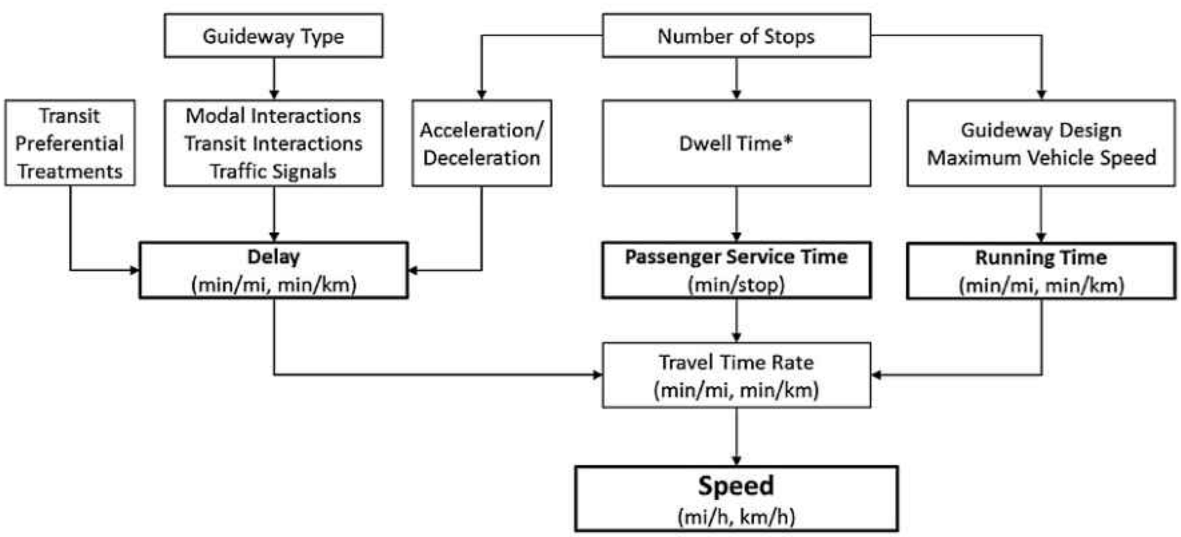


Figure 57: Factors Influencing Transit Speed (TCRP Report 165, 2013)

To determine the performance of the tested scenarios, the following measures of effectiveness (MOEs) were analyzed for each VISSIM scenario: total travel time (seconds), speed (fps), total delay (seconds), and number of stops (per one-way trip).

Table 16 shows the VISSIM model results for through traffic movements along the corridor for four MOEs, including the enhancement percentages of each scenario compared to the base scenario (No-TSP and No-BRT). There was significant enhancement for through traffic movements (both all vehicles and buses only) for all scenarios regarding average travel time (reduction up to 26%), average speed (increase up to 47%), average total delay per vehicle (reduction up to 64%), and average number of stops (reduction up to 46%).

Table 16: VISSIM Results on the Corridor

	EB All Vehicles	WB All Vehicles	EB Bus Only	WB Bus Only
Average Travel Time on the Corridor (Seconds)				
No TSP - No BRT	391	378	438	487
Unconditional TSP	297 (-24%)	320 (-15%)	340 (-22%)	416 (-15%)
Conditional TSP (3 Minutes)	334 (-15%)	342 (-10%)	351 (-20%)	451 (-7%)
Conditional TSP (5 Minutes)	360 (-8%)	360 (-5%)	367 (-16%)	461 (-5%)
BRT - No TSP	314 (-20%)	302 (-20%)	385 (-12%)	424 (-13%)
BRT Unconditional TSP	274 (-30%)	286 (-24%)	335 (-24%)	364 (-25%)
BRT Conditional TSP (3 Minutes)	294 (-25%)	281 (-26%)	357 (-18%)	406 (-17%)
BRT Conditional TSP (5 Minutes)	302 (-23%)	289 (-24%)	361 (-17%)	417 (-14%)
Average Speed on the Corridor (Feet/Sec)				
No TSP - No BRT	15.9	16.2	14.2	12.6
Unconditional TSP	20.9 (31%)	19.1 (18%)	18.3 (29%)	14.7 (16%)
Conditional TSP (3 Minutes)	18.7 (17%)	17.9 (11%)	17.6 (25%)	13.7 (8%)
Conditional TSP (5 Minutes)	17.3 (9%)	16.6 (3%)	16.8 (19%)	13.4 (6%)
BRT - No TSP	20.7 (30%)	20.0 (23%)	16.3 (15%)	14.8 (17%)
BRT Unconditional TSP	23.4 (47%)	22.8 (41%)	19.1 (35%)	17.2 (36%)
BRT Conditional TSP (3 Minutes)	22.1 (39%)	21.5 (33%)	18.6 (32%)	16.4 (30%)
BRT Conditional TSP (5 Minutes)	21.6 (36%)	20.7 (28%)	18.0 (27%)	15.1 (20%)
Average Total Delay per Vehicle on the Corridor (Seconds)				
No TSP - No BRT	166	153	193	175
Unconditional TSP	72 (-57%)	88 (-43%)	75 (-61%)	103 (-41%)
Conditional TSP (3 Minutes)	144 (-13%)	140 (-8%)	146 (-24%)	165 (-5%)
Conditional TSP (5 Minutes)	145 (-13%)	154 (1%)	172 (-11%)	172 (-1%)
BRT - No TSP	152 (-8%)	145 (-5%)	188 (-2%)	170 (-3%)
BRT Unconditional TSP	69 (-59%)	72 (-53%)	69 (-64%)	92 (-48%)
BRT Conditional TSP (3 Minutes)	130 (-22%)	136 (-11%)	132 (-32%)	148 (-15%)
BRT Conditional TSP (5 Minutes)	136 (-18%)	142 (-7%)	164 (-15%)	163 (-6%)
Average Number of Stops per Vehicle on the Corridor				
No TSP - No BRT	3.70	3.43	3.81	3.47
Unconditional TSP	2.41 (-35%)	2.81 (-18%)	2.31 (-40%)	2.48 (-29%)
Conditional TSP (3 Minutes)	3.40 (-8%)	3.08 (-10%)	3.04 (-20%)	3.42 (-1%)
Conditional TSP (5 Minutes)	3.50 (-5%)	3.41 (0%)	3.37 (-12%)	3.55 (2%)
BRT - No TSP	3.45 (-7%)	3.36 (-2%)	3.40 (-11%)	3.42 (-1%)
BRT Unconditional TSP	2.24 (-39%)	2.48 (-28%)	2.05 (-46%)	2.31 (-34%)
BRT Conditional TSP (3 Minutes)	3.08 (-17%)	2.90 (-16%)	2.77 (-27%)	2.86 (-17%)
BRT Conditional TSP (5 Minutes)	3.40 (-8%)	3.34 (-3%)	3.18 (-17%)	3.32 (-4%)

Table 16 also shows that BRT with Unconditional TSP provided the best travel time, speed, number of stops and delay enhancements along I-Drive. However, this scenario had a major negative impact on side street traffic delays (Table 18 later on), especially at major intersections with high traffic demand, showing this scenario is impractical for implementation in the corridor.

6.1 Average Travel Time (Seconds)

The No TSP – No BRT scenario had the highest travel times for all through vehicles and buses both eastbound and westbound. As expected, the travel time for BRT Unconditional TSP was the lowest for both directions and for all vehicles, as well as for buses only. Additionally, Conditional TSP 3 minutes behind had lower travel times than Conditional TSP 5 minutes behind for TSP only and BRT with TSP.

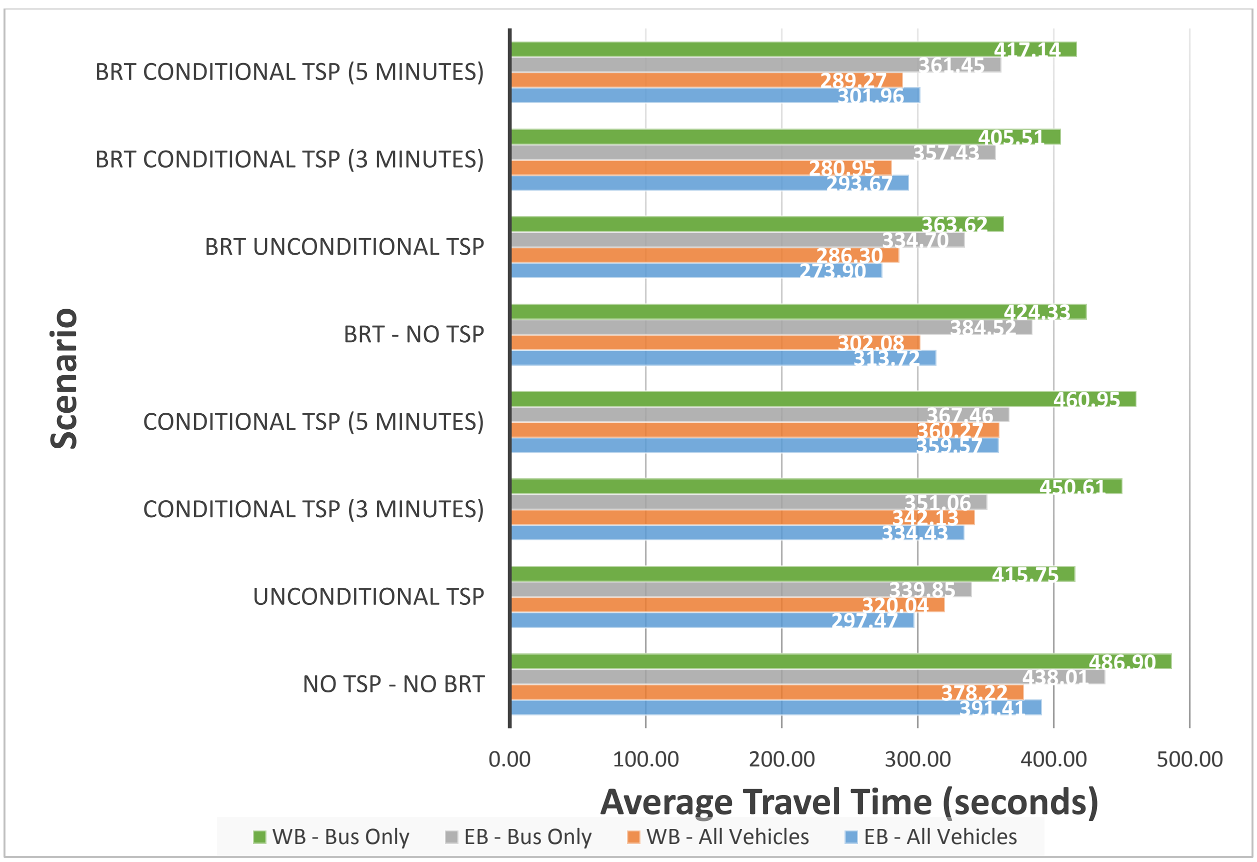


Figure 58: Average Travel Time (seconds)

6.2 Average Speed (Feet/Sec)

There was an increase in speed for all through vehicles compared to No TSP – No BRT for all scenarios. The BRT Unconditional TSP had the highest speed of all the scenarios. The Conditional TSP 3 minutes behind had higher average speeds than the Conditional TSP 5 minutes behind for TSP only and BRT with TSP.

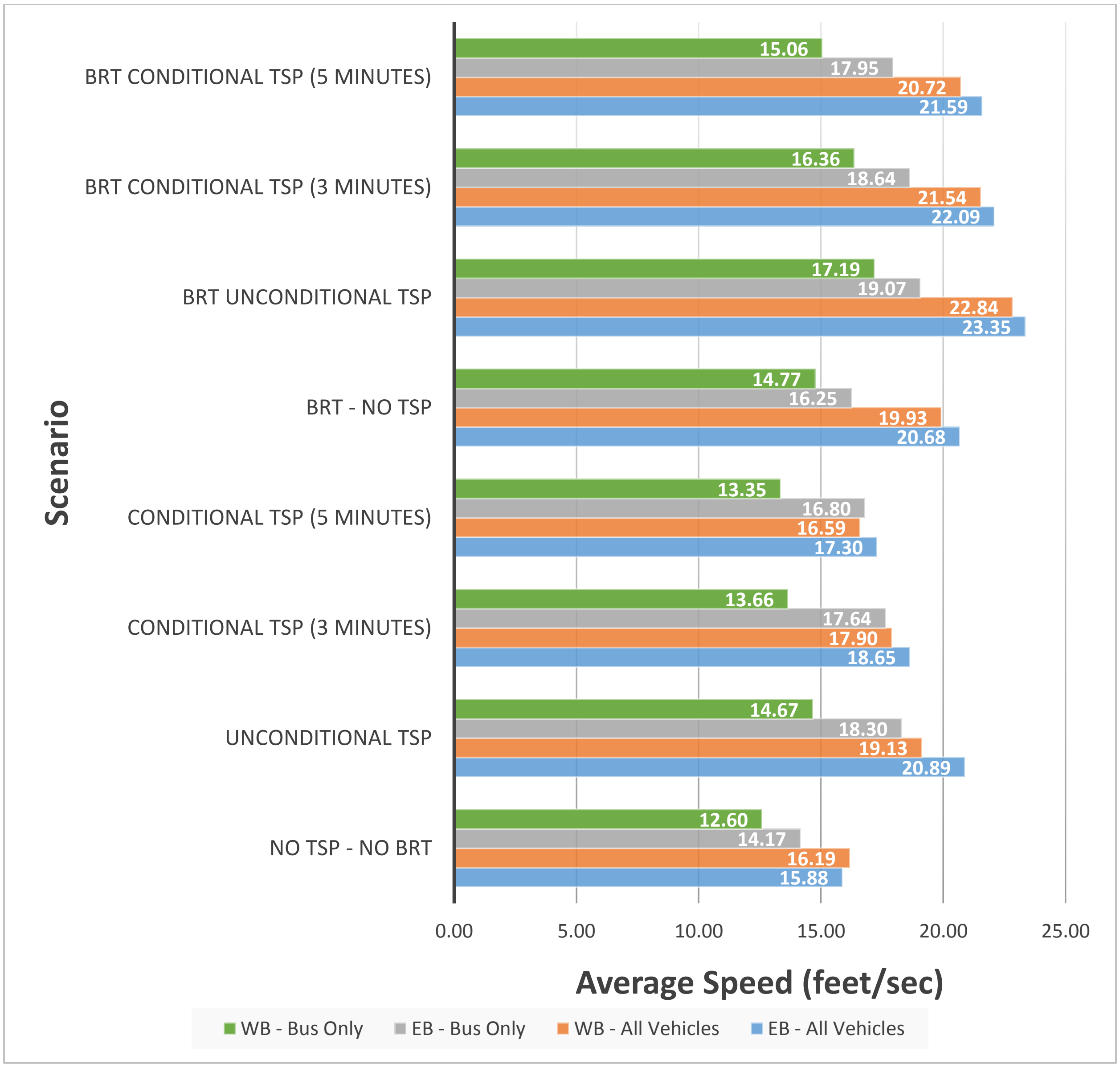


Figure 59: Average Speed (feet/sec)

6.3 Average Total Delay per Vehicle (Seconds)

The delays were highest for No TSP – No BRT and BRT with No TSP and lowest for both (Unconditional TSP) and (BRT Unconditional TSP) for all through vehicles. The Conditional TSP 3 minutes behind had lower total delay than the Conditional TSP 5 minutes behind for TSP only and BRT with TSP.

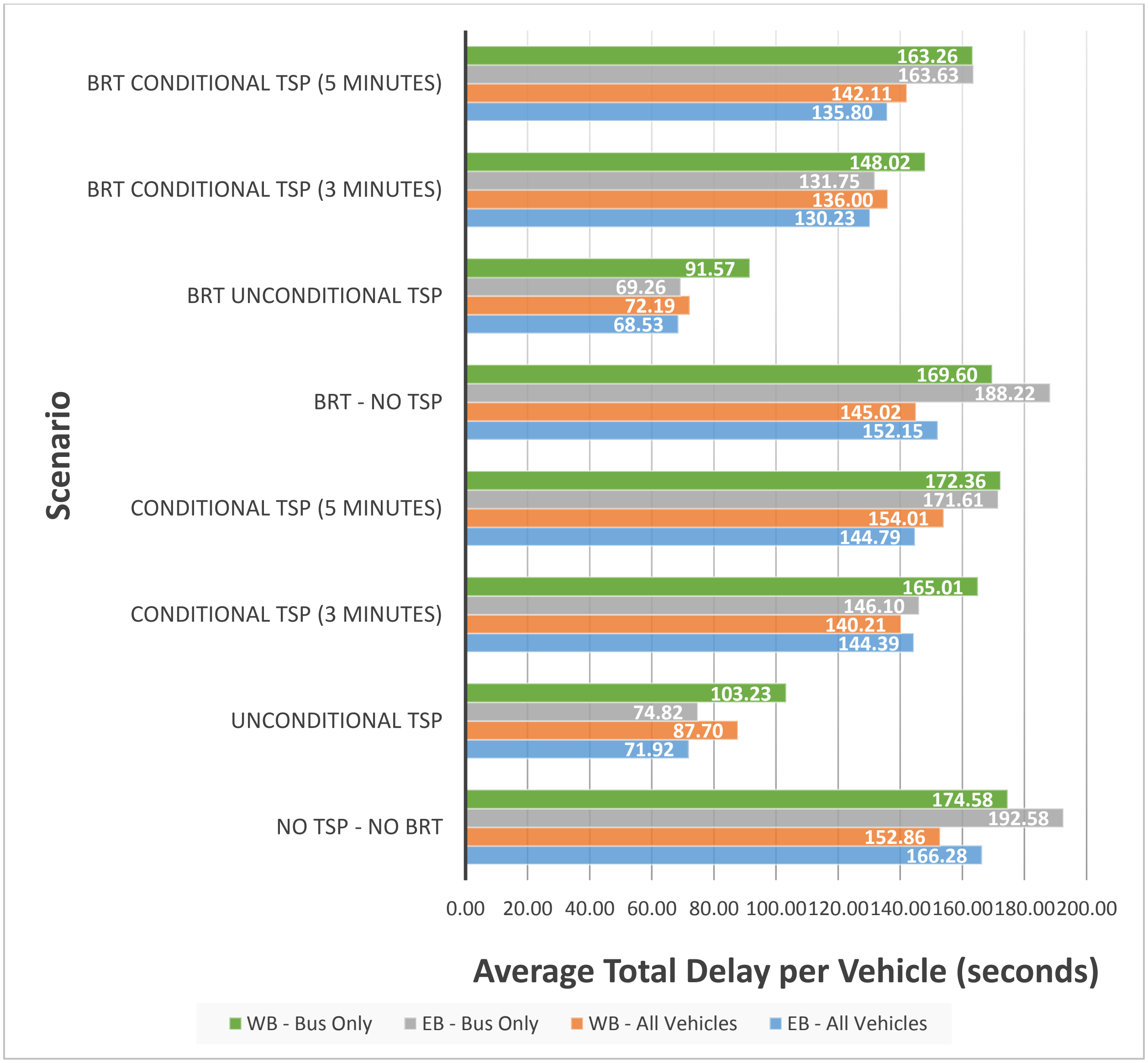


Figure 60: Average Total Delay per Vehicle (seconds)

6.4 Average Number of Stops per Vehicle

The tested scenarios did not significantly affect the number of stops. The highest number of stops per vehicle occurred for the base scenario (No TSP – No BRT) for all through vehicles and buses only; the lowest number of stops per vehicle occurred for BRT Unconditional TSP. Additionally, Conditional TSP 3 minutes behind schedule had less stops than Conditional TSP 5 minutes behind for TSP only and BRT with TSP.

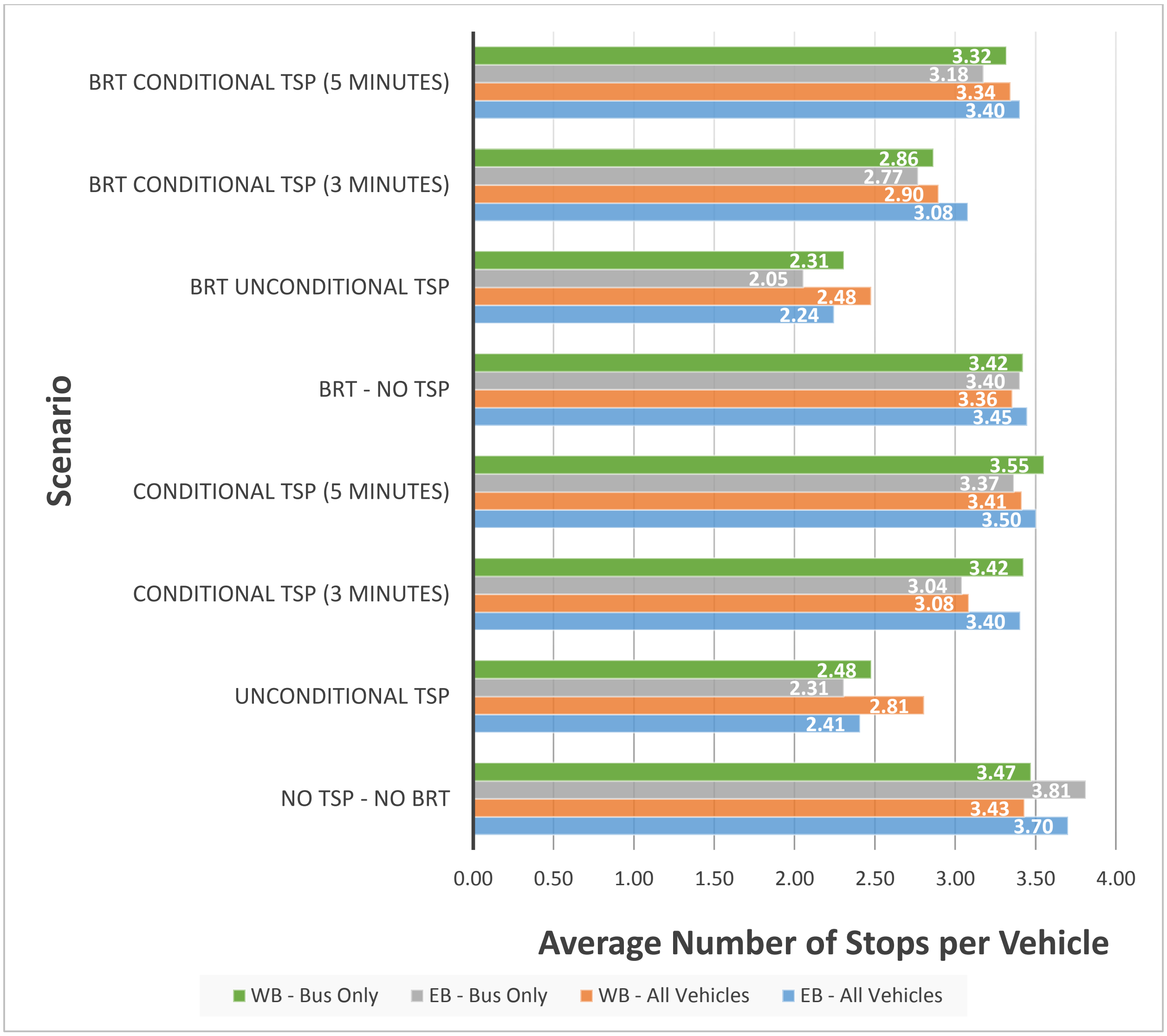


Figure 61: Average Number of Stops per Vehicle

6.5 Nested Sets (Hierarchical Design) Analysis on I-Drive

One of the significant components in the traffic simulation evaluation process is statistical analysis. The purpose of this analysis is to create a model that can store and organize all the data in hierarchical structures and then compare different sets of data. Figure 62 explains the hierarchical design for this analysis. MINITAB statistical software (Minitab, 2015) was used to conduct this analysis.

Data was categorized based on the major MOEs obtained from the VISSIM model analysis, including average travel times, average speed profiles, average delays, and average number of stops. These categories were sub-divided into more specific groups by direction (eastbound and westbound), then by vehicle classification (all vehicles and buses only), then by BRT and TSP scenario (the eight scenarios shown in Figure 62). There were a total of 57 measured observations identified (57 simulation runs with different random number of seeds) for each studied MOE for each scenario.

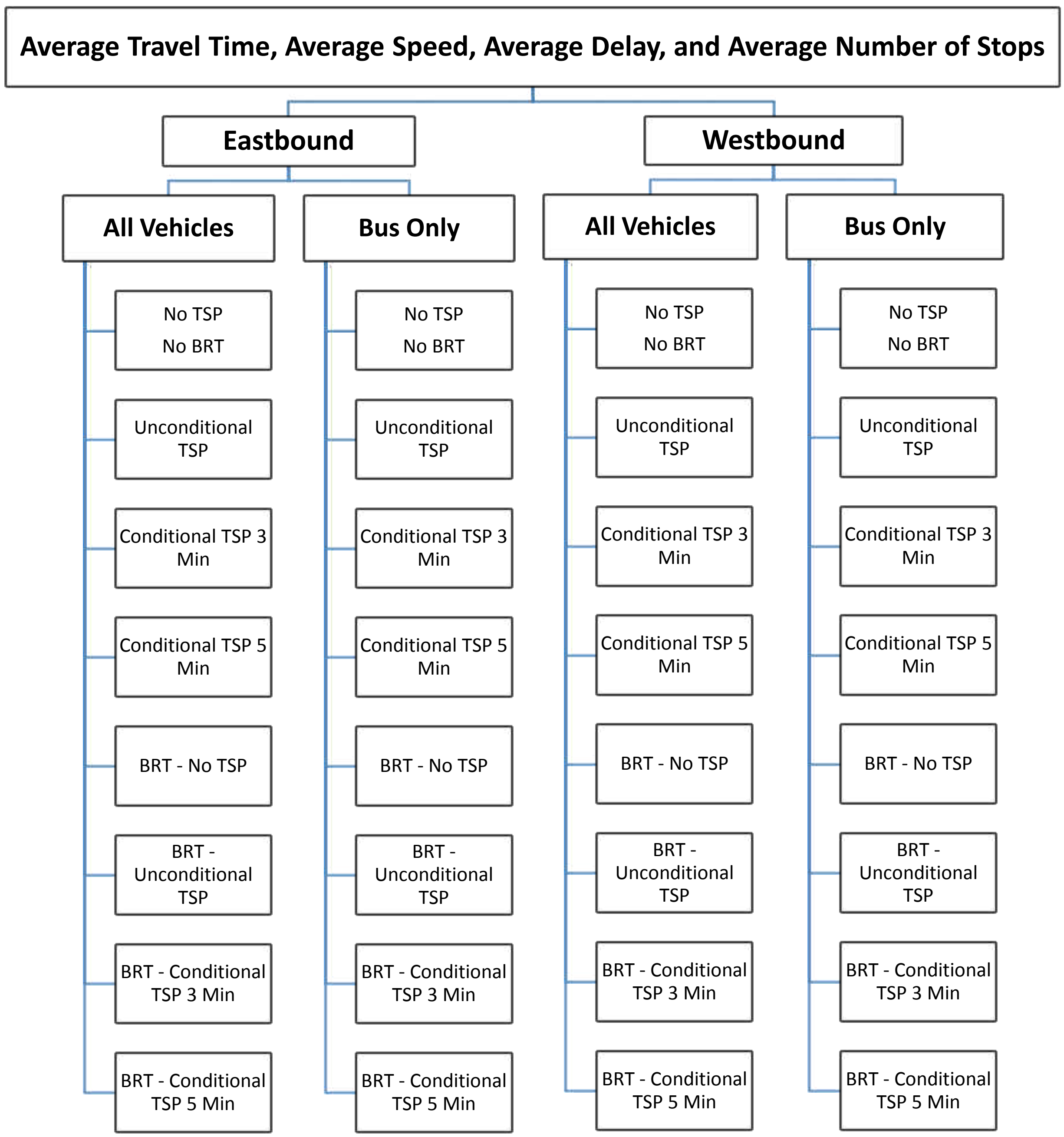


Figure 62: Multi-Stage Nested Design

In a previous study conducted by Al-Deek et al. (2014) that was sponsored by the Southeast Region University Transportation Center (UTC) showed that the statistical analysis using some field data (e.g. bus travel and delay time, traffic signal delay, passenger delay at stops, arrival time and departure time at stops, and the number of passengers boarding and alighting) did not show any certainty of a difference between the base scenario (No TSP and No BRT), and the TSP scenarios (Unconditional and Conditional TSP).

As mentioned before in the limitations of the study, the difficulty of controlling real life experiment (e.g. field bus reliability, bad weather, and the limited time frame of data collection for Unconditional TSP and Conditional TSP due to the start date of the BRT construction project) led to have an inconsistencies in some of these field results. This vagueness led to use micro-simulation to determine the statistical significant of applying TSP and BRT systems.

The following hypotheses about treatment means (μ_i) are tested to see if there is a significant difference between the base scenario (μ_1) and every other scenario (μ_i) for each studied MOE.

$$H_0: \mu_1 = \mu_i, \quad H_1: \mu_1 \neq \mu_i$$

Where: μ_i is the sample mean for each studied MOE and each scenario *i*.

Failing to reject the null hypothesis (H_0) means that there is no significant difference between the base scenario (μ_1) and the other compared scenario (μ_i). On the other hand, rejecting the null hypothesis (H_0) and accepting the alternative hypothesis (H_1) means there is a significant difference between the base scenario (μ_1) and the other compared scenario (μ_i). Table 17 summarizes the experiment results for all scenarios compared to the base scenario for all four MOEs.

Table 17: Experiment Results for Through Traffic Movements on I-Drive

Average Travel Time				
	EB - All Veh	WB - All Veh	EB - Bus Only	WB - Bus Only
No TSP - No BRT (μ_1)	*Base Scenario			
Unconditional TSP (μ_2)	All are **<u>Significant</u>** compared with the "Base Scenario"			
Conditional TSP (3 Minutes) (μ_3)				
Conditional TSP (5 Minutes) (μ_4)				
BRT - No TSP (μ_5)				
BRT Unconditional TSP (μ_6)				
BRT Conditional TSP 3 Min (μ_7)				
BRT Conditional TSP 5 Min (μ_8)				

Average Speed				
	EB - All Veh	WB - All Veh	EB - Bus Only	WB - Bus Only
No TSP - No BRT (μ_1)	*Base Scenario			
Unconditional TSP (μ_2)	All are **<u>Significant</u>** compared with the "Base Scenario"			
Conditional TSP (3 Minutes) (μ_3)				
Conditional TSP (5 Minutes) (μ_4)				
BRT - No TSP (μ_5)				
BRT Unconditional TSP (μ_6)				
BRT Conditional TSP 3 Min (μ_7)				
BRT Conditional TSP 5 Min (μ_8)				

Average Total Delay per Vehicle				
	EB - All Veh	WB - All Veh	EB - Bus Only	WB - Bus Only
No TSP - No BRT (μ_1)	*Base Scenario			
Unconditional TSP (μ_2)	All are **<u>Significant</u>** compared with the "Base Scenario", <u>Except for</u>: *Conditional TSP (5 Minutes) (μ_4)* -- WB (All Vehicles)			
Conditional TSP (3 Minutes) (μ_3)				
Conditional TSP (5 Minutes) (μ_4)				
BRT - No TSP (μ_5)				
BRT Unconditional TSP (μ_6)				
BRT Conditional TSP 3 Min (μ_7)				
BRT Conditional TSP 5 Min (μ_8)				

Average Number of Stops per Vehicle				
	EB - All Veh	WB - All Veh	EB - Bus Only	WB - Bus Only
No TSP - No BRT (μ_1)	*Base Scenario			
Unconditional TSP (μ_2)	All are **<u>Significant</u>** compared with the "Base Scenario", <u>Except for</u>: *Conditional TSP (3 Minutes) (μ_3)* -- WB (Bus Only) *Conditional TSP (5 Minutes) (μ_4)* -- WB (All Vehicles) *Conditional TSP (5 Minutes) (μ_4)* -- WB (Bus Only) *BRT - No TSP (μ_5)* -- WB (Bus Only)			
Conditional TSP (3 Minutes) (μ_3)				
Conditional TSP (5 Minutes) (μ_4)				
BRT - No TSP (μ_5)				
BRT Unconditional TSP (μ_6)				
BRT Conditional TSP 3 Min (μ_7)				
BRT Conditional TSP 5 Min (μ_8)				

Together, Tables 16 and 17 indicate that there was significant enhancement for through traffic movements for all scenarios for the average travel time (reduction), average speed (increase), average total delay per vehicle (reduction), and average number of stops (reduction). There was one minor non-significant enhancement for the average total delay on the westbound direction (all vehicles) for Conditional TSP 5 minutes behind and there were also non-significant enhancements in the westbound direction for Conditional TSP 5 minutes behind (all vehicles and buses only), Conditional TSP 3 minutes behind, Conditional TSP 5 minutes behind (buses only), and BRT with No TSP (buses only) regarding the average number of stops. For the eastbound direction, all scenarios showed significant differences with respect to the base scenario for all four MOEs.

6.6 Crossing Street Average Delay per Vehicle (Seconds)

The previous results in Table 1 showed that the BRT Unconditional TSP scenario provided the best performance for all through vehicles traveling along the I-Drive corridor. Table 18 and Figures (63 - 68) show the average crossing street delay for each tested scenario at each intersection. They show that the Unconditional TSP scenarios often caused the largest increases in side street delays, due to the extension of the green or truncation of red on I-Drive any time the bus approaches the signal, causing vehicles at the side streets to wait longer.

Table 18: Crossing Street Average Delay per Vehicle (Seconds)

Scenario	Universal Boulevard (T1)		Kirkman Road (T2)		Grand National Drive (T3)		Municipal Drive (T4)		Del Verde Way (T5)	Fun Spot Way (T6)	
Direction	NB	SB	NB	SB	NB	SB	NB	SB	EB	EB	WB
No TSP - No BRT	26.95	18.66	41.53	41.14	88.58	32.25	13.95	1.01	5.47	17.01	14.90
Unconditional TSP	27.18	20.14	216.04	258.61	280.32	64.62	17.12	0.99	6.62	18.13	15.63
Cond. TSP 3 Min	28.67	22.31	31.98	37.88	103.42	27.08	10.64	1.00	4.90	20.11	13.93
Cond. TSP 5 Min	27.48	19.04	38.51	37.67	90.78	32.29	12.21	0.99	5.72	17.26	14.67
BRT - No TSP	23.31	16.74	34.33	31.17	50.78	30.88	12.17	1.19	8.10	16.48	15.11
BRT Uncond. TSP	23.76	17.08	80.19	59.89	68.03	49.72	13.76	1.44	9.53	19.00	17.00
BRT Cond. TSP 3 Min	23.65	16.37	32.43	35.52	60.21	36.15	10.69	1.23	9.41	18.74	13.30
BRT Cond. TSP 5 Min	23.25	16.25	32.37	31.43	55.32	35.48	12.27	1.22	9.51	16.18	12.40

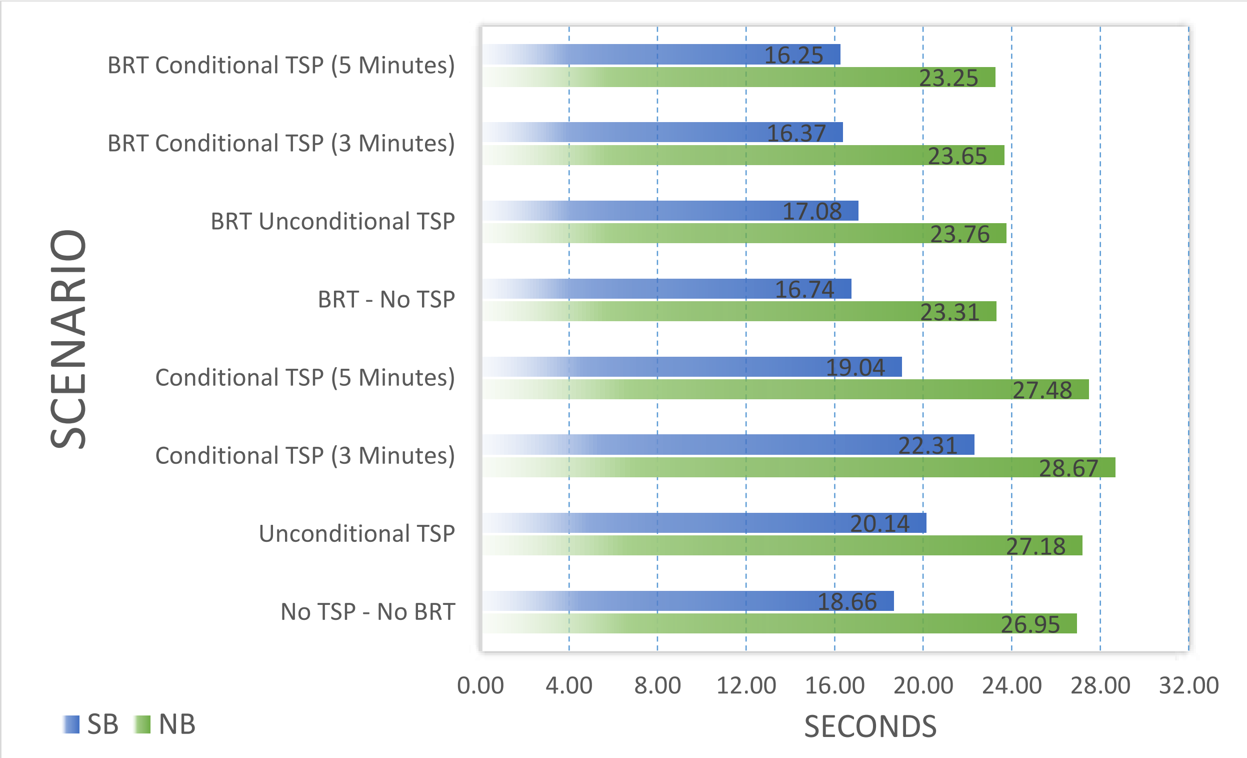


Figure 63: Crossing Street Average Delay per Vehicle on Universal Boulevard (T1)

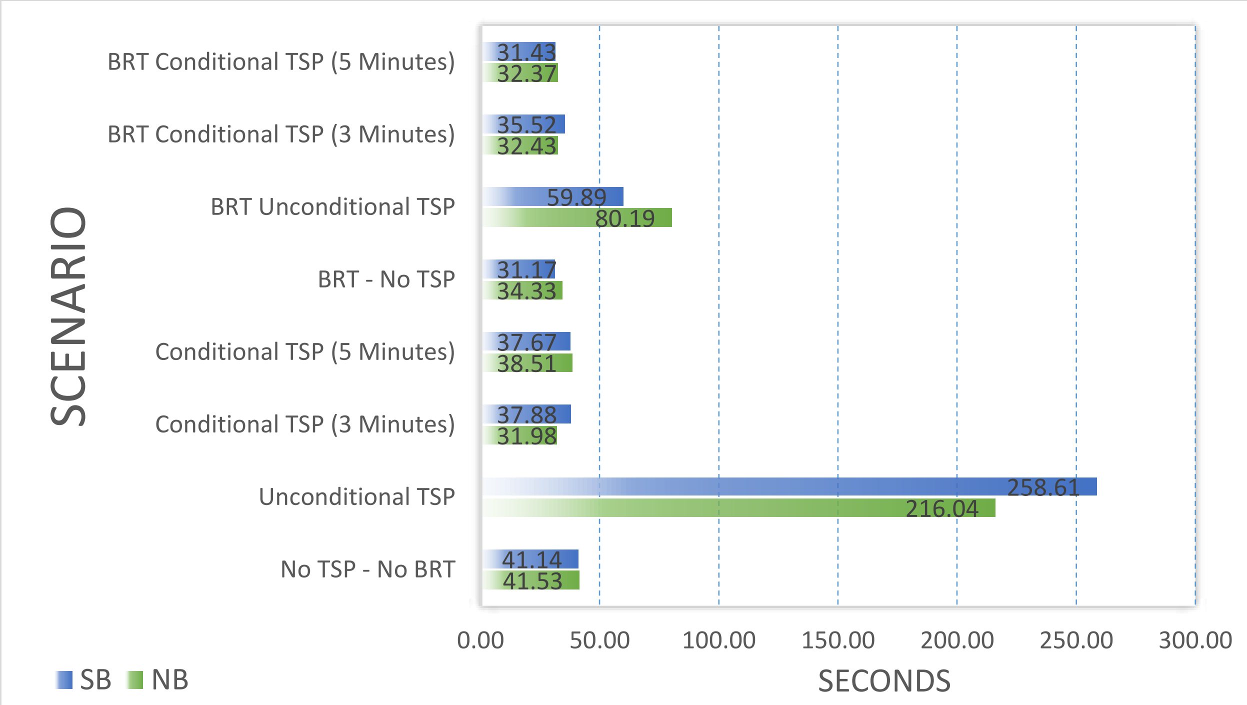


Figure 64: Crossing Street Average Delay per Vehicle on Kirkman Road (T2)

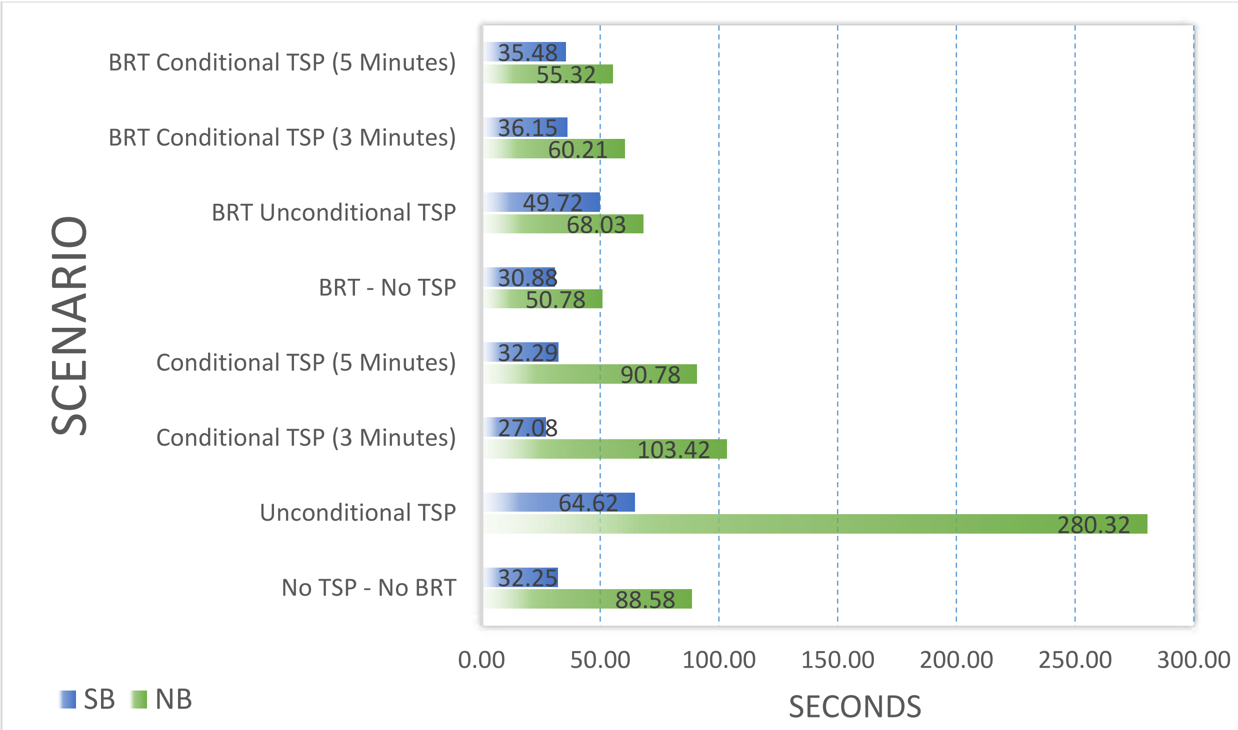


Figure 65: Crossing Street Average Delay per Vehicle on Grand National Drive (T3)

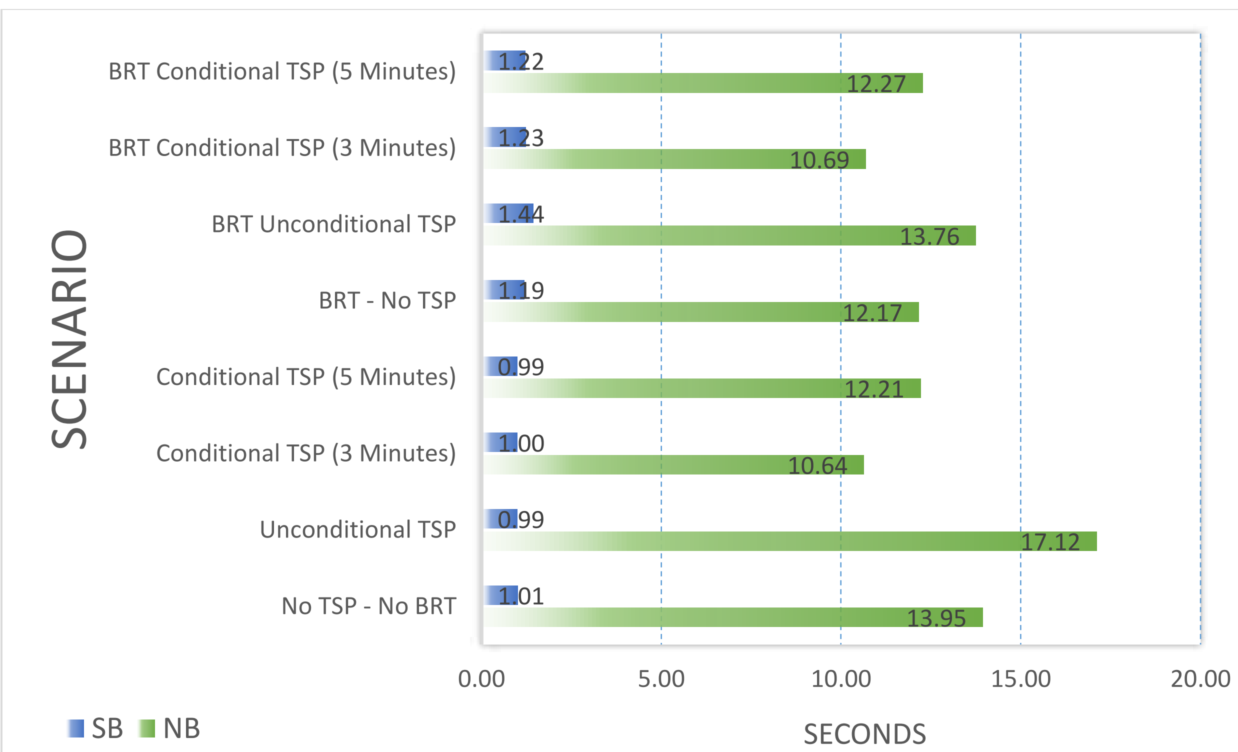


Figure 66: Crossing Street Average Delay per Vehicle on Municipal Drive (T4)

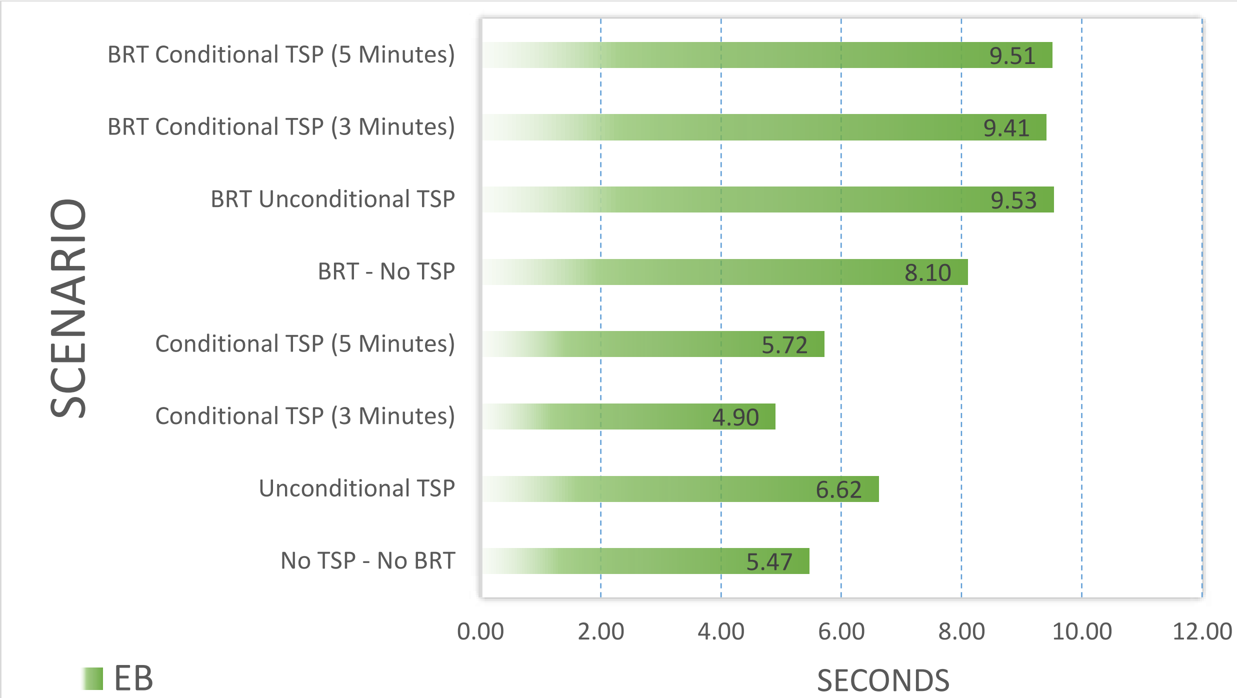


Figure 67: Crossing Street Average Delay per Vehicle on Del Verde Way (T5)

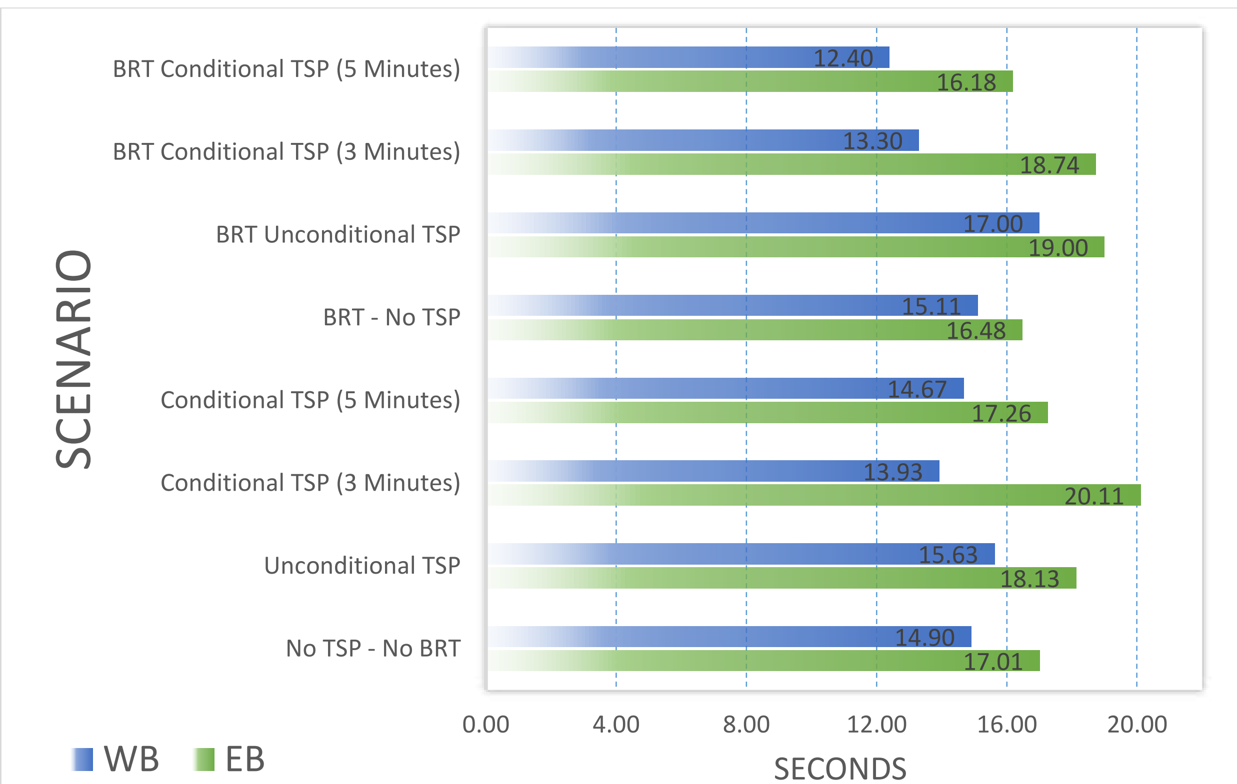


Figure 68: Crossing Street Average Delay per Vehicle on Fun Spot Way (T6)

Excessive side street delays occurred at Grand National Drive (T3) and Kirkman Road (T2) for Unconditional TSP and BRT with Unconditional TSP scenarios, with delays of almost 60 to 280 seconds. These two streets had the highest traffic volumes (Figure 5). The high traffic volumes on these streets (Kirkman and Grand National) contributed to these higher side street delays. Side street delays at the other intersections were low (not significant) compared to major intersections. In most of the intersections, the side street delays for all scenarios were higher than the base scenario (No TSP – No BRT). Municipal Drive (T4), Del Verde Way (T5), and Fun Spot Way (T6) are minor streets with relatively low volumes compared to I-Drive. Therefore, there were no major changes on the crossing side streets delay at these intersections (changes were in the ±4 seconds range).

Overall, BRT with Conditional TSP 3 minutes behind schedule is the most encouraging scenario, it has provided significant travel benefits for the through vehicles without having a large negative influence on side streets, especially at high volume intersections such as Kirkman Road (T2).

Distribution of Data

The following histogram charts (Figures 69 - 95) show the density distribution of the data. Each figure contains the mean (μ) that controls the location of the peak of the distribution, the standard deviation (σ), and the sample size (number of observation "N") for each scenario.

It can be seen that the data approximately follow the common normal distribution (bell shape) which represents the real-valued random MOE VISSIM outputs. More details about each MOE and each scenario are available in **Appendix F.**

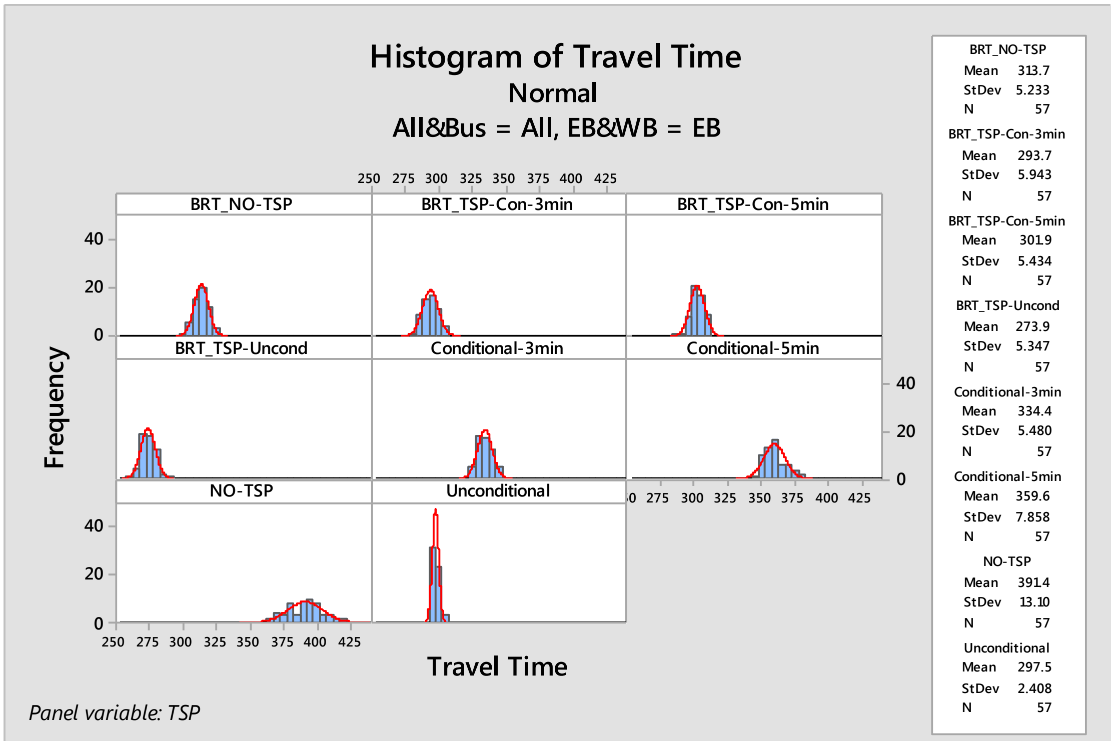


Figure 69: Average Travel Time (seconds) – All Vehicles – EB

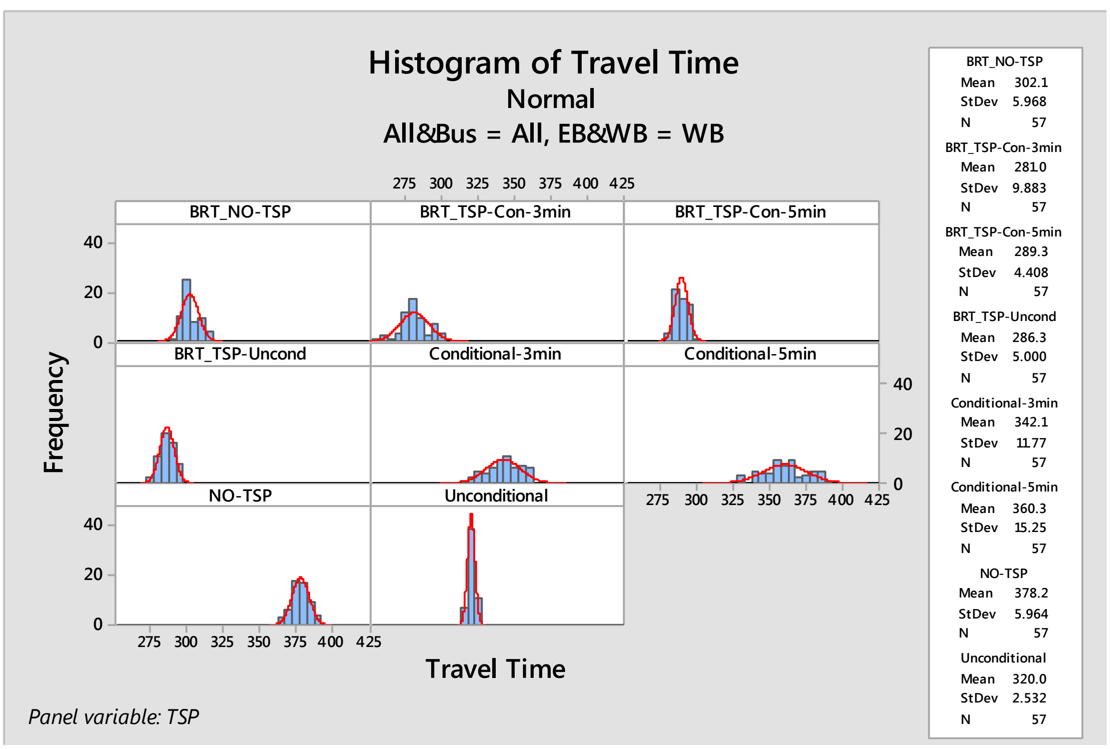


Figure 70: Average Travel Time (seconds) – All Vehicles – WB

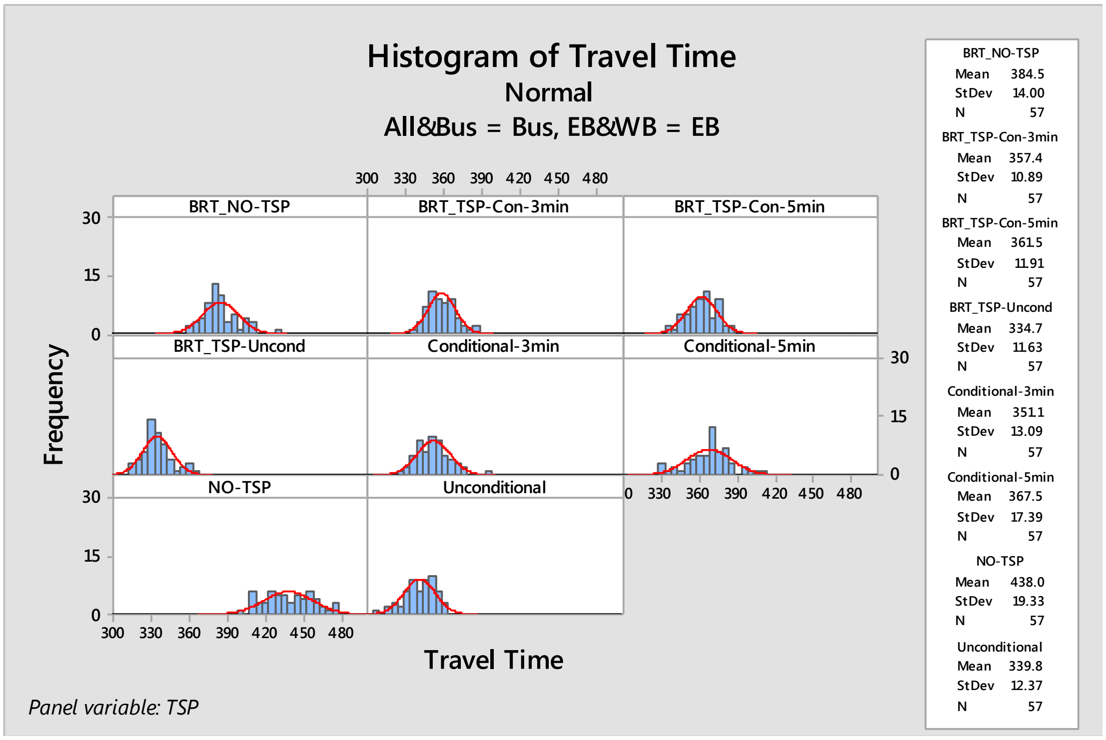


Figure 71: Average Travel Time (seconds) – Buses Only – EB

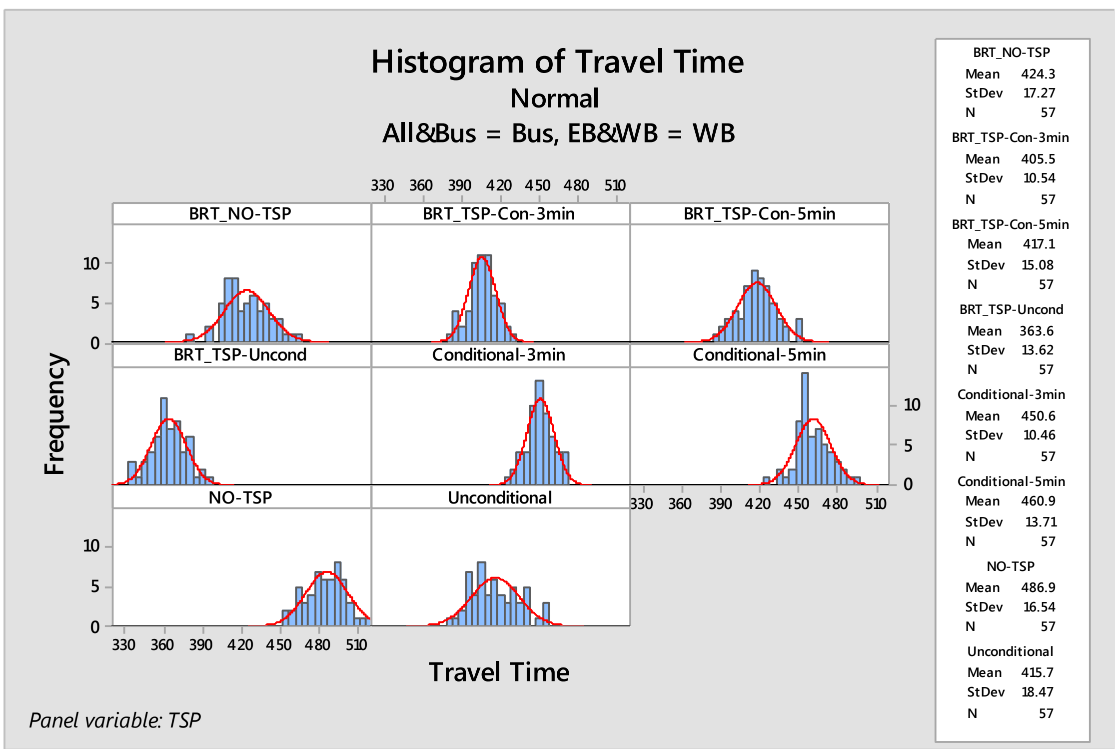


Figure 72: Average Travel Time (seconds) – Buses Only – WB

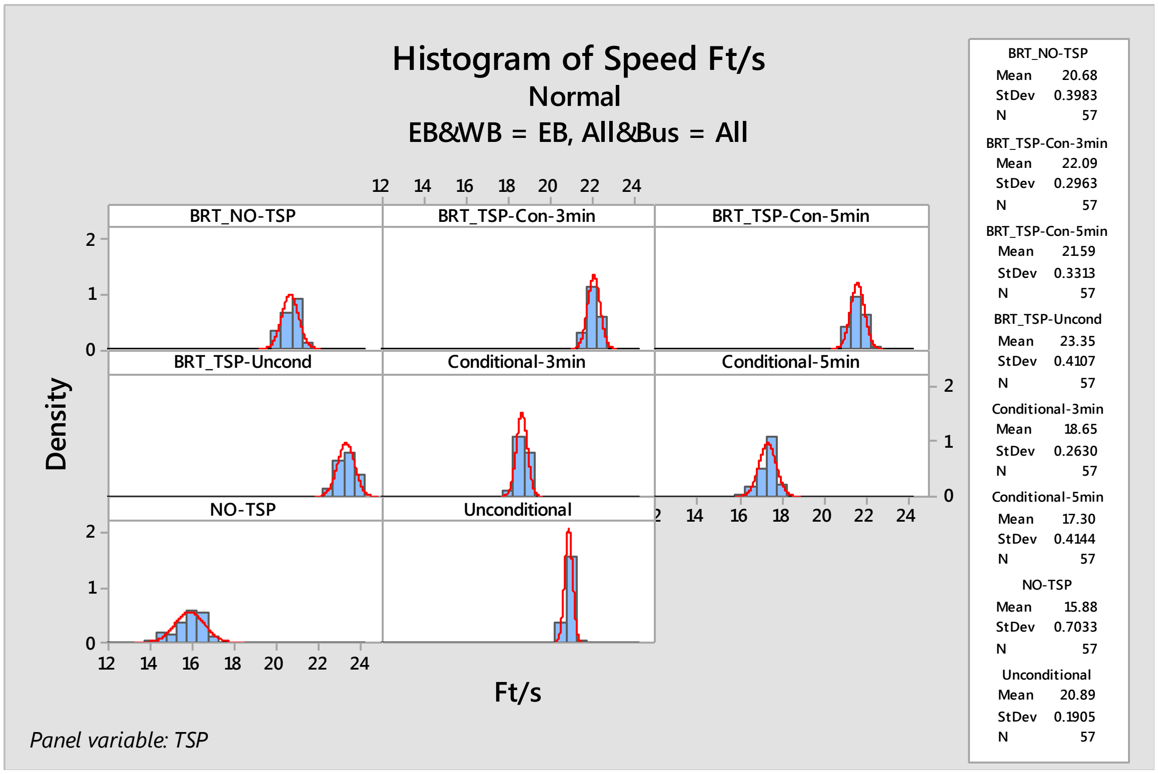


Figure 73: Average Speed (feet/sec) – All Vehicles – EB

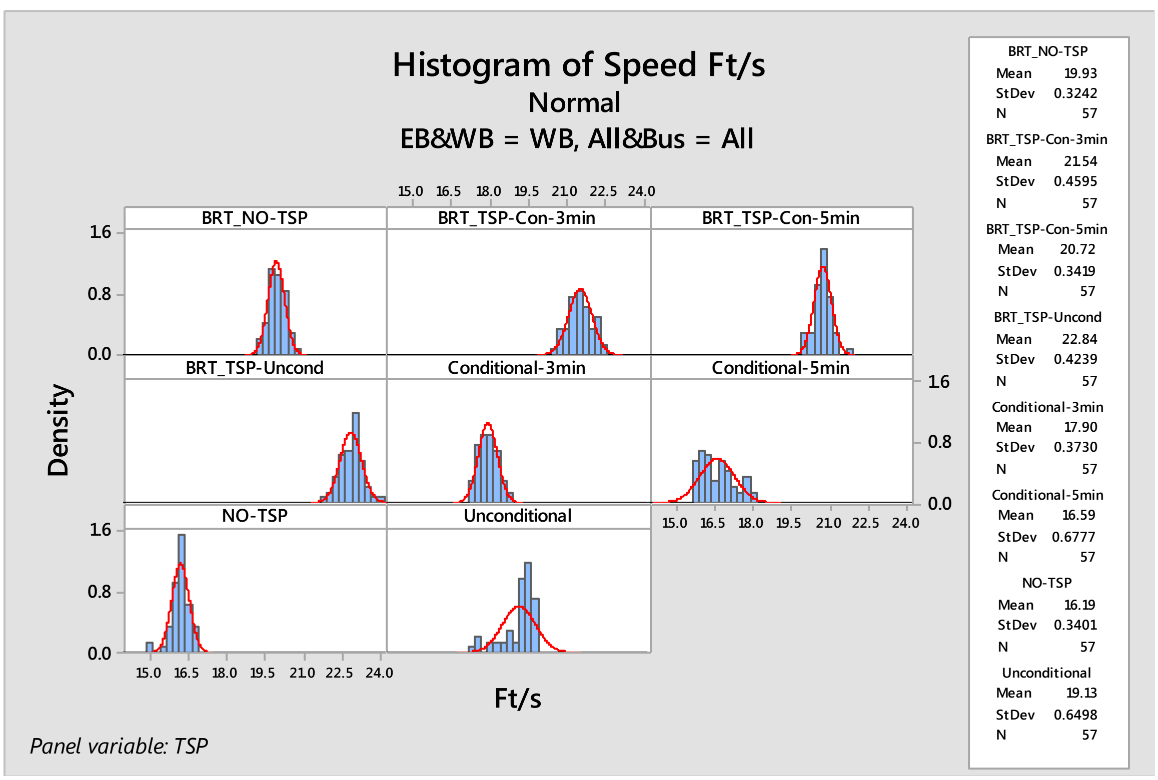


Figure 74: Average Speed (feet/sec) – All Vehicles – WB

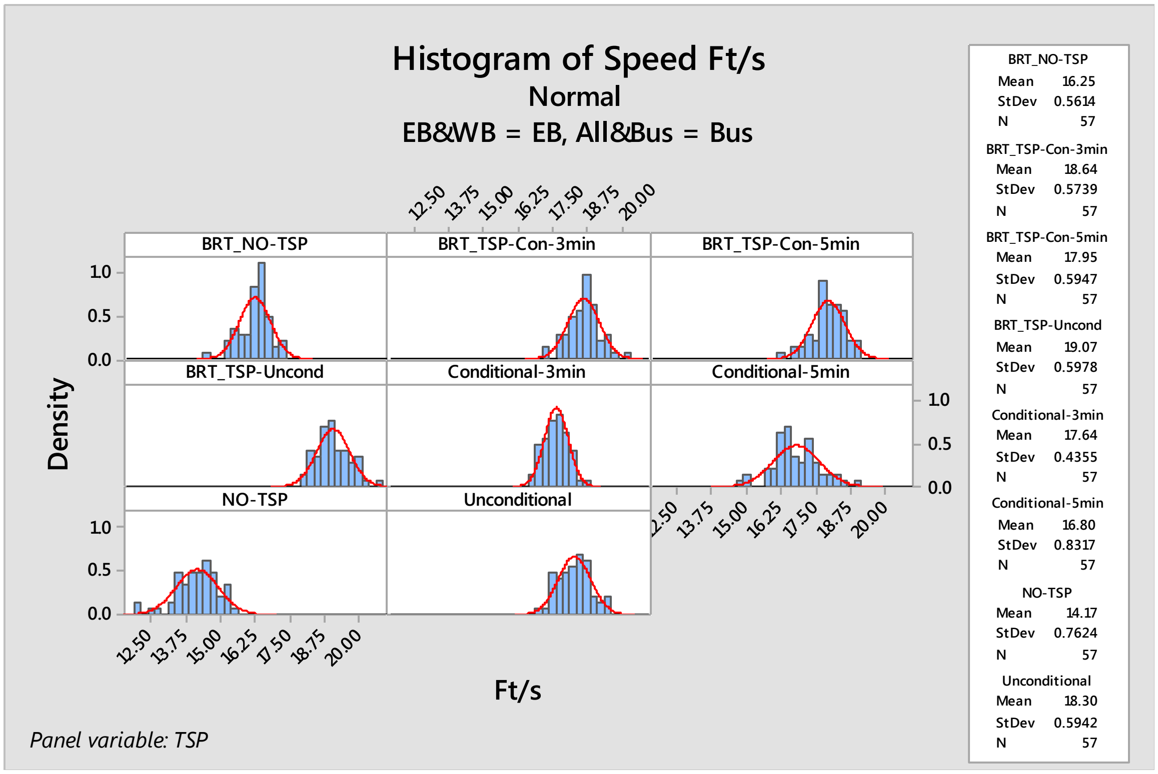


Figure 75: Average Speed (feet/sec) – Buses Only – EB

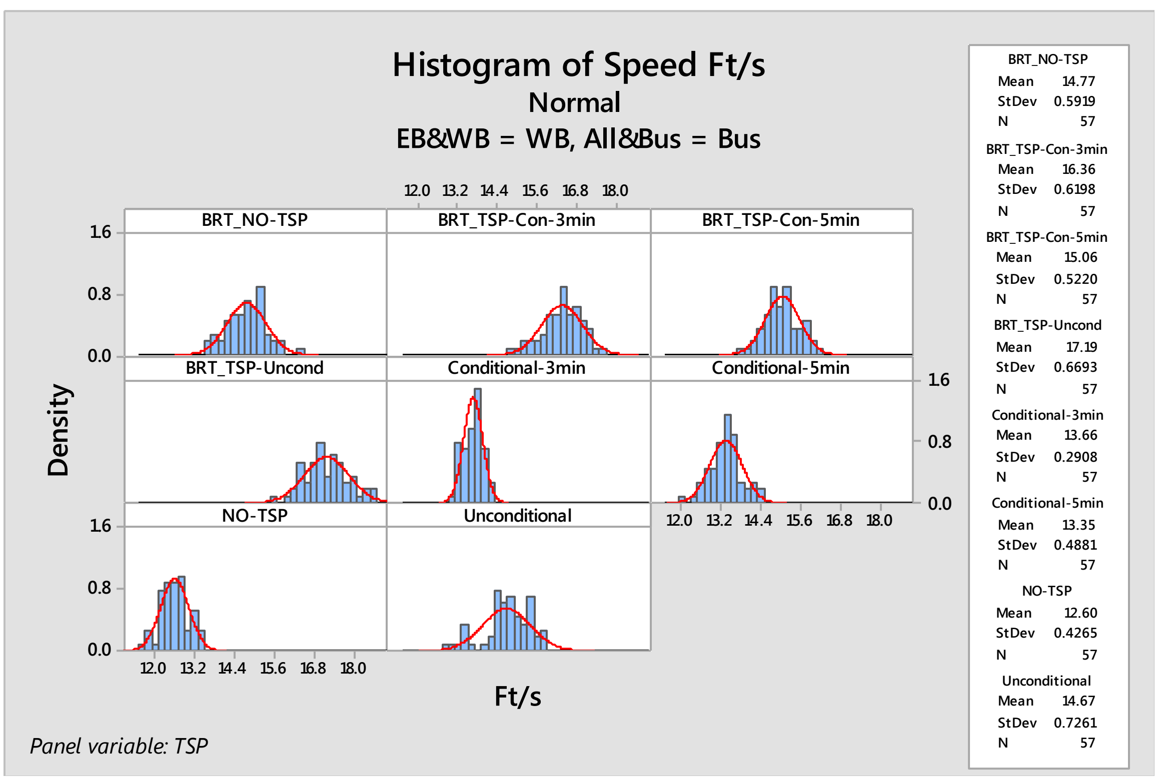


Figure 76: Average Speed (feet/sec) – Buses Only – WB

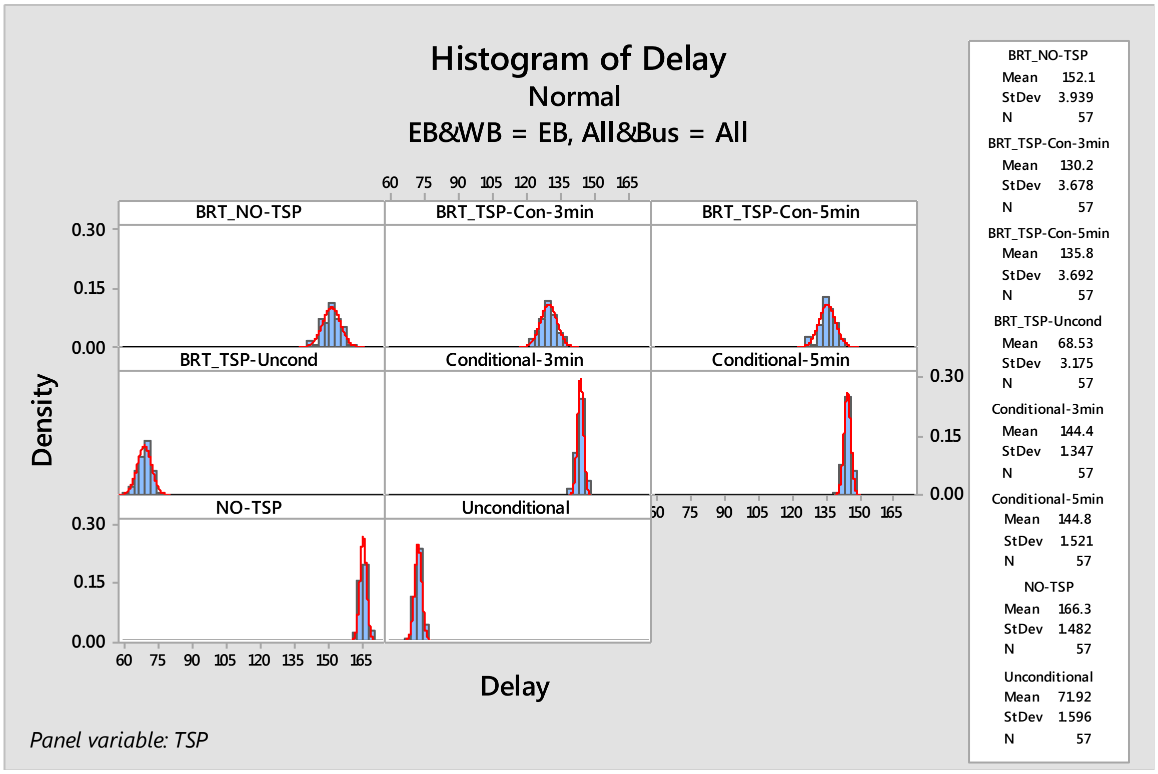


Figure 77: Average Total Delay per Vehicle (seconds) – All Vehicles – EB

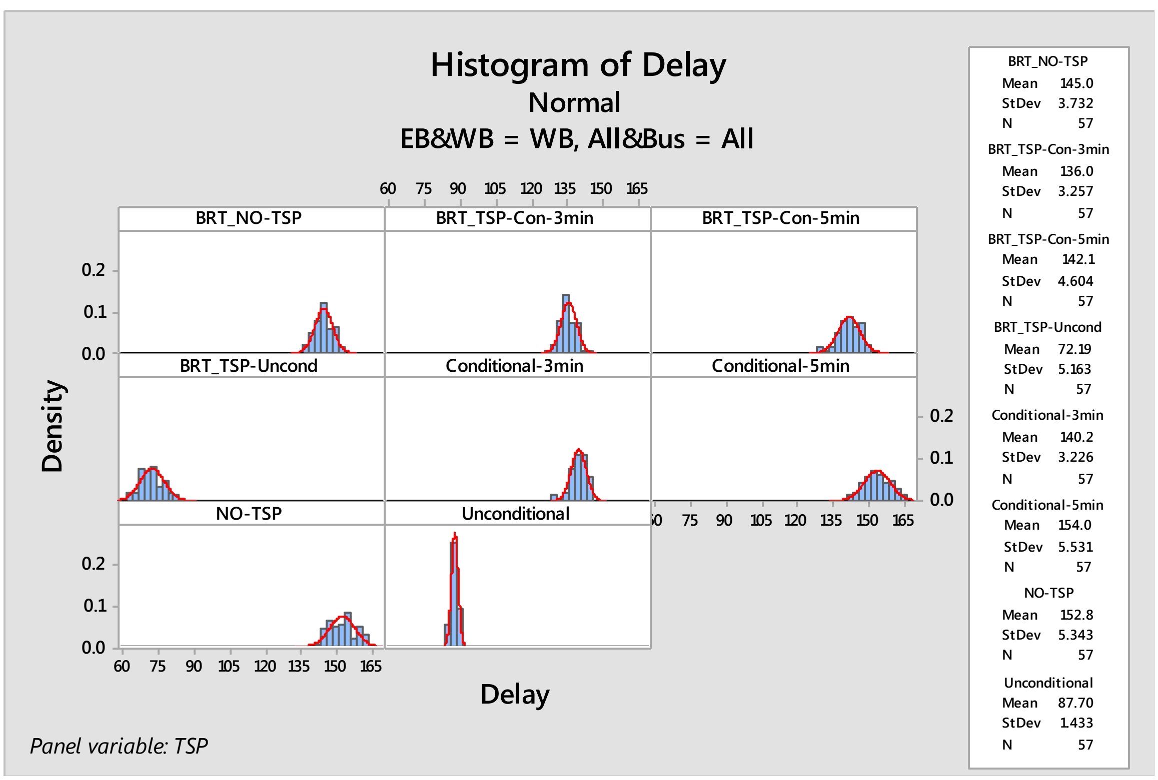


Figure 78: Average Total Delay per Vehicle (seconds) – All Vehicles – WB

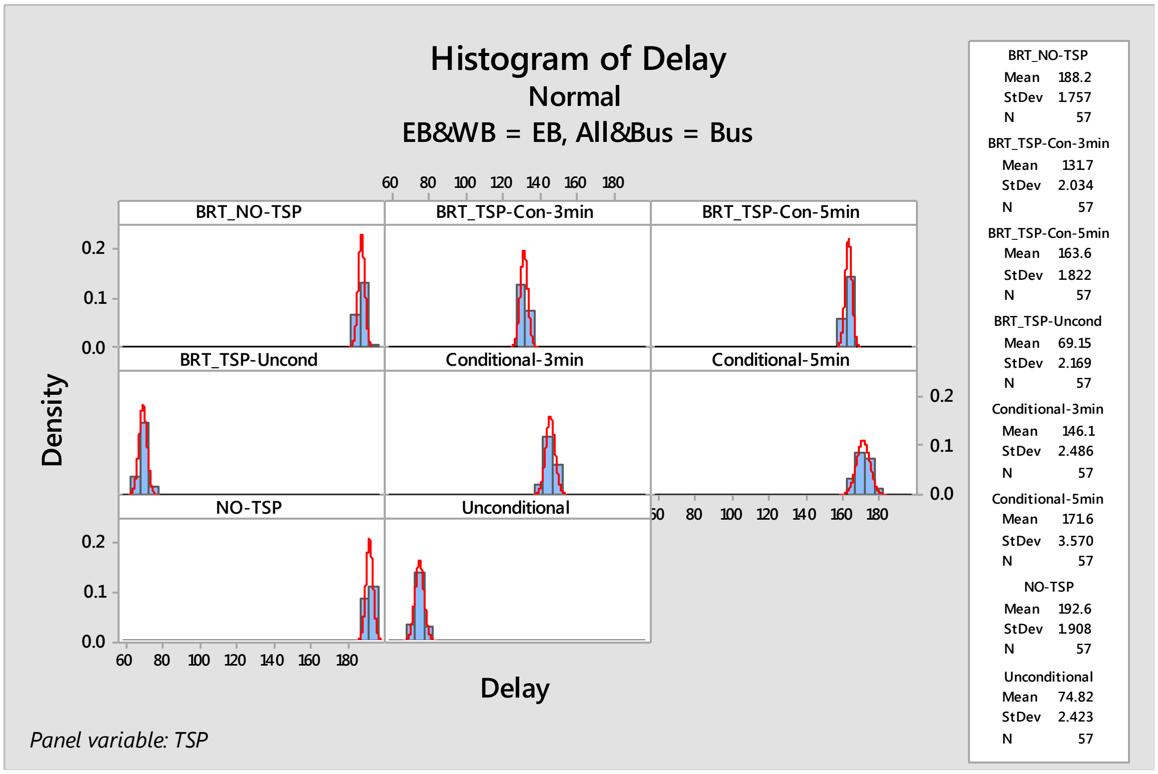


Figure 79: Average Total Delay per Vehicle (seconds) – Buses Only – EB

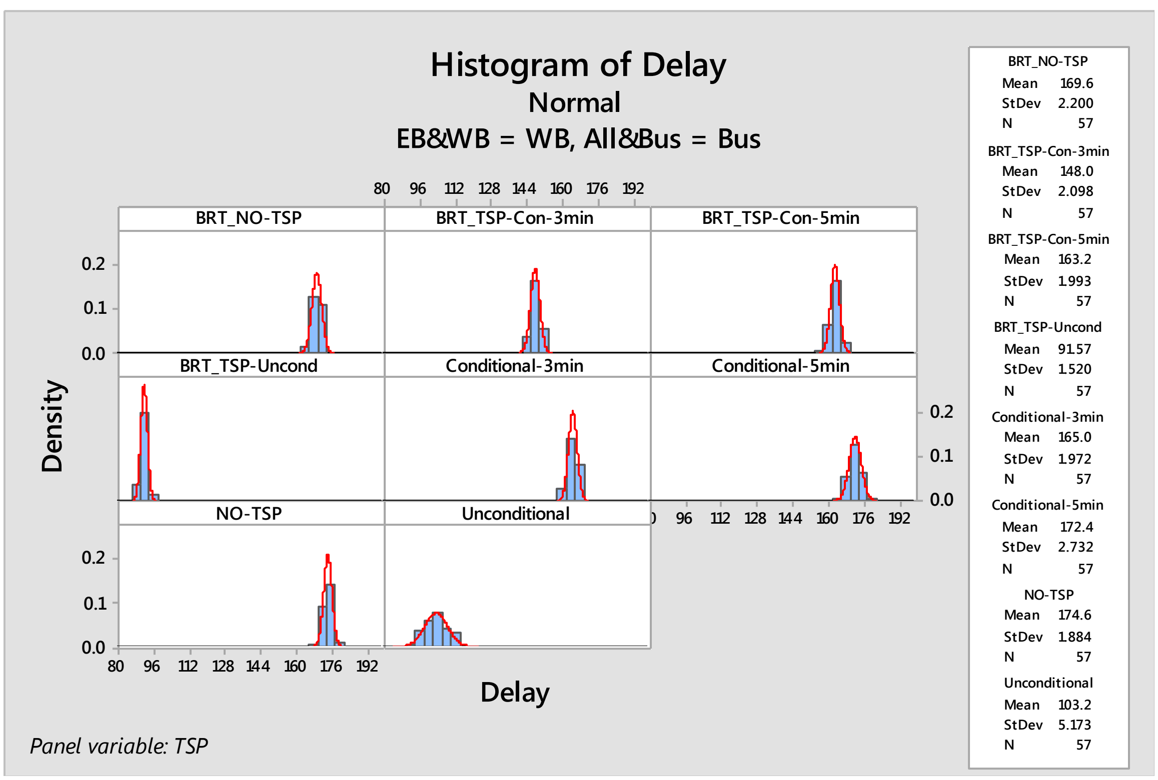


Figure 80: Average Total Delay per Vehicle (seconds) – Buses Only – WB

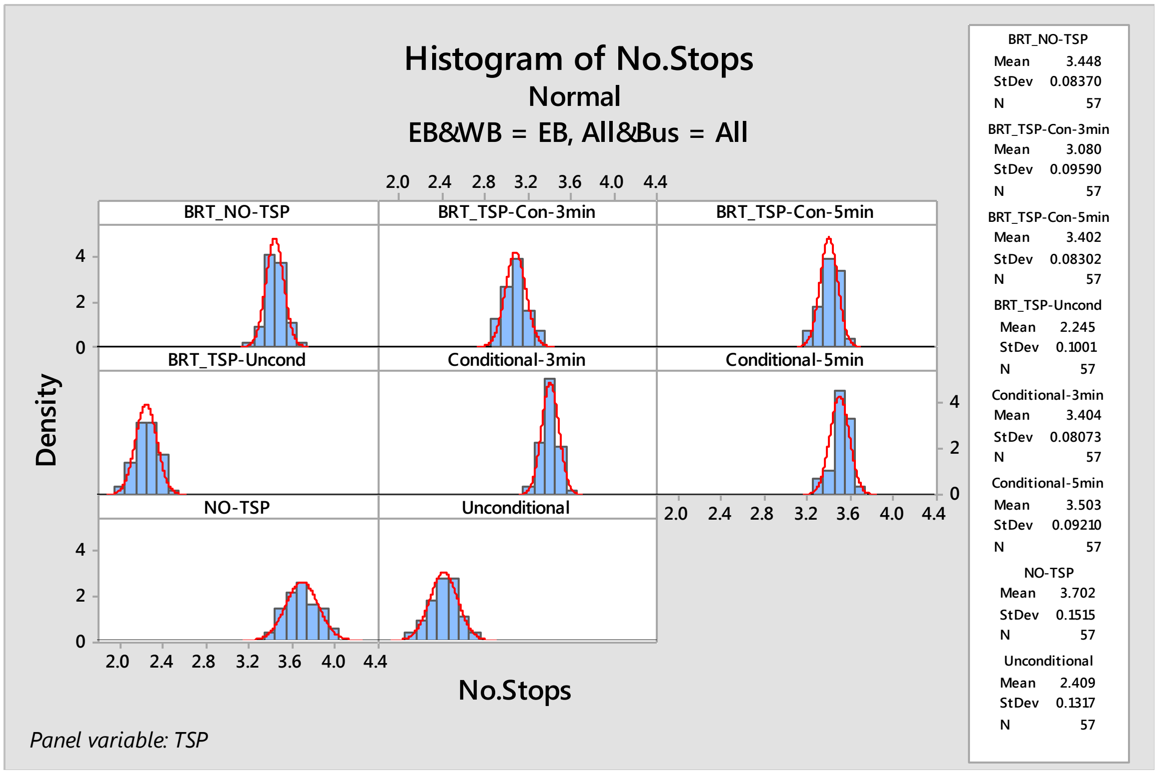


Figure 81: Average Number of Stops per Vehicle – All Vehicles – EB

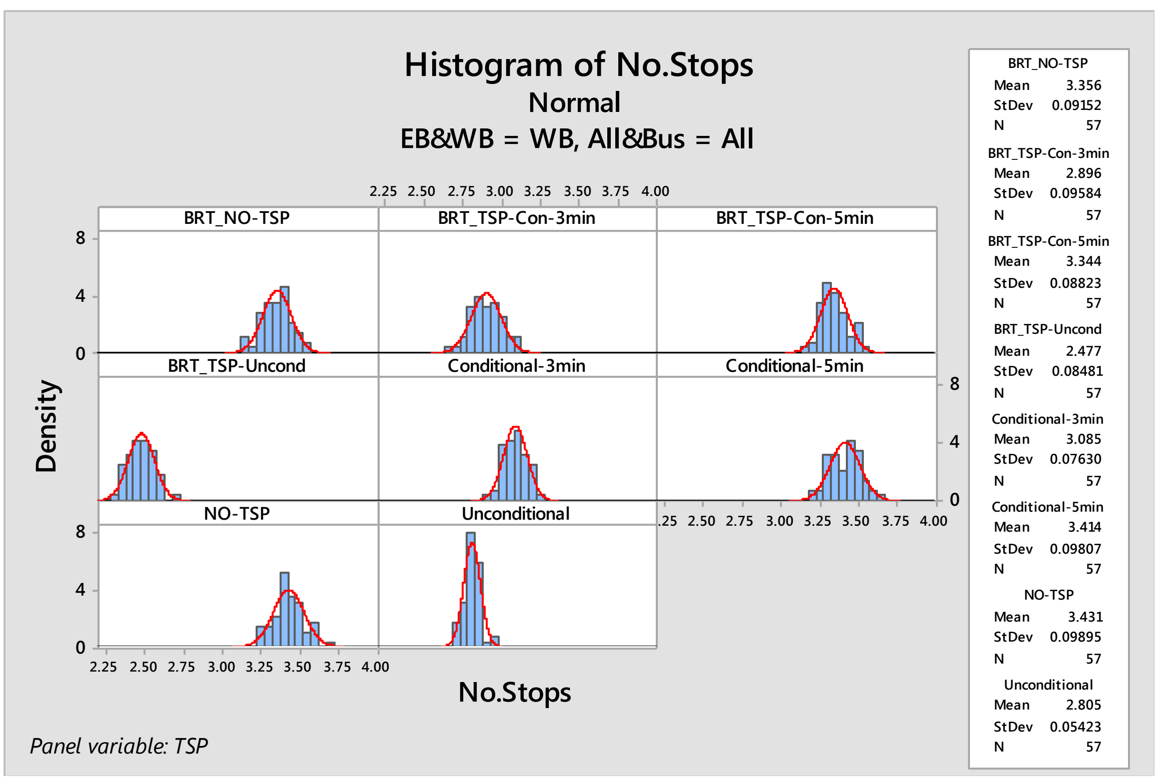


Figure 82: Average Number of Stops per Vehicle – All Vehicles – WB

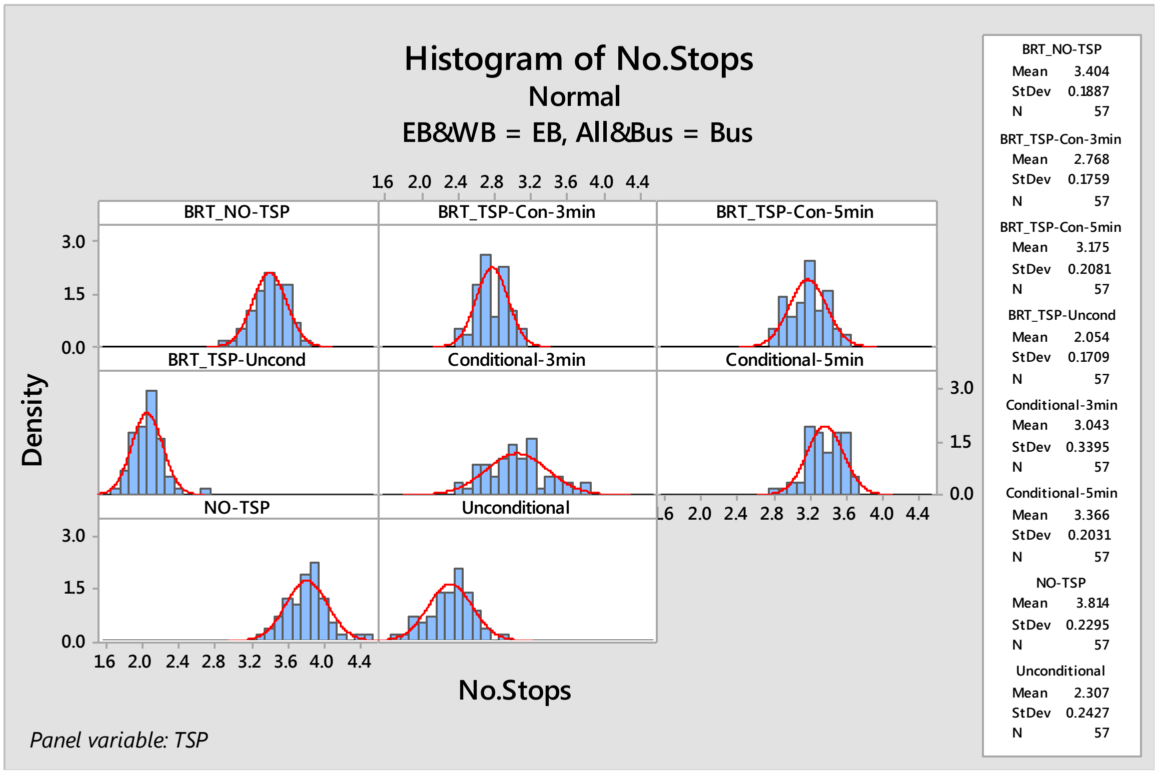


Figure 83: Average Number of Stops per Vehicle – Buses Only – EB

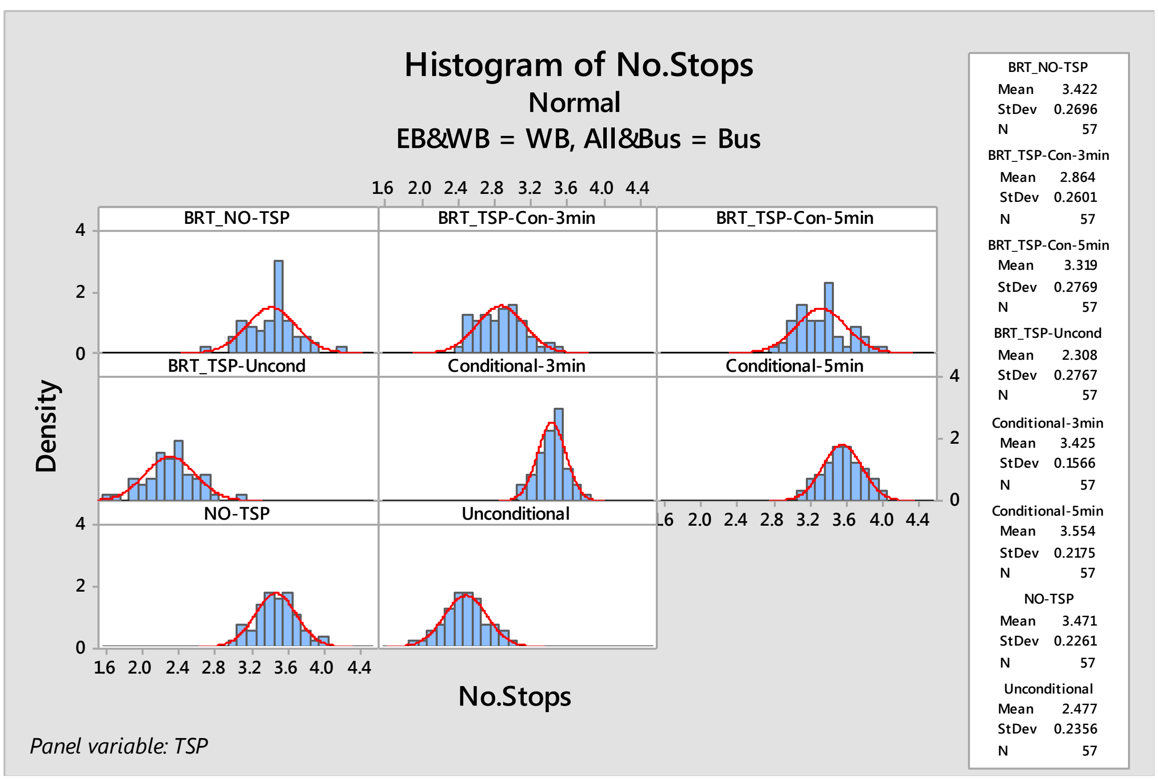


Figure 84: Average Number of Stops per Vehicle – Buses Only – WB

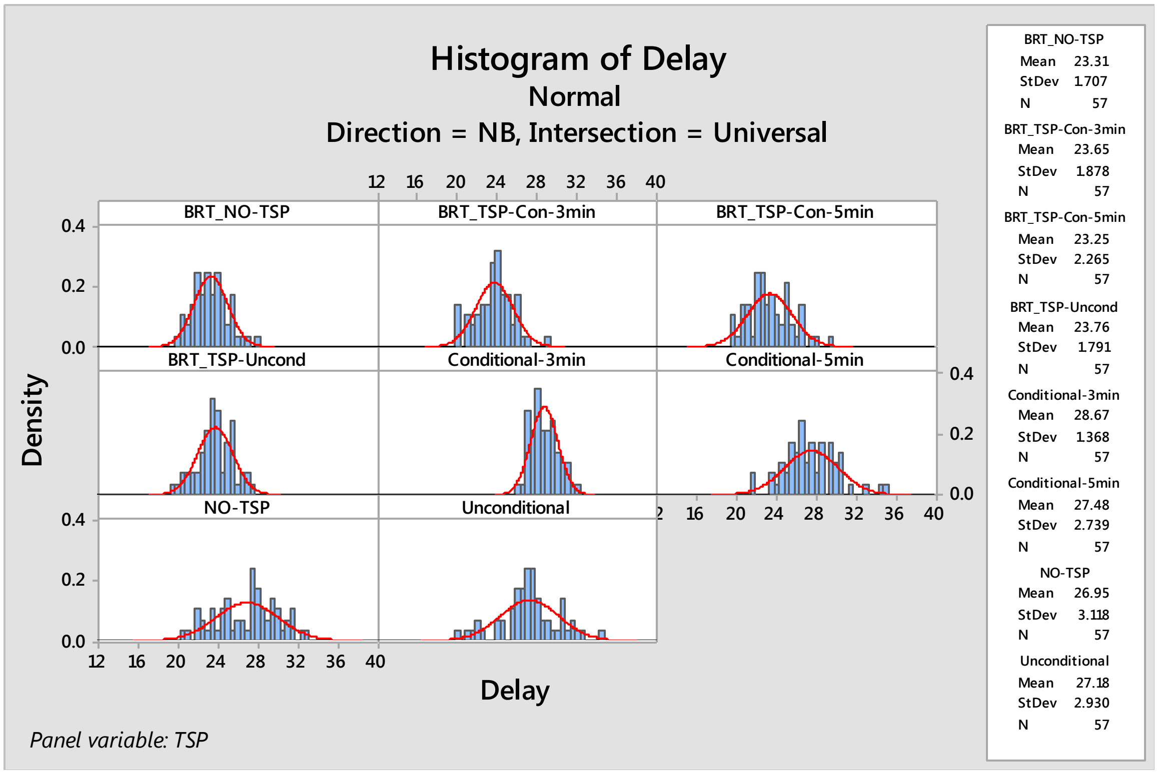


Figure 85: Crossing Street Average Delay per Vehicle (seconds) – Universal Blvd - NB

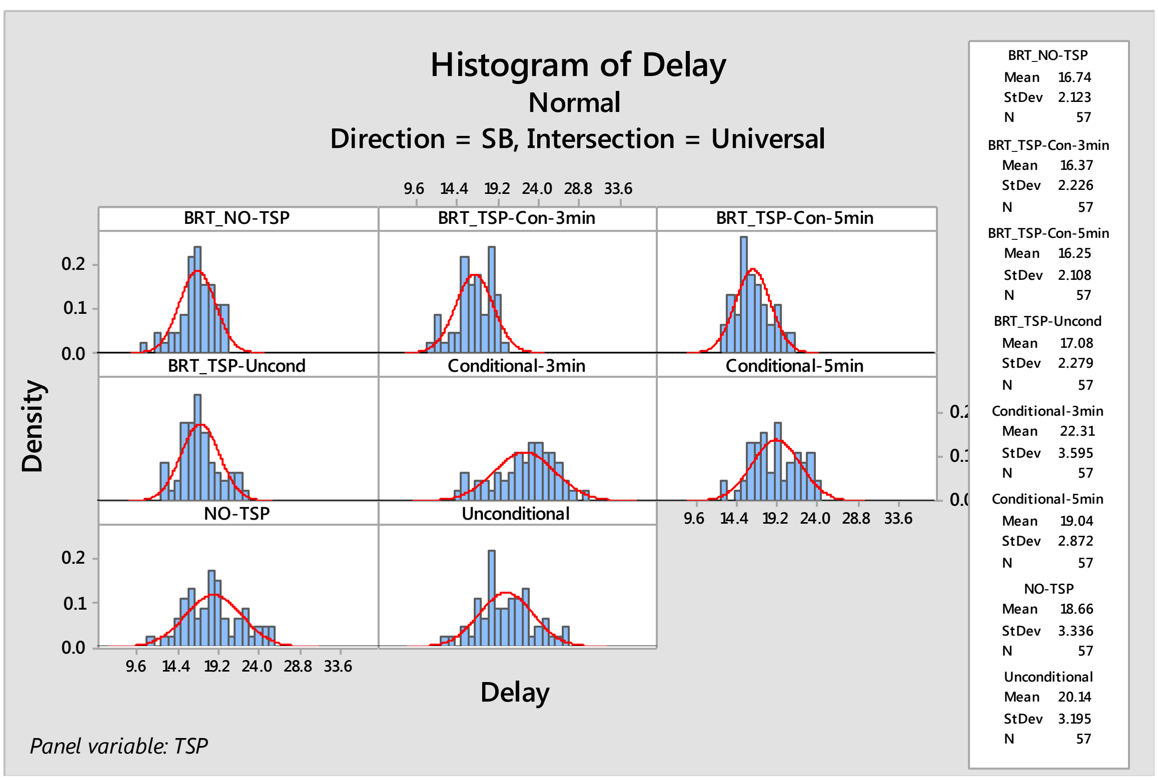


Figure 86: Crossing Street Average Delay per Vehicle (seconds) – Universal Blvd - SB

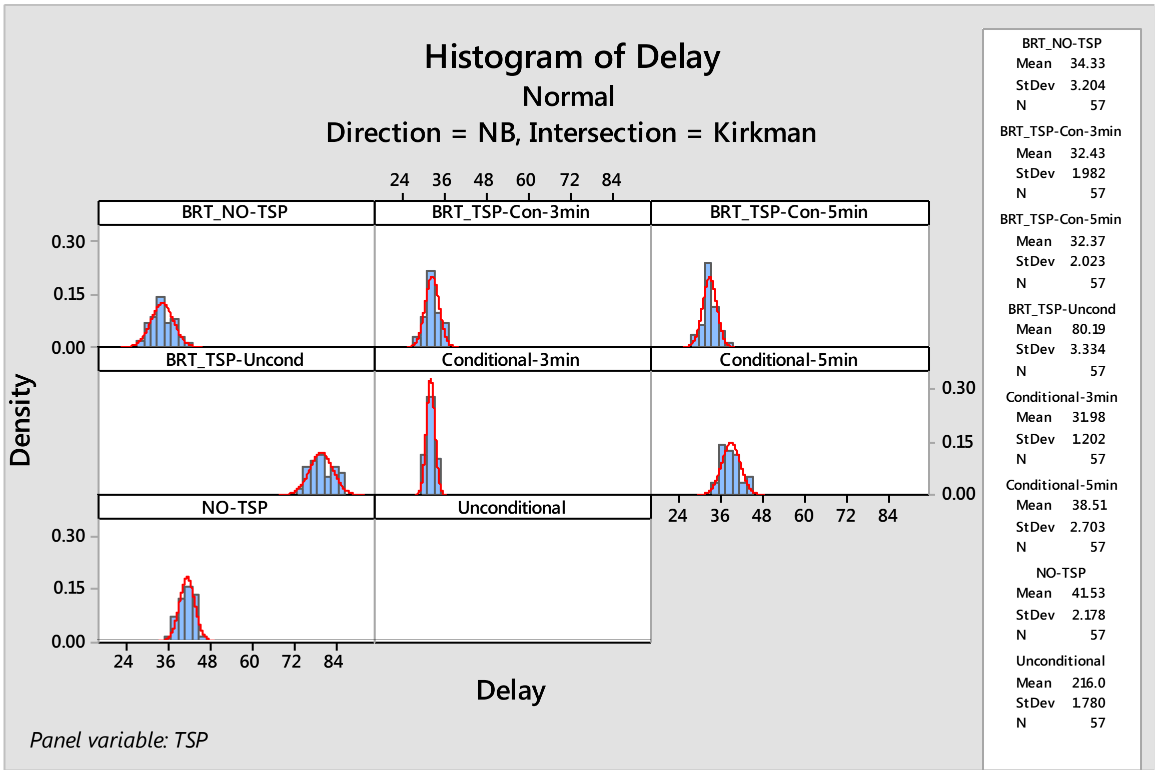


Figure 87: Crossing Street Average Delay per Vehicle (seconds) – Kirkman Rd – NB

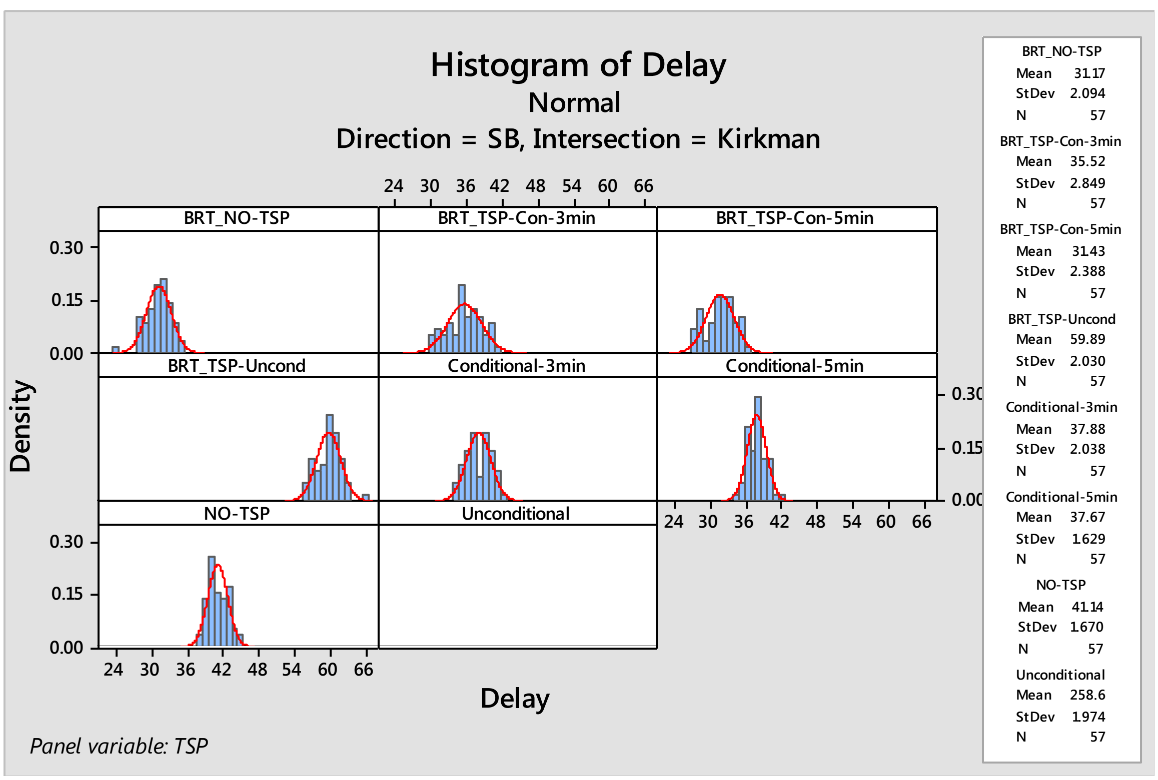


Figure 88: Crossing Street Average Delay per Vehicle (seconds) – Kirkman Rd – SB

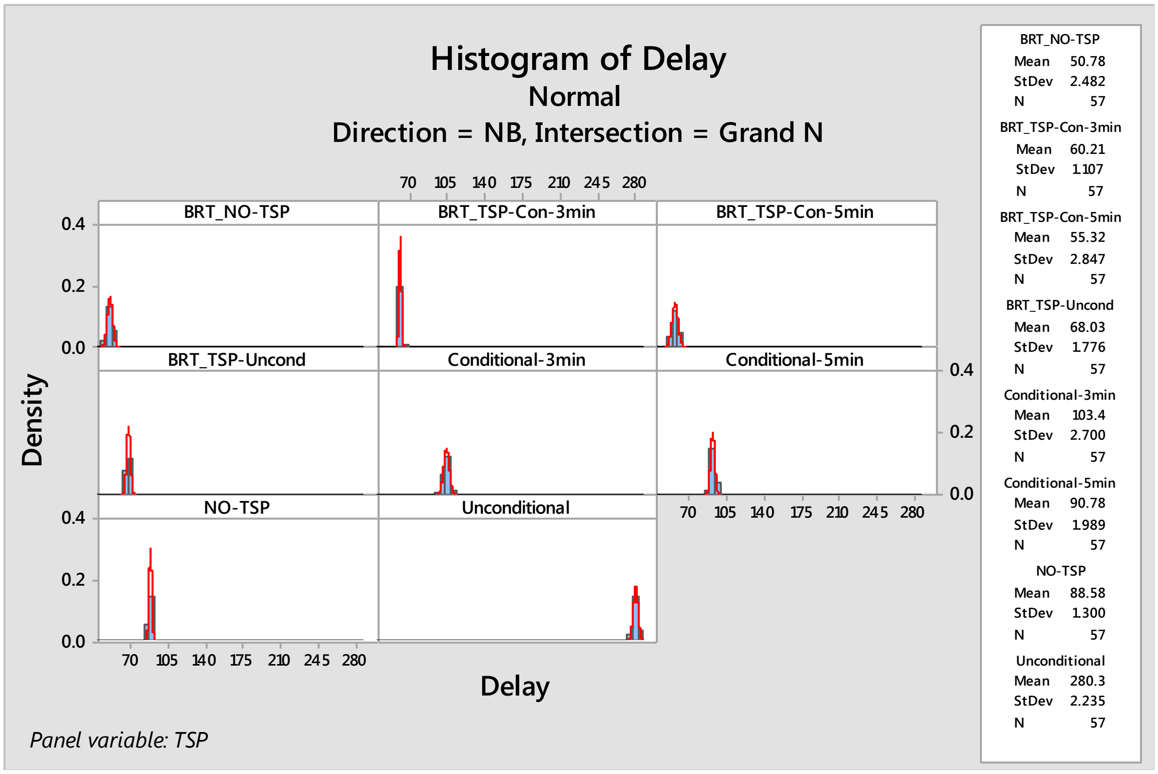


Figure 89: Crossing Street Average Delay per Vehicle (seconds) – Grand National – NB

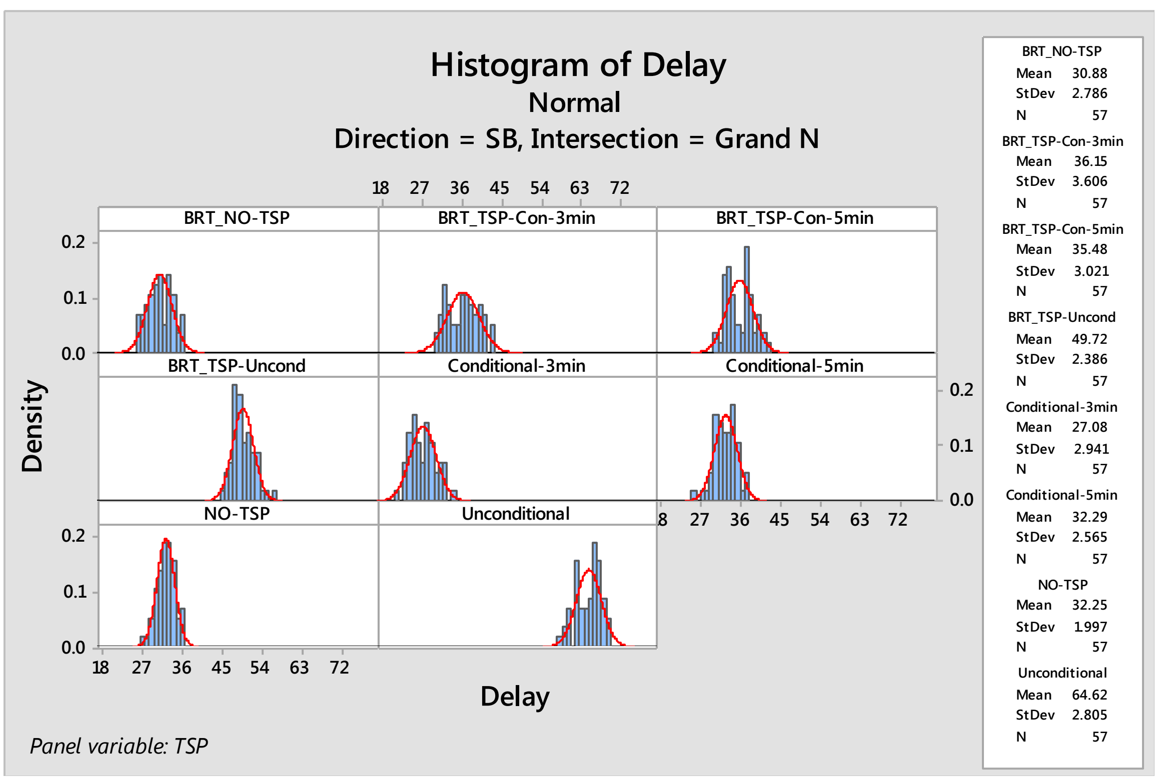


Figure 90: Crossing Street Average Delay per Vehicle (seconds) – Grand National – SB

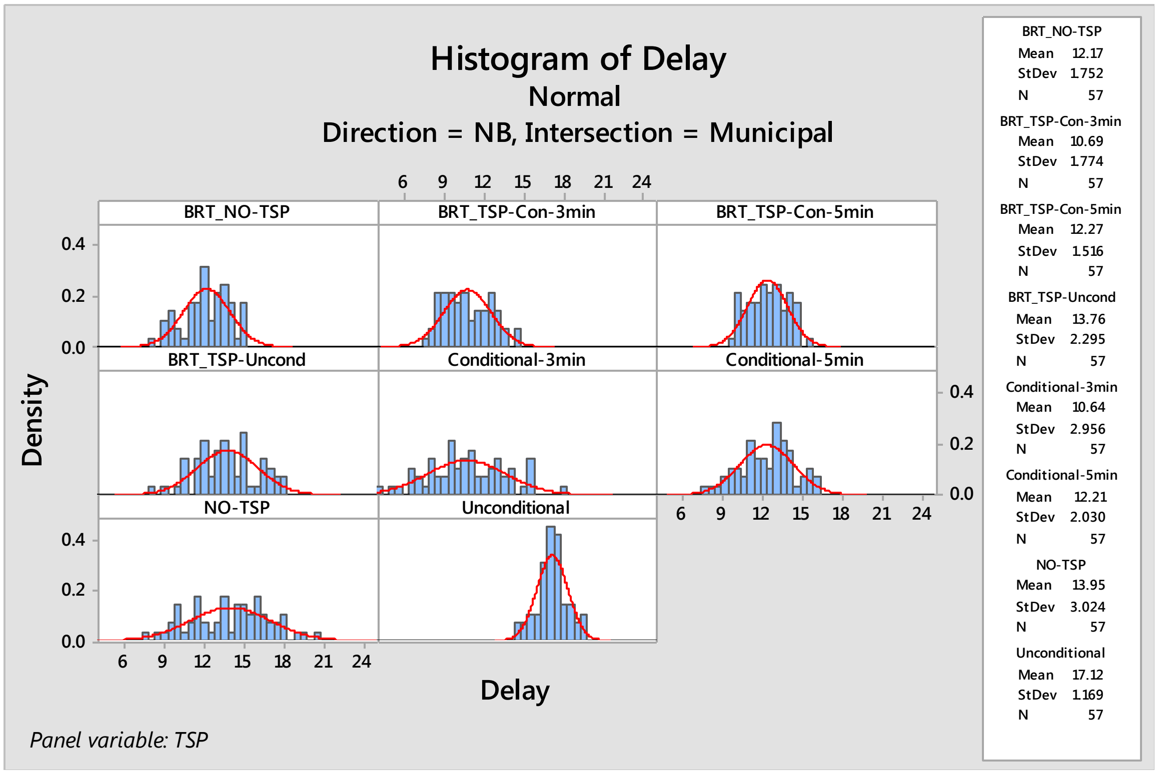


Figure 91: Crossing Street Average Delay per Vehicle (seconds) – Municipal – NB

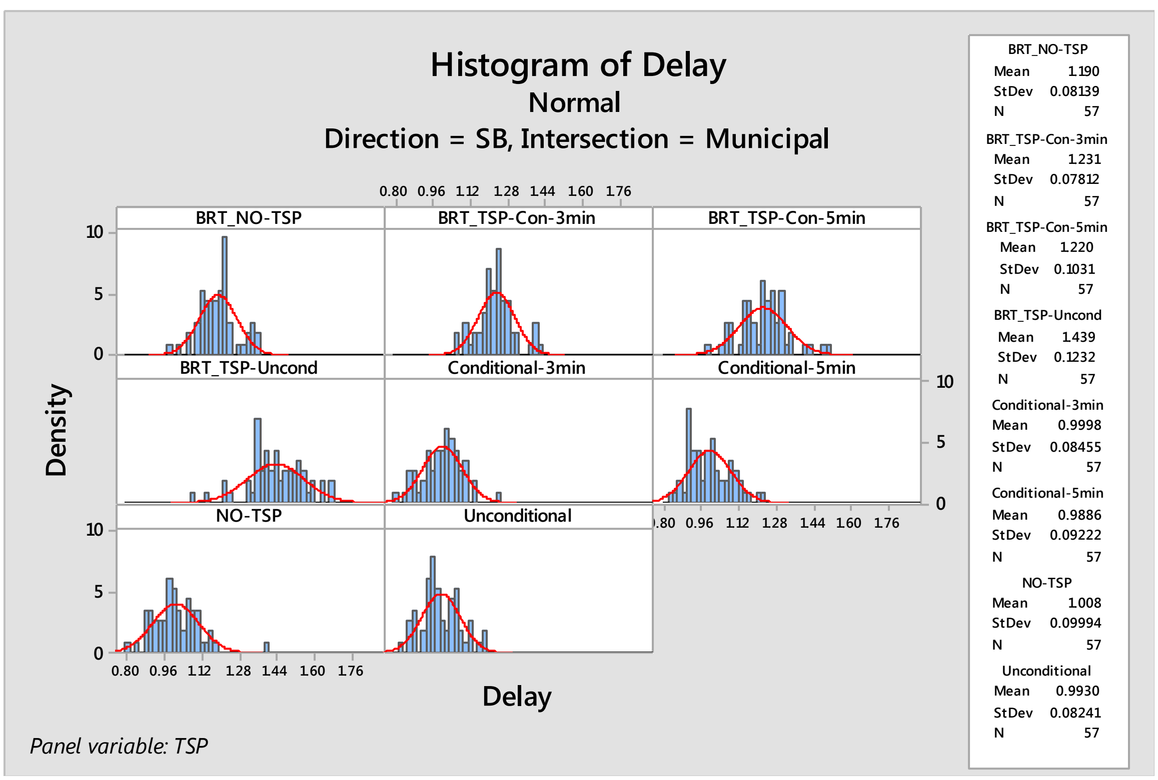


Figure 92: Crossing Street Average Delay per Vehicle (seconds) – Municipal – SB

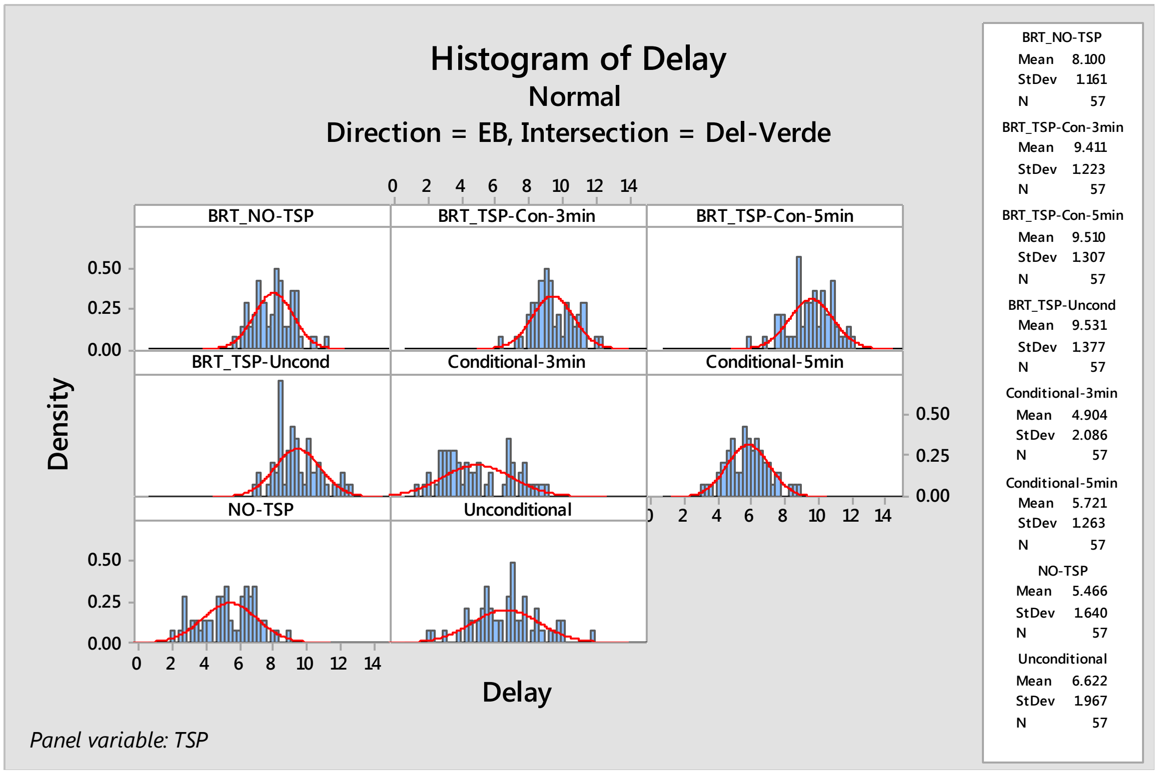


Figure 93: Crossing Street Average Delay per Vehicle (seconds) – Del Verde – EB

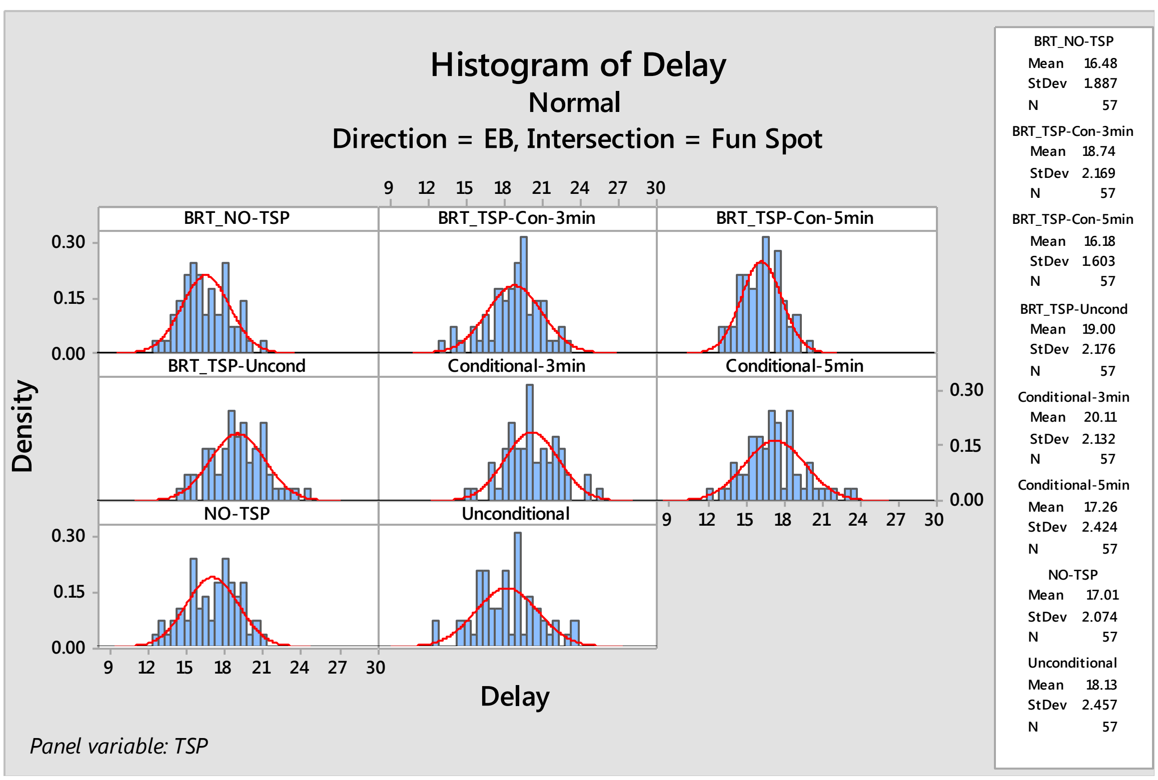


Figure 94: Crossing Street Average Delay per Vehicle (seconds) – Fun Spot Way – EB

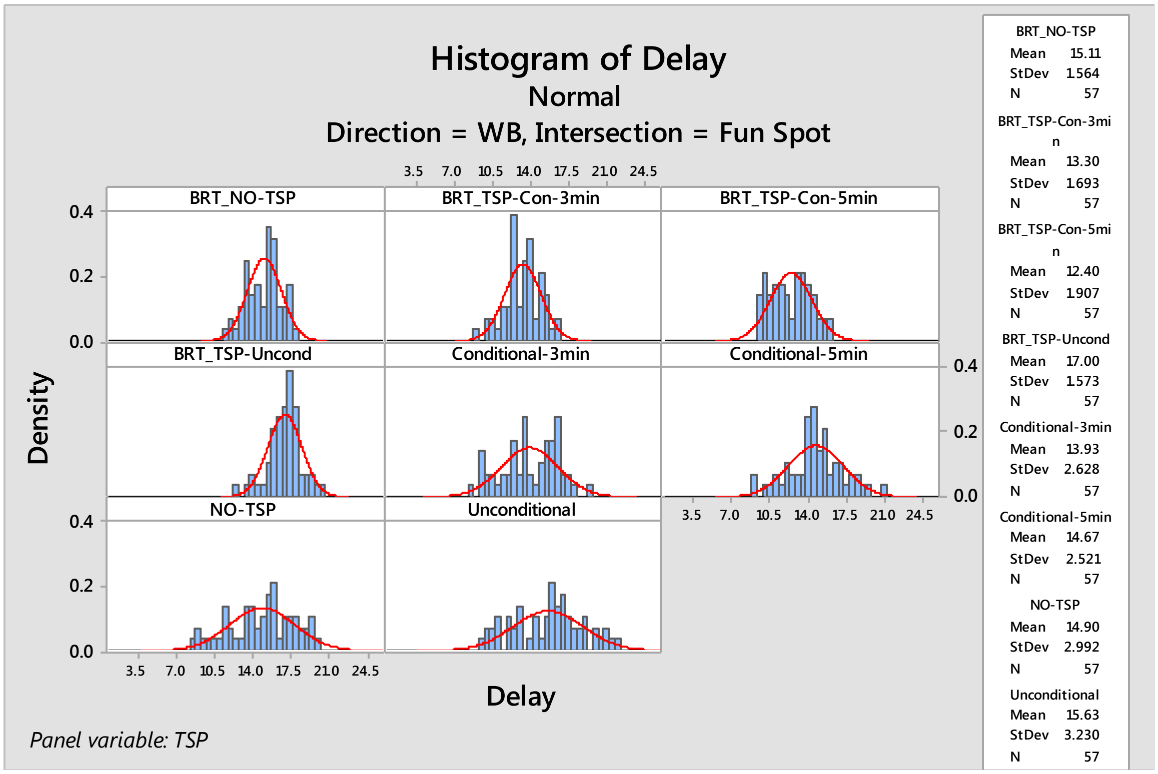


Figure 95: Crossing Street Average Delay per Vehicle (seconds) – Fun Spot Way – WB

CHAPTER 7 FITTING REGRESSION MODELS

7.1 BRT and the Florida Regional Growth Vision

This BRT corridor is an important component of the planned future regional transit system in Central Florida, which will include commuter rail, Light Rail Transit (LRT), and BRT (FDOT, 2010). Florida Department of Transportation (FDOT, 2010) published a guidance report showing the future vision for connecting Central Florida region with transit systems taking into consideration the growth characteristics by the year 2050.

Figure 96 shows the planned transit corridors in the Central Florida region. SunRail, which is the commuter rail system in Central Florida region, began its phase-1 service back in May 2014 with 31 miles of rail. Phase-2 (Figure 97) is expected to be completed in 2017 and will include 61 miles of rail (Bogren, 2012). In order to be beneficial to users, this SunRail service needs connectivity with other ground transportation systems to create a multimodal transportation system.

The proposed LRT system (identified by the Metropolitan planning organization MPO for Orange, Osceola, and Seminole counties [known as METROPLAN Orlando] in the 2035 long range plan) will connect International Drive to Medical City/Innovation Way and have stops at the Orlando International Airport and the Orange County Convention Center. Another potential LRT corridor is along Interstate 4 from Altamonte Springs to Central Florida Parkway; this corridor will provide more frequent stops than SunRail (FDOT, 2010).

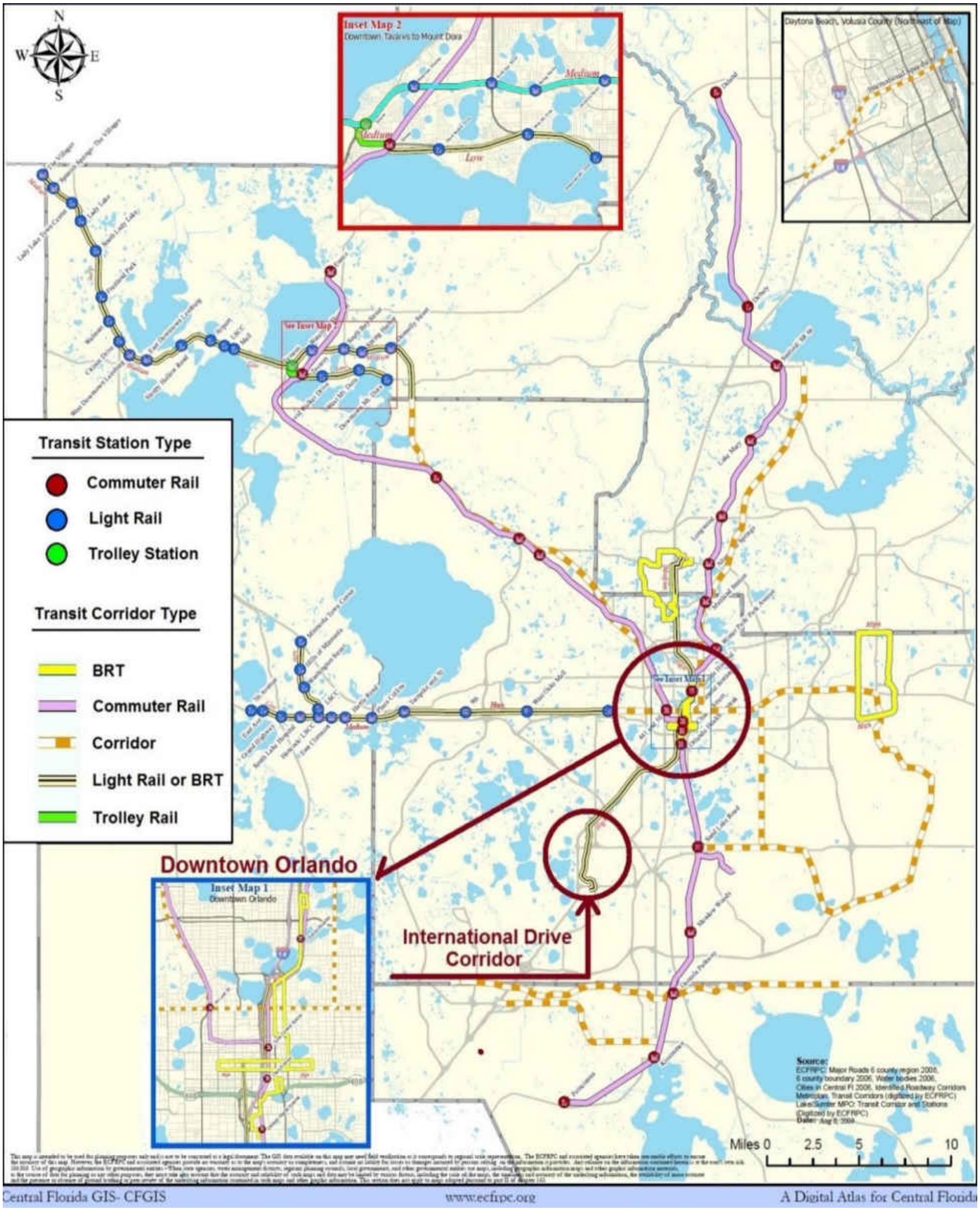


Figure 96: Central Florida Planned Transit Network (FDOT, 2010)

Figure 97: Phase-2 SunRail Corridor (Bogren, 2012)

BRT is already implemented in downtown Orlando as the LYMMO circulator. This will be expanded to include an "East/West Downtown Circulator connecting the Thornton Park and Parramore neighborhoods to the future performing arts center, sports arena, and Citrus Bowl and a North/South Circulator from Orlando Regional Healthcare System to Florida Hospital" (FDOT, 2010). Also, BRT has been implemented on the I-Drive corridor (which is the study area of this research).

The different public transportation systems do not compete with each other, but rather supplement each other in the regional network. In order for commuter rail to be effective, there needs to be fast and reliable connectivity to the rail stations. It is expected that the combination of BRT and TSP can provide this connectivity more so than a regular bus system that cannot avoid traffic congestion and can impede vehicular traffic. LRT is also important to service areas that do not have the space or capacity for BRT operations. This research examines the use of BRT and TSP to improve the performance of the regional transportation network.

7.2 Regression Models and Dummy-Variable Regression

The VISSIM results show that TSP and BRT are effective in improving transit performance. To better understand the effects of each tested TSP and BRT scenario, multiple regression models were developed for each MOE. Multiple regression allows prediction about one variable ($\mathbf{y}$) based on its relationship to other variables ($\boldsymbol{x_i}$). Since this is a prediction, there will be always some kind of error ($\boldsymbol{\varepsilon}$) in performing this process.

This research used regression analysis to observe the effect of the tested scenarios analyzed in VISSIM software compared to the No TSP – No BRT base model (**β_o**) for all vehicles and for buses only. The developed regression model can predict the effect of each scenario on each studied MOE (**y**). Minitab statistical software (MINITAB, 2015) was used to conduct this multiple regression analysis in three separate ways:

1. TSP scenarios compared with the base scenario (MODEL 1).
2. BRT scenarios compared with the base scenario (MODEL 2).
3. TSP and BRT scenarios compared with the base scenario (MODEL 3).

A multiple linear regression model has the following general form (Equation 6):

$$y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_k x_k + \varepsilon \qquad \textbf{(6)}$$

Where $\boldsymbol{k}$ is the number of regressor (independent or predictor) variables. The parameters $\boldsymbol{\beta_j}$, j = 0, 1, 2, … k, are called the regression coefficients (Montgomery, 2013).

Dummy variables were used in the model to represent the various differences between the scenarios. These variables take the value of either 0 or 1. In the regression model, a dummy variable with a value of 0 will remove its coefficient from the equation, while a value of 1 will cause the variable's coefficient to behave like a supplemental intercept (Garavaglia and Sharma, 1998). Using dummy variables in this model helps to "define subsets of observations that have different intercepts and/or slopes without the creation of separate models" and makes the model more suitable for use as a decision tool (Garavaglia and Sharma, 1998).

The data for this model were categorized into a hierarchical design as shown in Figure 62. Regression models were developed for the four major MOEs obtained from the VISSIM model analysis (travel times, speed, delays, and number of stops). These categories were sub-divided into more specific groups by direction (eastbound and westbound), vehicle classification (all vehicles and buses only), and the Base, TSP and BRT scenarios. The data were analyzed and found to have a normal distribution. These distributions were shown in details in Chapter 6 and **Appendix F**.

7.3 The Base and TSP Scenarios Model (Model 1)

In this model, TSP scenarios were compared to the base scenario (the before: No TSP – No BRT). The multiple linear regression model can be expressed as

y = function of (No TSP – No BRT, Unconditional TSP, Conditional TSP 3 Min, and Conditional TSP 5 Min).

Where (y) is the studied MOE for through movement along I-Drive that was obtained from the VISSIM model analysis (average travel times, average speed, average delays, and average number of stops). Both vehicle classifications (all vehicles and buses only) were used in this model. Other models for (buses only) can be found in **Appendix G**.

7.3.1 Travel Time

The following table shows the analysis of variance, model summary, and regression equation that was developed in Minitab. Results are discussed following Table 19 and Figure 98.

Table 19: Minitab Output - Regression Analysis for Model 1 (Travel Time)

```
-    Analysis of Variance
-    Source                 DF    Adj SS    Adj MS  F-Value  P-Value
-    Regression              5   3415920    683184   490.68    0.000
-      Unconditional         1     22886     22886    16.44    0.000
-      Conditional-3min      1     44522     44522    31.98    0.000
-      Conditional-5min      1    204562    204562   146.92    0.000
-      All                   1   2712355   2712355  1948.10    0.000
-      WB                    1    416524    416524   299.16    0.000
-    Error                1818   2531217      1392
-      Lack-of-Fit          10    651987     65199    62.73    0.000
-      Pure Error         1808   1879230      1039
-    Total                1823   5947137
-
-    Model Summary
-          S     R-sq  R-sq(adj)  R-sq(pred)
-    37.3137   57.44%     57.32%      57.21%
-
-    Coefficients
-    Term                  Coef  SE Coef  T-Value  P-Value    VIF
-    Constant            377.70     1.66   227.85    0.000
-    Unconditional       -10.98     2.71    -4.05    0.000   1.05
-    Conditional-3min     15.31     2.71     5.65    0.000   1.05
-    Conditional-5min     32.81     2.71    12.12    0.000   1.05
-    All                 -77.12     1.75   -44.14    0.000   1.00
-    WB                   30.22     1.75    17.30    0.000   1.00
-
-    Regression Equation
-    Travel Time = 377.70 - 10.98 Unconditional + 15.31 Conditional-3min
                  + 32.81 Conditional-5min - 77.12 All + 30.22 WB
```

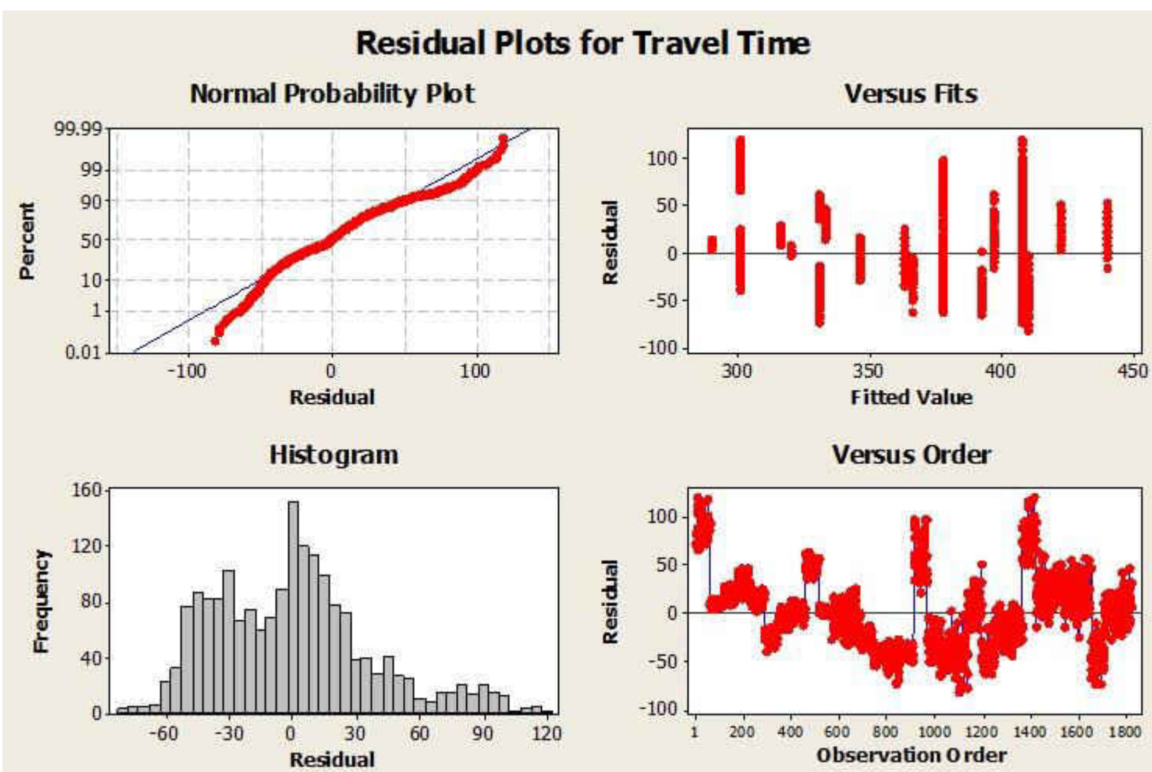


Figure 98: Minitab Output – Residual Plots for Model 1 (Travel Time)

The generalized regression model developed for travel time based on the data of the before (No TSP - No BRT), Unconditional TSP, Conditional TSP 3 Min, and Conditional TSP 5 Min scenarios listed below:

Travel Time = 377.70 - 10.98 Unconditional + 15.31 Conditional-3min + 32.81 Conditional-5min - 77.12 All + 30.22 WB

The coefficient of determination (**R^2**) as a measure of goodness of fit listed in the output table was (57.44 %) which implies that about 57% of the sample variation explained by the model.

To determine how useful each predictor variable in the model equation, we test the hypothesis (H_0: $\beta_i = 0$, H_1: $\beta_i \neq 0$). **P-value** associated with the F-value (and t-value) for all terms in the table were (P-value < 0.05) which indicate that each variable found to be significant (reject the null hypothesis H_0 and accept the alternative hypothesis H_1) and should be included in the model.

Residual plots in Figure 98 (top left and bottom left) show that there are no extreme values (no unusual patterns appearing in the plots) and the residuals appear to follow normal distribution (data points clustered around the fitted "blue" line). Also, in the same Figure 98 (top right and bottom right) show that approximately half of the points are above and the other half are below the zero line (with a clear cyclic pattern) indicating that the assumption of error terms having mean zero is valid.

7.3.2 Delay

The following table shows the analysis of variance, model summary, and regression equation that was developed in Minitab. Results are discussed following Table 20 and Figure 99.

Table 20: Minitab Output - Regression Analysis for Model 1 (Delay)

```
-   Analysis of Variance
-   Source                DF    Adj SS   Adj MS  F-Value  P-Value
-   Regression             5    947252   189450   233.78    0.000
-     Unconditional        1    580145   580145   715.90    0.000
-     Conditional-3min     1     16274    16274    20.08    0.000
-     Conditional-5min     1     83923    83923   103.56    0.000
-     All                  1    140930   140930   173.91    0.000
-     WB                   1      7702     7702     9.50    0.002
-   Error               1818   1473258      810
-     Lack-of-Fit         10     42816     4282     5.41    0.000
-     Pure Error        1808   1430442      791
-   Total               1823   2420509
-
-   Model Summary
-         S    R-sq  R-sq(adj)  R-sq(pred)
-   28.4670  39.13%     38.97%      38.88%
-
-   Coefficients
-   Term                Coef  SE Coef  T-Value  P-Value   VIF
-   Constant          146.41     1.26   115.77    0.000
-   Unconditional     -55.26     2.07   -26.76    0.000  1.05
-   Conditional-3min    9.25     2.07     4.48    0.000  1.05
-   Conditional-5min   21.02     2.07    10.18    0.000  1.05
-   All               -17.58     1.33   -13.19    0.000  1.00
-   WB                  4.11     1.33     3.08    0.002  1.00
-
-   Regression Equation
-   Delay = 146.41 - 55.26 Unconditional + 9.25 Conditional-3min
            + 21.02 Conditional-5min - 17.58 All + 4.11 WB
```

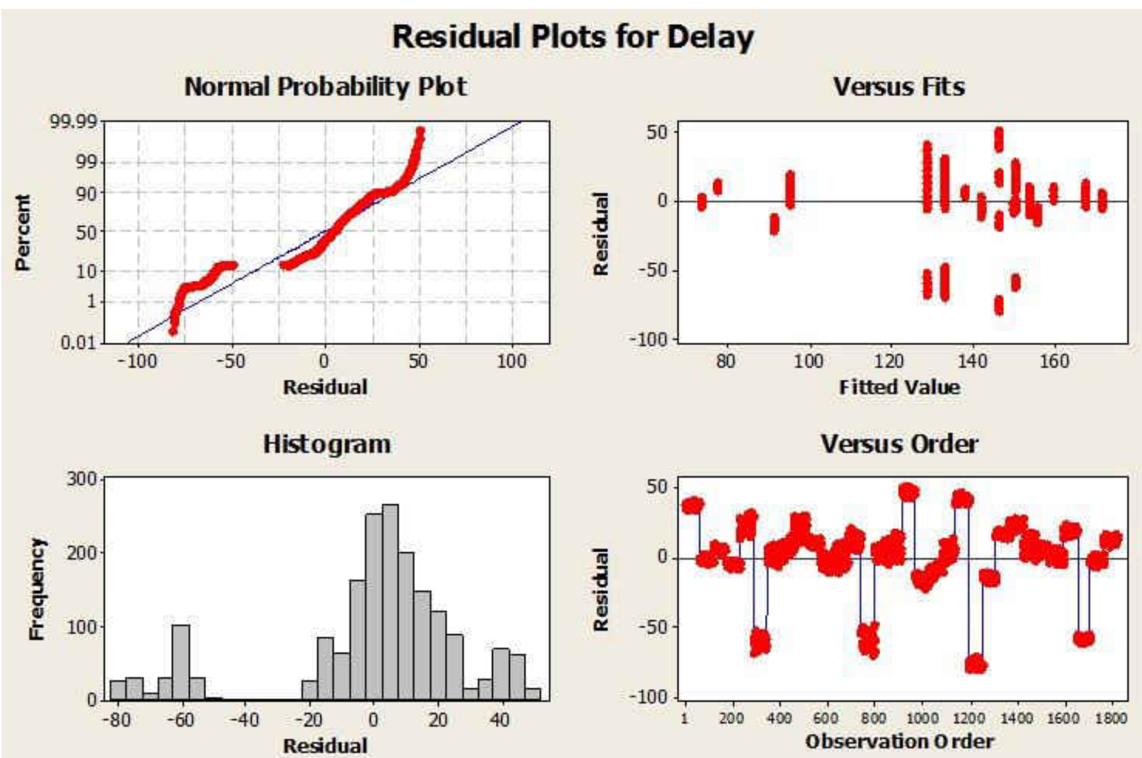


Figure 99: Minitab Output – Residual Plots for Model 1 (Delay)

The generalized regression model developed for delay based on the data of the before (No TSP - No BRT), Unconditional TSP, Conditional TSP 3 Min, and Conditional TSP 5 Min scenarios listed below:

Delay = 146.41 - 55.26 Unconditional + 9.25 Conditional-3min + 21.02 Conditional-5min - 17.58 All + 4.11 WB

The coefficient of determination (**R^2**) as a measure of goodness of fit listed in the output table was (39 %) which implies that about 39% of the sample variation explained by the model.

To determine how useful each predictor variable in the model equation, we test the hypothesis (H_0: $\beta_i = 0$, H_1: $\beta_i \neq 0$). **P-value** associated with the F-value (and t-value) for all terms in the table were (P-value < 0.05) which indicate that each variable found to be significant (reject the null hypothesis H_0 and accept the alternative hypothesis H_1) and should be included in the model.

Residual plots in Figure 99 (top left and bottom left) show that there are no extreme values (no unusual patterns appearing in the plots except some cutouts in the middle) and the residuals appear to follow normal distribution (data points clustered around the fitted "blue" line). Also, in the same Figure 99 (top right and bottom right) show that approximately half of the points are above and the other half are below the zero line (with a clear cyclic pattern) indicating that the assumption of error terms having mean zero is valid.

7.3.3 Speed

The following table shows the analysis of variance, model summary, and regression equation that was developed in Minitab. Results are discussed following Table 21 and Figure 100.

Table 21: Minitab Output - Regression Analysis for Model 1 (Speed)

```
-   Analysis of Variance
-   Source                DF    Adj SS    Adj MS  F-Value  P-Value
-   Regression             5    8695.9   1739.18   493.79    0.000
-     Unconditional        1       1.8      1.83     0.52    0.471
-     Conditional-3min     1     362.4    362.36   102.88    0.000
-     Conditional-5min     1    1033.5   1033.49   293.43    0.000
-     All                  1    6156.0   6155.96  1747.80    0.000
-     WB                   1    1276.8   1276.75   362.50    0.000
-   Error               1818    6403.2      3.52
-     Lack-of-Fit         10     975.4     97.54    32.49    0.000
-     Pure Error        1808    5427.9      3.00
-   Total               1823   15099.1
-
-   Model Summary
-         S     R-sq  R-sq(adj)  R-sq(pred)
-   1.87673   57.59%     57.48%      57.38%
-
-   Coefficients
-   Term                  Coef  SE Coef  T-Value  P-Value    VIF
-   Constant           17.3426   0.0834   208.00    0.000
-   Unconditional       -0.098    0.136    -0.72    0.471   1.05
-   Conditional-3min    -1.381    0.136   -10.14    0.000   1.05
-   Conditional-5min    -2.332    0.136   -17.13    0.000   1.05
-   All                 3.6742   0.0879    41.81    0.000   1.00
-   WB                 -1.6733   0.0879   -19.04    0.000   1.00
-
-   Regression Equation
-   Speed = 17.3426 - 0.098 Unconditional - 1.381 Conditional-3min
            - 2.332 Conditional-5min + 3.6742 All - 1.6733 WB
```

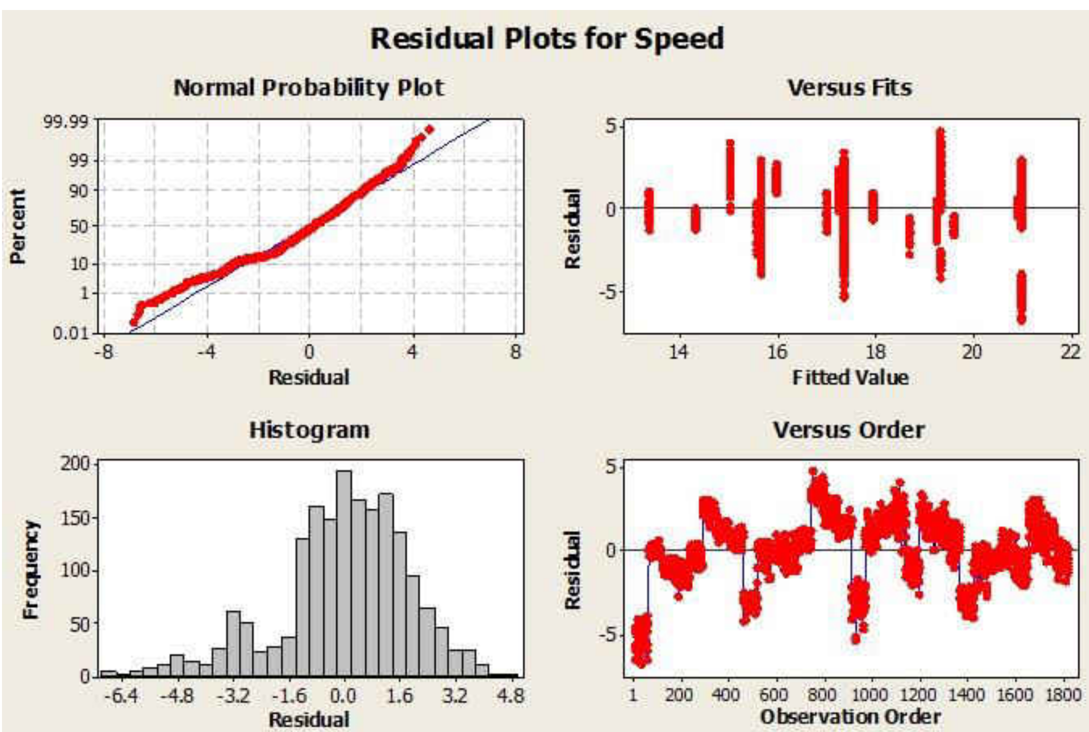


Figure 100: Minitab Output – Residual Plots for Model 1 (Speed)

The generalized regression model developed for speed based on the data of the before (No TSP - No BRT), Unconditional TSP, Conditional TSP 3 Min, and Conditional TSP 5 Min scenarios listed below:

Speed = 17.3426 - 0.098 Unconditional - 1.381 Conditional-3min - 2.332 Conditional-5min + 3.6742 All - 1.6733 WB

The coefficient of determination (**R^2**) as a measure of goodness of fit listed in the output table was (58 %) which implies that about 58% of the sample variation explained by the model.

To determine how useful each predictor variable in the model equation, we test the hypothesis (H_0: $\beta_i = 0$, H_1: $\beta_i \neq 0$). **P-value** associated with the F-value (and t-value) for all terms in the table were (P-value < 0.05) which indicate that each variable found to be significant (reject the null hypothesis H_0 and accept the alternative hypothesis H_1) and should be included in the model.

Residual plots in Figure 100 (top left and bottom left) show that there are no extreme values (no unusual patterns appearing in the plots) and the residuals appear to follow normal distribution (data points clustered around the fitted "blue" line). Also, in the same Figure 100 (top right and bottom right) show that approximately half of the points are above and the other half are below the zero line (with a clear cyclic pattern) indicating that the assumption of error terms having mean zero is valid.

7.3.4 Number of Stops

The following table shows the analysis of variance, model summary, and regression equation that was developed in Minitab. Results are discussed following Table 22 and Figure 101.

Table 22: Minitab Output - Regression Analysis for Model 1 (Number of Stops)

```
-   Analysis of Variance
-   Source                DF    Adj SS    Adj MS   F-Value   P-Value
-   Regression             5   118.956   23.7913    126.60     0.000
-     Unconditional        1    68.289   68.2887    363.40     0.000
-     Conditional-3min     1     3.742    3.7423     19.91     0.000
-     Conditional-5min     1    24.674   24.6736    131.30     0.000
-     All                  1     2.704    2.7041     14.39     0.000
-     WB                   1     0.485    0.4849      2.58     0.108
-   Error               1818   341.634    0.1879
-     Lack-of-Fit         10    15.720    1.5720      8.72     0.000
-     Pure Error        1808   325.914    0.1803
-   Total               1823   460.591
-
-   Model Summary
-          S     R-sq  R-sq(adj)  R-sq(pred)
-   0.433495  25.83%     25.62%      25.48%
-
-   Coefficients
-   Term                 Coef   SE Coef   T-Value   P-Value    VIF
-   Constant           3.0442    0.0193    158.07     0.000
-   Unconditional     -0.5995    0.0314    -19.06     0.000   1.05
-   Conditional-3min   0.1403    0.0314      4.46     0.000   1.05
-   Conditional-5min   0.3604    0.0314     11.46     0.000   1.05
-   All                0.0770    0.0203      3.79     0.000   1.00
-   WB                 0.0326    0.0203      1.61     0.108   1.00
-
-   Regression Equation
-   No.Stops = 3.0442 - 0.5995 Unconditional + 0.1403 Conditional-3min
               + 0.3604 Conditional-5min + 0.0770 All + 0.0326 WB
```

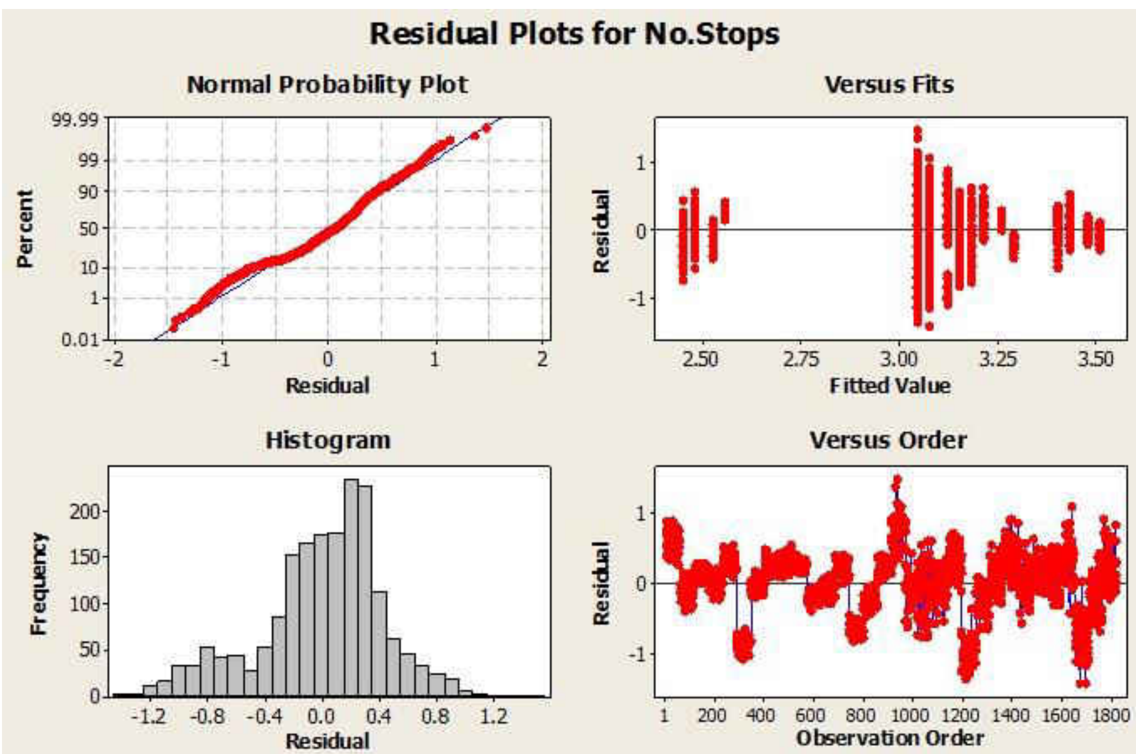


Figure 101: Minitab Output – Residual Plots for Model 1 (Number of Stops)

To determine how useful each predictor variable in the model equation, we test the hypothesis (H_0: $\boldsymbol{\beta_i} = 0$, H_1: $\boldsymbol{\beta_i} \neq 0$). **P-value** associated with the F-value (and t-value) for westbound direction was (P-value = 0.108 > 0.05) which indicate that this variable found to be not significant (fail to reject the null hypothesis H_0 and accept the alternative hypothesis H_1), would not change (y), and should not be included in the model. The **P-value** associated with the F-value (and t-value) for all other variables in the table were (P-value < 0.05) which indicate that each variable found to be significant (reject the null hypothesis H_0 and accept the alternative hypothesis H_1) and should be included in the model.

A new model developed in Minitab without the predictor variable (westbound direction). Results are discussed following Table 23 and Figure 102.

Table 23: Minitab Output - Regression Analysis for Model 1 (Number of Stops) Adjusted

```
-   Analysis of Variance
-   Source                DF   Seq SS   Adj SS   Adj MS        F          P
-   Regression             4  118.471  118.471  29.6179  157.474  0.0000000
-     Unconditional        1   89.834   68.289  68.2887  363.082  0.0000000
-     Conditional-3min     1    1.260    3.742   3.7423   19.898  0.0000087
-     Conditional-5min     1   24.674   24.674  24.6736  131.186  0.0000000
-     All                  1    2.704    2.704   2.7041   14.377  0.0001545
-   Error               1819  342.119  342.119   0.1881
-     Lack-of-Fit          3    1.678    1.678   0.5595    2.984  0.0301824
-     Pure Error        1816  340.441  340.441   0.1875
-   Total               1823  460.59
-
-   Summary of Model
-   S = 0.433683     R-Sq = 25.72%        R-Sq(adj) = 25.56%
-   PRESS = 343.361  R-Sq(pred) = 25.45%
-
-   Coefficients
-   Term                  Coef    SE Coef        T      P
-   Constant           3.06049  0.0163737  186.915  0.000
-   Unconditional     -0.59951  0.0314627  -19.055  0.000
-   Conditional-3min   0.14034  0.0314627    4.461  0.000
-   Conditional-5min   0.36036  0.0314627   11.454  0.000
-   All                0.07701  0.0203091    3.792  0.000
-
-   Regression Equation
-   No.Stops  =  3.06049 - 0.599512 Unconditional + 0.140344 Conditional-3min +
-                0.360362 Conditional-5min + 0.0770066 All
```

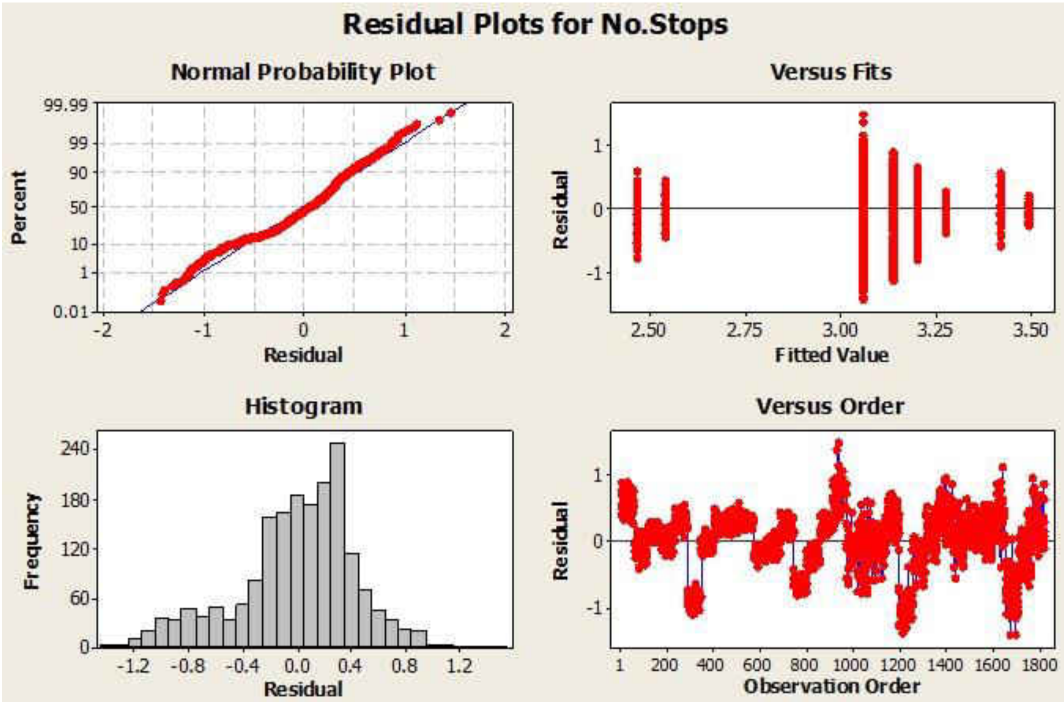


Figure 102: Minitab Output – Residual Plots for Model 1 (Number of Stops) Adjusted

The generalized regression model developed for <u>number of stops</u> based on the data of the before (No TSP - No BRT), Unconditional TSP, Conditional TSP 3 Min, and Conditional TSP 5 Min scenarios listed below:

No. Stops = 3.06049 - 0.599512 Unconditional + 0.140344 Conditional_3min + 0.360362 Conditional_5min + 0.0770066 All

The coefficient of determination (**R^2**) as a measure of goodness of fit listed in the output table was (25.72%) which implies that about 26% of the sample variation explained by the model.

To determine how useful each predictor variable in the model equation, we test the hypothesis (H_0: $\beta_i = 0$, H_1: $\beta_i \neq 0$). **P-value** associated with the F-value (and t-value) for all terms in the table were

(P-value < 0.05) which indicate that each variable found to be significant (reject the null hypothesis H_0 and accept the alternative hypothesis H_1) and should be included in the model.

Residual plots in Figure 102 (top left and bottom left) show that there are no extreme values (no unusual patterns appearing in the plots) and the residuals appear to follow normal distribution (data points clustered around the fitted "blue" line). Also, in the same Figure 102 (top right and bottom right) show that approximately half of the points are above and the other half are below the zero line (with a clear cyclic pattern) indicating that the assumption of error terms having mean zero is valid.

7.4 The Base and BRT Scenarios Model (Model 2)

In this model, BRT scenarios were compared to the base scenario (the before: No TSP – No BRT). The multiple linear regression model can be expressed as

y = function of (No TSP – No BRT, BRT No TSP, BRT Unconditional TSP, BRT Conditional TSP 3 Min, and BRT Conditional TSP 5 Min).

Where (y) is the studied MOE for through movement along I-Drive that was obtained from the VISSIM model analysis (average travel times, average speed, average delays, and average number of stops). Both vehicle classifications (all vehicles and buses only) were used in this model. Other models for (buses only) can be found in **Appendix G**.

7.4.1 Travel Time

The following table shows the analysis of variance, model summary, and regression equation that was developed in Minitab. Results are discussed following Table 24 and Figure 103.

Table 24: Minitab Output - Regression Analysis for Model 2 (Travel Time)

```
-    Analysis of Variance
-    Source                 DF   Adj SS    Adj MS  F-Value  P-Value
-    Regression              6  4216842    702807   738.02    0.000
-      BRT_NO-TSP            1   111433    111433   117.02    0.000
-      BRT_TSP-Uncond        1   800618    800618   840.74    0.000
-      BRT_TSP-Con-3min      1   394100    394100   413.85    0.000
-      BRT_TSP-Con-5min      1   269716    269716   283.23    0.000
-      All                   1  2712355   2712355  2848.27    0.000
-      WB                    1   416524    416524   437.40    0.000
-    Error                1817  1730295       952
-      Lack-of-Fit          13   632277     48637    79.91    0.000
-      Pure Error         1804  1098018       609
-    Total                1823  5947137
-
-    Model Summary
-          S     R-sq  R-sq(adj)  R-sq(pred)
-    30.8591   70.91%     70.81%      70.74%
-
-    Coefficients
-    Term                Coef  SE Coef  T-Value  P-Value    VIF
-    Constant          404.33     1.45   279.79    0.000
-    BRT_NO-TSP        -24.72     2.28   -10.82    0.000   1.09
-    BRT_TSP-Uncond    -66.25     2.28   -29.00    0.000   1.09
-    BRT_TSP-Con-3min  -46.48     2.28   -20.34    0.000   1.09
-    BRT_TSP-Con-5min  -38.45     2.28   -16.83    0.000   1.09
-    All               -77.12     1.45   -53.37    0.000   1.00
-    WB                 30.22     1.45    20.91    0.000   1.00
-
-    Regression Equation
-    Travel Time = 404.33 - 24.72 BRT_NO-TSP - 66.25 BRT_TSP-Uncond
                  - 46.48 BRT_TSP-Con-3min - 38.45 BRT_TSP-Con-5min - 77.12 All
                  + 30.22 WB
```

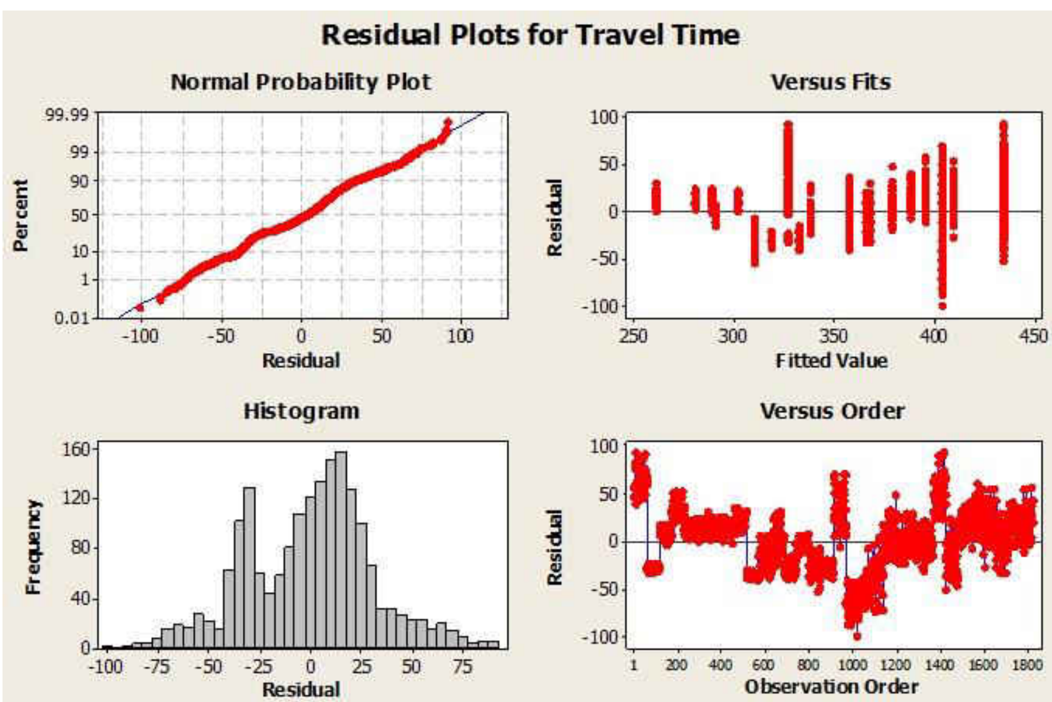


Figure 103: Minitab Output – Residual Plots for Model 2 (Travel Time)

The generalized regression model developed for travel time based on the data of the before (No TSP – No BRT), BRT No TSP, BRT Unconditional TSP, BRT Conditional TSP 3 Min, and BRT Conditional TSP 5 Min scenarios listed below:

Travel Time = 404.33 - 24.72 BRT_NO_TSP - 66.25 BRT_TSP_Uncond
- 46.48 BRT_TSP_Cond_3min - 38.45 BRT_TSP_Cond_5min
- 77.12 All + 30.22 WB

The coefficient of determination (**R^2**) as a measure of goodness of fit listed in the output table was (70.91 %) which implies that about 71% of the sample variation explained by the model.

To determine how useful each predictor variable in the model equation, we test the hypothesis (H_0: $\beta_i = 0$, H_1: $\beta_i \neq 0$). **P-value** associated with the F-value (and t-value) for all terms in the table were (P-value < 0.05) which indicate that each variable found to be significant (reject the null hypothesis H_0 and accept the alternative hypothesis H_1) and should be included in the model.

Residual plots in Figure 103 (top left and bottom left) show that there are no extreme values (no unusual patterns appearing in the plots) and the residuals appear to follow normal distribution (data points clustered around the fitted "blue" line). Also, in the same Figure 103 (top right and bottom right) show that approximately half of the points are above and the other half are below the zero line (with a clear cyclic pattern) indicating that the assumption of error terms having mean zero is valid.

7.4.2 Delay

The following table shows the analysis of variance, model summary, and regression equation that was developed in Minitab. Results are discussed following Table 25 and Figure 104.

Table 25: Minitab Output - Regression Analysis for Model 2 (Delay)

```
-   Analysis of Variance
-   Source                DF   Adj SS   Adj MS  F-Value  P-Value
-   Regression             6  1241379   206896   318.82    0.000
-     BRT_NO-TSP           1    91074    91074   140.34    0.000
-     BRT_TSP-Uncond       1   795576   795576  1225.96    0.000
-     BRT_TSP-Con-3min     1     4386     4386     6.76    0.009
-     BRT_TSP-Con-5min     1    17497    17497    26.96    0.000
-     All                  1   140930   140930   217.17    0.000
-     WB                   1     7702     7702    11.87    0.001
-   Error               1817  1179130      649
-     Lack-of-Fit         13    56726     4364     7.01    0.000
-     Pure Error        1804  1122404      622
-   Total               1823  2420509
-
-   Model Summary
-         S    R-sq  R-sq(adj)  R-sq(pred)
-   25.4744  51.29%     51.12%      51.05%
-
-   Coefficients
-   Term                Coef  SE Coef  T-Value  P-Value   VIF
-   Constant          148.14     1.19   124.18    0.000
-   BRT_NO-TSP         22.35     1.89    11.85    0.000  1.09
-   BRT_TSP-Uncond    -66.04     1.89   -35.01    0.000  1.09
-   BRT_TSP-Con-3min   -4.90     1.89    -2.60    0.009  1.09
-   BRT_TSP-Con-5min    9.79     1.89     5.19    0.000  1.09
-   All               -17.58     1.19   -14.74    0.000  1.00
-   WB                  4.11     1.19     3.45    0.001  1.00
-
-   Regression Equation
-   Delay = 148.14 + 22.35 BRT_NO-TSP - 66.04 BRT_TSP-Uncond
            - 4.90 BRT_TSP-Con-3min + 9.79 BRT_TSP-Con-5min - 17.58 All + 4.11 WB
```

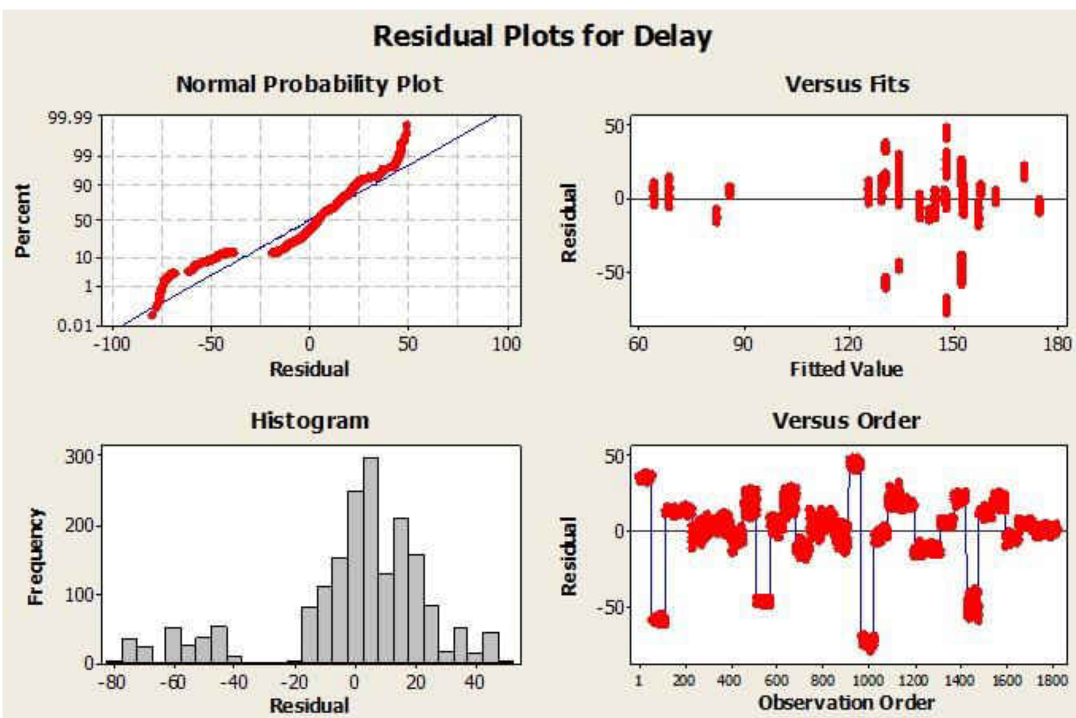


Figure 104: Minitab Output – Residual Plots for Model 2 (Delay)

The generalized regression model developed for delay based on the data of the before (No TSP - No BRT), BRT No TSP, BRT Unconditional TSP, BRT Conditional TSP 3 Min, and BRT Conditional TSP 5 Min scenarios listed below:

Delay = 148.14 + 22.35 BRT_NO_TSP - 66.04 BRT_TSP_Uncond - 4.90 BRT_TSP_Cond_3min + 9.79 BRT_TSP_Cond_5min - 17.58 All + 4.11 WB

The coefficient of determination (**R^2**) as a measure of goodness of fit listed in the output table was (51.29 %) which implies that about 51% of the sample variation explained by the model.

To determine how useful each predictor variable in the model equation, we test the hypothesis (H_0: $\beta_i = 0$, H_1: $\beta_i \neq 0$). **P-value** associated with the F-value (and t-value) for all terms in the table were (P-value < 0.05) which indicate that each variable found to be significant (reject the null hypothesis H_0 and accept the alternative hypothesis H_1) and should be included in the model.

Residual plots in Figure 104 (top left and bottom left) show that there are no extreme values (no unusual patterns appearing in the plots except some cutouts in the middle) and the residuals appear to follow normal distribution (data points clustered around the fitted "blue" line). Also, in the same Figure 104 (top right and bottom right) show that approximately half of the points are above and the other half are below the zero line (with a clear cyclic pattern) indicating that the assumption of error terms having mean zero is valid.

7.4.3 Speed

The following table shows the analysis of variance, model summary, and regression equation that was developed in Minitab. Results are discussed following Table 26 and Figure 105.

Table 26: Minitab Output - Regression Analysis for Model 2 (Speed)

```
-   Analysis of Variance
-   Source                DF   Adj SS   Adj MS  F-Value  P-Value
-   Regression             6  11844.1  1974.02  1101.94    0.000
-     BRT_NO-TSP           1    370.9   370.87   207.03    0.000
-     BRT_TSP-Uncond       1   3111.9  3111.86  1737.11    0.000
-     BRT_TSP-Con-3min     1   1839.6  1839.58  1026.89    0.000
-     BRT_TSP-Con-5min     1   1006.5  1006.52   561.86    0.000
-     All                  1   6156.0  6155.96  3436.38    0.000
-     WB                   1   1276.8  1276.75   712.71    0.000
-   Error               1817   3255.0     1.79
-     Lack-of-Fit         13    999.2    76.86    61.47    0.000
-     Pure Error        1804   2255.8     1.25
-   Total               1823  15099.1
-
-
-   Model Summary
-         S    R-sq  R-sq(adj)  R-sq(pred)
-   1.33843  78.44%     78.37%      78.32%
-
-   Coefficients
-   Term                 Coef  SE Coef  T-Value  P-Value   VIF
-   Constant          15.4810   0.0627   246.99    0.000
-   BRT_NO-TSP         1.4259   0.0991    14.39    0.000  1.09
-   BRT_TSP-Uncond     4.1305   0.0991    41.68    0.000  1.09
-   BRT_TSP-Con-3min   3.1758   0.0991    32.05    0.000  1.09
-   BRT_TSP-Con-5min   2.3491   0.0991    23.70    0.000  1.09
-   All                3.6742   0.0627    58.62    0.000  1.00
-   WB                -1.6733   0.0627   -26.70    0.000  1.00
-
-   Regression Equation
-   Speed = 15.4810 + 1.4259 BRT_NO-TSP + 4.1305 BRT_TSP-Uncond
            + 3.1758 BRT_TSP-Con-3min + 2.3491 BRT_TSP-Con-5min + 3.6742 All
            - 1.6733 WB
```

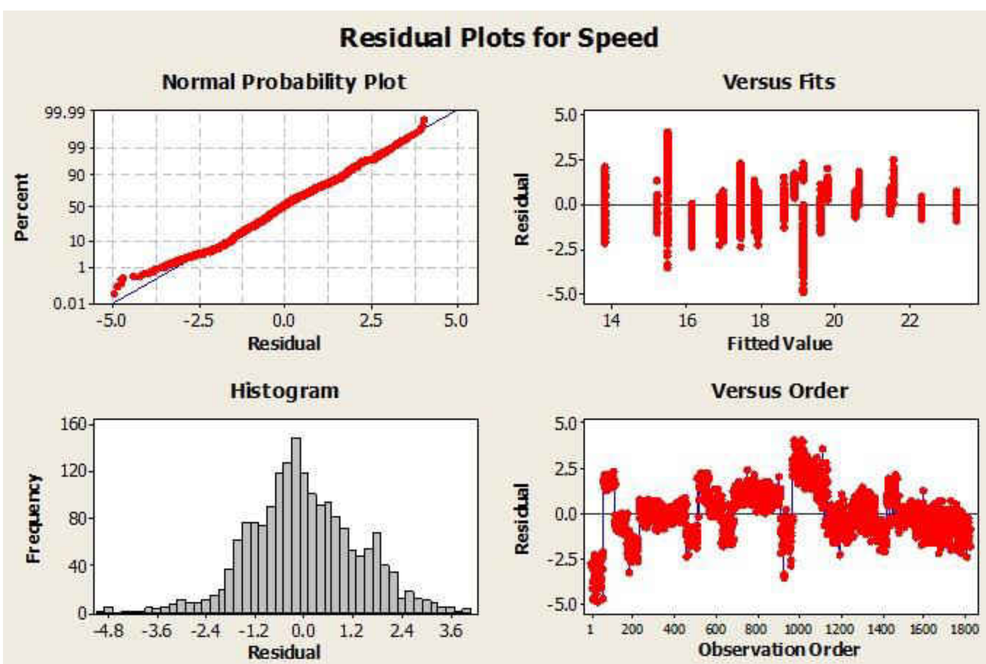


Figure 105: Minitab Output – Residual Plots for Model 2 (Speed)

The generalized regression model developed for speed based on the data of the before (No TSP - No BRT), BRT No TSP, Unconditional TSP, Conditional TSP 3 Min, and Conditional TSP 5 Min scenarios listed below:

Speed = 15.4810 + 1.4259 BRT_NO_TSP + 4.1305 BRT_TSP_Uncond + 3.1758 BRT_TSP_Cond_3min + 2.3491 BRT_TSP_Cond_5min + 3.6742 All - 1.6733 WB

The coefficient of determination (**R^2**) as a measure of goodness of fit listed in the output table was (78.44 %) which implies that about 78% of the sample variation explained by the model.

To determine how useful each predictor variable in the model equation, we test the hypothesis (H_0: $\beta_i = 0$, H_1: $\beta_i \neq 0$). **P-value** associated with the F-value (and t-value) for all terms in the table were (P-value < 0.05) which indicate that each variable found to be significant (reject the null hypothesis H_0 and accept the alternative hypothesis H_1) and should be included in the model.

Residual plots in Figure 105 (top left and bottom left) show that there are no extreme values (no unusual patterns appearing in the plots) and the residuals appear to follow normal distribution (data points clustered around the fitted "blue" line). Also, in the same Figure 105 (top right and bottom right) show that approximately half of the points are above and the other half are below the zero line (with a clear cyclic pattern) indicating that the assumption of error terms having mean zero is valid.

7.4.4 Number of Stops

The following table shows the analysis of variance, model summary, and regression equation that was developed in Minitab. Results are discussed following Table 27 and Figure 106.

Table 27: Minitab Output - Regression Analysis for Model 2 (Number of Stops)

```
-   Analysis of Variance
-   Source                DF   Adj SS    Adj MS  F-Value  P-Value
-   Regression             6  209.361    34.893   252.36    0.000
-     BRT_NO-TSP           1    7.787     7.787    56.32    0.000
-     BRT_TSP-Uncond       1  157.685   157.685  1140.45    0.000
-     BRT_TSP-Con-3min     1   16.251    16.251   117.54    0.000
-     BRT_TSP-Con-5min     1    2.186     2.186    15.81    0.000
-     All                  1    2.704     2.704    19.56    0.000
-     WB                   1    0.485     0.485     3.51    0.061
-   Error               1817  251.230     0.138
-     Lack-of-Fit         13    8.806     0.677     5.04    0.000
-     Pure Error        1804  242.424     0.134
-   Total               1823  460.591
-
-   Model Summary
-          S    R-sq  R-sq(adj)  R-sq(pred)
-   0.371842  45.45%     45.27%      45.16%
-
-   Coefficients
-   Term                 Coef  SE Coef  T-Value  P-Value   VIF
-   Constant           3.1459   0.0174   180.66    0.000
-   BRT_NO-TSP         0.2066   0.0275     7.50    0.000  1.09
-   BRT_TSP-Uncond    -0.9298   0.0275   -33.77    0.000  1.09
-   BRT_TSP-Con-3min  -0.2985   0.0275   -10.84    0.000  1.09
-   BRT_TSP-Con-5min   0.1095   0.0275     3.98    0.000  1.09
-   All                0.0770   0.0174     4.42    0.000  1.00
-   WB                 0.0326   0.0174     1.87    0.061  1.00
-
-   Regression Equation
-   No.Stops = 3.1459 + 0.2066 BRT_NO-TSP - 0.9298 BRT_TSP-Uncond
               - 0.2985 BRT_TSP-Con-3min + 0.1095 BRT_TSP-Con-5min + 0.0770 All
               + 0.0326 WB
```

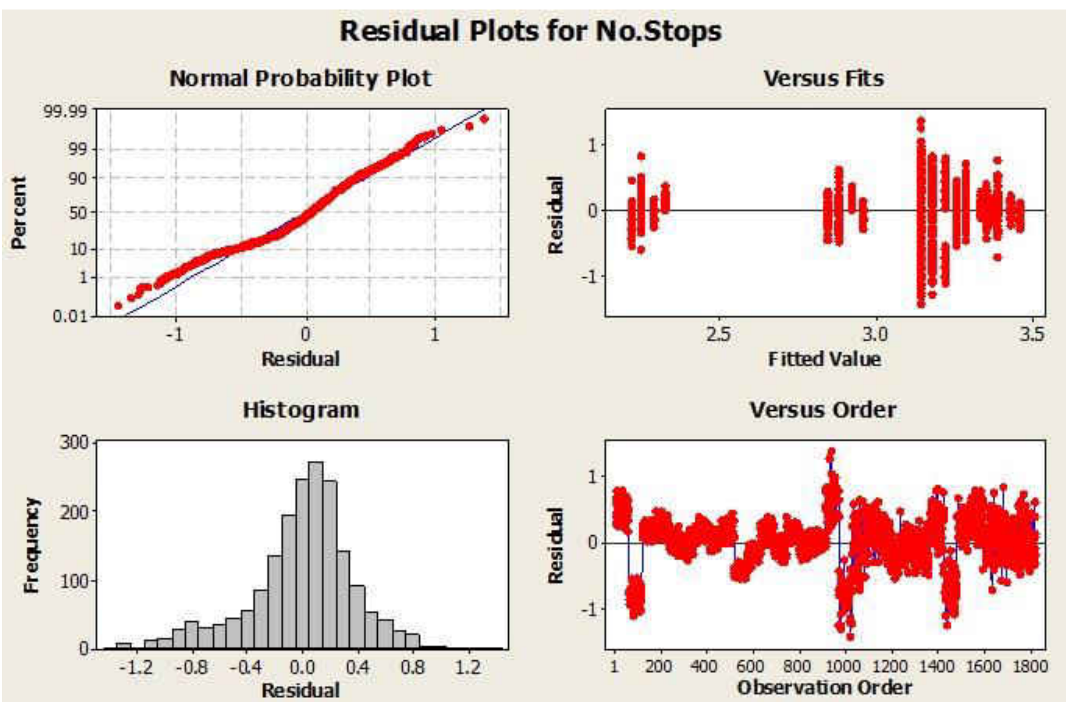


Figure 106: Minitab Output – Residual Plots for Model 2 (Number of Stops)

To determine how useful each predictor variable in the model equation, we test the hypothesis (H_0: $\boldsymbol{\beta_i} = 0$, H_1: $\boldsymbol{\beta_i} \neq 0$). **P-value** associated with the F-value (and t-value) for westbound direction was (P-value = 0.061 > 0.05) which indicate that this variable found to be not significant (fail to reject the null hypothesis H_0 and accept the alternative hypothesis H_1), would not change (y), and should not be included in the model. The **P-value** associated with the F-value (and t-value) for all other variables in the table were (P-value < 0.05) which indicate that each variable found to be significant (reject the null hypothesis H_0 and accept the alternative hypothesis H_1) and should be included in the model.

A new model developed in Minitab without the predictor variable (westbound direction). Results are discussed following Table 28 and Figure 107.

Table 28: Minitab Output - Regression Analysis for Model 2 (Number of Stops) Adjusted

```
-   Analysis of Variance
-   Source                DF   Seq SS   Adj SS   Adj MS        F          P
-   Regression             5  208.876  208.876   41.775   301.72  0.0000000
-     BRT_NO-TSP           1   26.790    7.787    7.787    56.24  0.0000000
-     BRT_TSP-Uncond       1  157.694  157.685  157.685  1138.87  0.0000000
-     BRT_TSP-Con-3min     1   19.503   16.251   16.251   117.37  0.0000000
-     BRT_TSP-Con-5min     1    2.186    2.186    2.186    15.79  0.0000737
-     All                  1    2.704    2.704    2.704    19.53  0.0000105
-   Error               1818  251.715  251.715    0.138
-     Lack-of-Fit          4    2.059    2.059    0.515     3.74  0.0048937
-     Pure Error        1814  249.656  249.656    0.138
-   Total               1823  460.591
-
-   Summary of Model
-   S = 0.372098     R-Sq = 45.35%        R-Sq(adj) = 45.20%
-   PRESS = 252.778  R-Sq(pred) = 45.12%
-
-   Coefficients
-   Term                  Coef    SE Coef        T      P
-   Constant           3.16216  0.0150906  209.545  0.000
-   BRT_NO-TSP         0.20662  0.0275515    7.499  0.000
-   BRT_TSP-Uncond    -0.92979  0.0275515  -33.747  0.000
-   BRT_TSP-Con-3min  -0.29849  0.0275515  -10.834  0.000
-   BRT_TSP-Con-5min   0.10947  0.0275515    3.973  0.000
-   All                0.07701  0.0174251    4.419  0.000
-
-   Regression Equation
-   No.Stops  =  3.16216 + 0.206617 BRT_NO-TSP - 0.929786 BRT_TSP-Uncond - 0.29849
                 BRT_TSP-Con-3min + 0.109468 BRT_TSP-Con-5min + 0.0770066 All
```

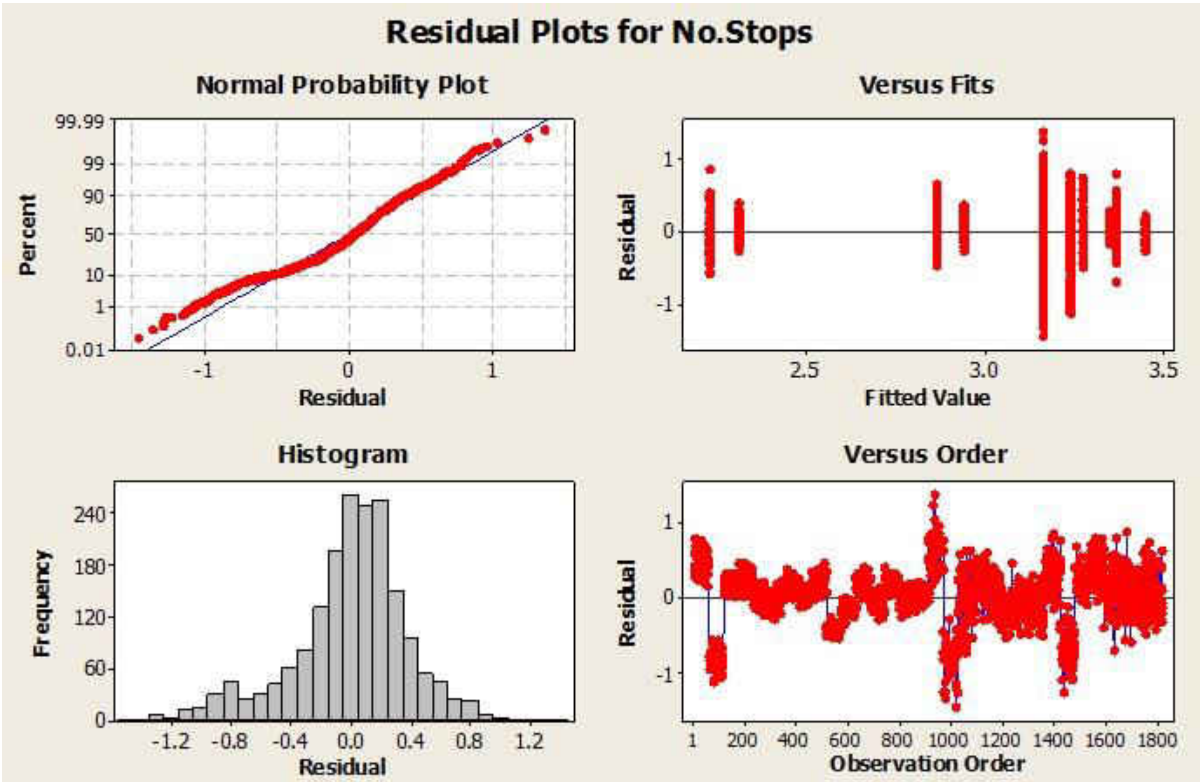


Figure 107: Minitab Output – Residual Plots for Model 2 (Number of Stops) Adjusted

The generalized regression model developed for <u>number of stops</u> based on the data of the before (No TSP - No BRT), BRT No TSP, BRT Unconditional TSP, BRT Conditional TSP 3 Min, and BRT Conditional TSP 5 Min scenarios listed below:

No.Stops = 3.16216 + 0.206617 BRT_NO-TSP - 0.929786 BRT_TSP_Uncond - 0.29849 BRT_TSP_Cond_3min + 0.109468 BRT_TSP_Cond_5min + 0.0770066 All

The coefficient of determination (**R^2**) as a measure of goodness of fit listed in the output table was (45.35%) which implies that about 45% of the sample variation explained by the model.

To determine how useful each predictor variable in the model equation, we test the hypothesis (H_0: $\beta_i = 0$, H_1: $\beta_i \neq 0$). **P-value** associated with the F-value (and t-value) for all terms in the table were

(P-value < 0.05) which indicate that each variable found to be significant (reject the null hypothesis H_0 and accept the alternative hypothesis H_1) and should be included in the model.

Residual plots in Figure 107 (top left and bottom left) show that there are no extreme values (no unusual patterns appearing in the plots) and the residuals appear to follow normal distribution (data points clustered around the fitted "blue" line). Also, in the same Figure 107 (top right and bottom right) show that approximately half of the points are above and the other half are below the zero line (with a clear cyclic pattern) indicating that the assumption of error terms having mean zero is valid.

7.5 The Base, TSP, and BRT Scenarios Model (Model 3)

In this model, the base (the before: No TSP – No BRT), TSP, and BRT scenarios were included. The multiple linear regression model can be expressed as

y = function of (No TSP – No BRT, Unconditional TSP, Conditional TSP 3 Min, and Conditional TSP 5 Min, BRT No TSP, BRT Unconditional TSP, BRT Conditional TSP 3 Min, and BRT Conditional TSP 5 Min).

Where (y) is the studied MOE for through movement along I-Drive that was obtained from the VISSIM model analysis (average travel times, average speed, average delays, and average number of stops). Both vehicle classifications (all vehicles and buses only) were used in this model. Other models for (buses only) can be found in **Appendix G**.

7.5.1 Travel Time

The following table shows the analysis of variance, model summary, and regression equation that was developed in Minitab. Results are discussed following Table 29 and Figure 108.

Table 29: Minitab Output - Regression Analysis for Model 3 (Travel Time)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	9	4993902	554878	1055.93	0.000
Unconditional	1	736099	736099	1400.79	0.000
Conditional-3min	1	333320	333320	634.31	0.000
Conditional-5min	1	152445	152445	290.10	0.000
BRT_NO-TSP	1	518889	518889	987.44	0.000
BRT_TSP-Uncond	1	1354467	1354467	2577.54	0.000
BRT_TSP-Con-3min	1	907703	907703	1727.35	0.000
BRT_TSP-Con-5min	1	751710	751710	1430.50	0.000
All	1	2712355	2712355	5161.59	0.000
WB	1	416524	416524	792.64	0.000
Error	1814	953235	525		
Lack-of-Fit	22	712060	32366	240.49	0.000
Pure Error	1792	241175	135		
Total	1823	5947137			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
22.9235	83.97%	83.89%	83.79%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	447.08	1.70	263.40	0.000	
Unconditional	-80.36	2.15	-37.43	0.000	1.75
Conditional-3min	-54.07	2.15	-25.19	0.000	1.75
Conditional-5min	-36.57	2.15	-17.03	0.000	1.75
BRT_NO-TSP	-67.47	2.15	-31.42	0.000	1.75
BRT_TSP-Uncond	-109.00	2.15	-50.77	0.000	1.75
BRT_TSP-Con-3min	-89.23	2.15	-41.56	0.000	1.75
BRT_TSP-Con-5min	-81.20	2.15	-37.82	0.000	1.75
All	-77.12	1.07	-71.84	0.000	1.00
WB	30.22	1.07	28.15	0.000	1.00

Regression Equation

```
Travel Time = 447.08 - 80.36 Unconditional - 54.07 Conditional-3min
              - 36.57 Conditional-5min - 67.47 BRT_NO-TSP
              - 109.00 BRT_TSP-Uncond - 89.23 BRT_TSP-Con-3min
              - 81.20 BRT_TSP-Con-5min - 77.12 All + 30.22 WB
```

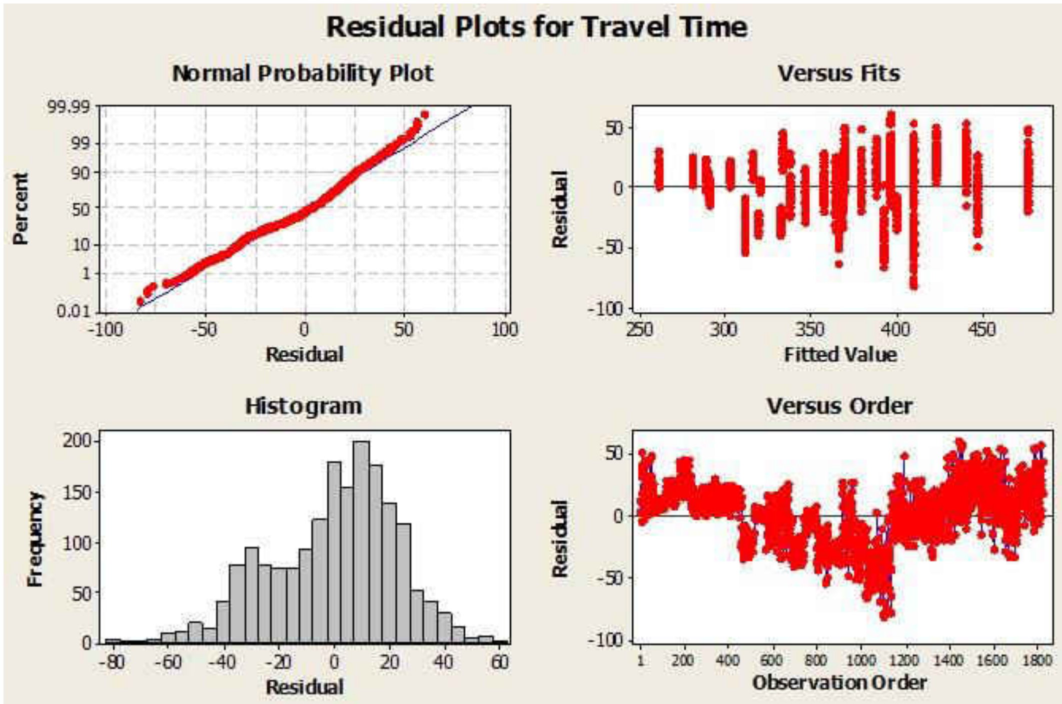


Figure 108: Minitab Output – Residual Plots for Model 3 (Travel Time)

The generalized regression model developed for travel time based on the data of the before (No TSP – No BRT), Unconditional TSP, Conditional TSP 3 Min, and Conditional TSP 5 Min, BRT No TSP, BRT Unconditional TSP, BRT Conditional TSP 3 Min, and BRT Conditional TSP 5 Min scenarios listed below:

Travel Time = 447.08 - 80.36 Unconditional - 54.07 Conditional_3min
- 36.57 Conditional_5min - 67.47 BRT_NO_TSP
- 109.00 BRT_TSP_Uncond - 89.23 BRT_TSP_Cond_3min
- 81.20 BRT_TSP_Con_5min - 77.12 All + 30.22 WB

The coefficient of determination (**R^2**) as a measure of goodness of fit listed in the output table was (83.97 %) which implies that about 84% of the sample variation explained by the model.

To determine how useful each predictor variable in the model equation, we test the hypothesis (H_0: $\boldsymbol{\beta_i} = 0$, H_1: $\boldsymbol{\beta_i} \neq 0$). **P-value** associated with the F-value (and t-value) for all terms in the table were (P-value < 0.05) which indicate that each variable found to be significant (reject the null hypothesis H_0 and accept the alternative hypothesis H_1) and should be included in the model.

Residual plots in Figure 108 (top left and bottom left) show that there are no extreme values (no unusual patterns appearing in the plots) and the residuals appear to follow normal distribution (data points clustered around the fitted "blue" line). Also, in the same Figure 108 (top right and bottom right) show that approximately half of the points are above and the other half are below the zero line (with a clear cyclic pattern) indicating that the assumption of error terms having mean zero is valid.

7.5.2 Delay

The following table shows the analysis of variance, model summary, and regression equation that was developed in Minitab. Results are discussed following Table 30 and Figure 109.

Table 30: Minitab Output - Regression Analysis for Model 3 (Delay)

```
-   Analysis of Variance
-   Source               DF   Adj SS   Adj MS   F-Value  P-Value
-   Regression            9  2287032   254115   3453.50    0.000
-     Unconditional       1   865924   865924  11768.19    0.000
-     Conditional-3min    1    58441    58441    794.23    0.000
-     Conditional-5min    1    13494    13494    183.39    0.000
-     BRT_NO-TSP          1     6978     6978     94.83    0.000
-     BRT_TSP-Uncond      1  1055272  1055272  14341.49    0.000
-     BRT_TSP-Con-3min    1   140227   140227   1905.73    0.000
-     BRT_TSP-Con-5min    1    47324    47324    643.15    0.000
-     All                 1   140930   140930   1915.29    0.000
-     WB                  1     7702     7702    104.68    0.000
-   Error              1814   133477       74
-     Lack-of-Fit        22   116314     5287    552.03    0.000
-     Pure Error       1792    17163       10
-   Total              1823  2420509
-
-   Model Summary
-         S    R-sq  R-sq(adj)  R-sq(pred)
-   8.57798  94.49%     94.46%      94.42%
-
-   Coefficients
-   Term                 Coef  SE Coef  T-Value  P-Value   VIF
-   Constant          178.306    0.635   280.73    0.000
-   Unconditional     -87.154    0.803  -108.48    0.000  1.75
-   Conditional-3min  -22.642    0.803   -28.18    0.000  1.75
-   Conditional-5min  -10.880    0.803   -13.54    0.000  1.75
-   BRT_NO-TSP         -7.824    0.803    -9.74    0.000  1.75
-   BRT_TSP-Uncond    -96.212    0.803  -119.76    0.000  1.75
-   BRT_TSP-Con-3min  -35.072    0.803   -43.65    0.000  1.75
-   BRT_TSP-Con-5min  -20.375    0.803   -25.36    0.000  1.75
-   All               -17.580    0.402   -43.76    0.000  1.00
-   WB                  4.110    0.402    10.23    0.000  1.00
-
-   Regression Equation
-   Delay = 178.306 - 87.154 Unconditional - 22.642 Conditional-3min
            - 10.880 Conditional-5min - 7.824 BRT_NO-TSP - 96.212 BRT_TSP-Uncond
            - 35.072 BRT_TSP-Con-3min - 20.375 BRT_TSP-Con-5min - 17.580 All
            + 4.110 WB
```

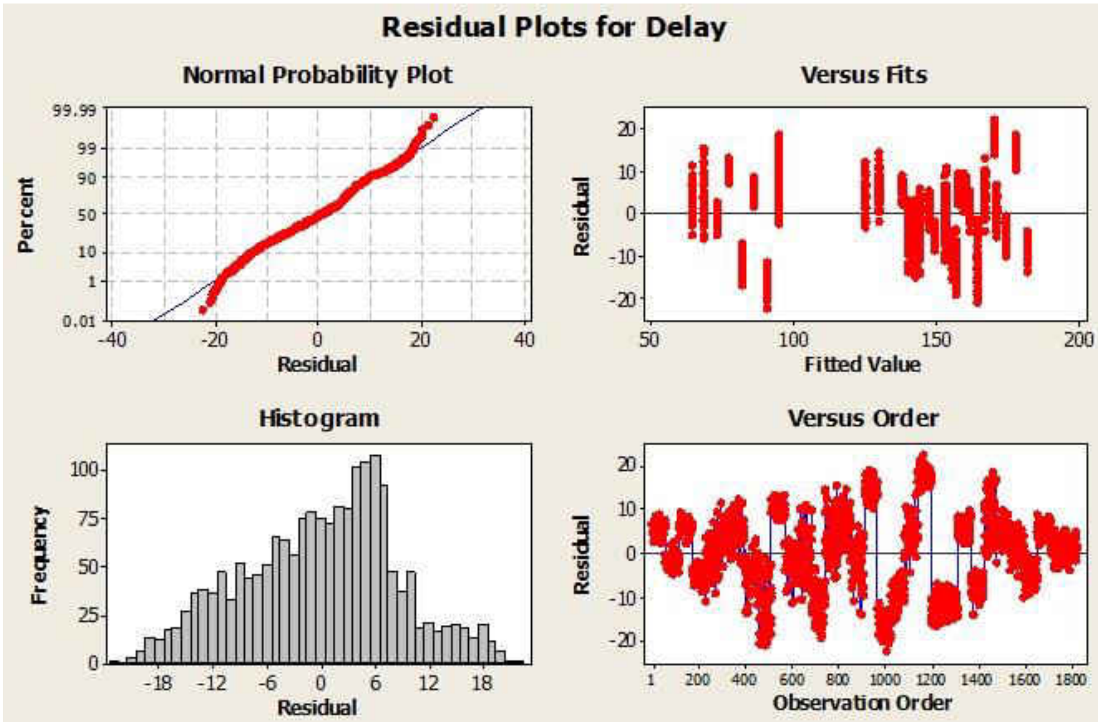


Figure 109: Minitab Output – Residual Plots for Model 3 (Delay)

The generalized regression model developed for delay based on the data of the before (No TSP - No BRT), Unconditional TSP, Conditional TSP 3 Min, and Conditional TSP 5 Min BRT No TSP, BRT Unconditional TSP, BRT Conditional TSP 3 Min, and BRT Conditional TSP 5 Min scenarios listed below:

Delay = 178.306 - 87.154 Unconditional - 22.642 Conditional_3min
- 10.880 Conditional_5min - 7.824 BRT_NO_TSP
- 96.212 BRT_TSP_Uncond - 35.072 BRT_TSP_Cond_3min
- 20.375 BRT_TSP_Cond_5min - 17.580 All + 4.110 WB

The coefficient of determination (**R^2**) as a measure of goodness of fit listed in the output table was (94.49 %) which implies that about 94% of the sample variation explained by the model.

To determine how useful each predictor variable in the model equation, we test the hypothesis (H_0: $\boldsymbol{\beta_i} = 0$, H_1: $\boldsymbol{\beta_i} \neq 0$). **P-value** associated with the F-value (and t-value) for all terms in the table were (P-value < 0.05) which indicate that each variable found to be significant (reject the null hypothesis H_0 and accept the alternative hypothesis H_1) and should be included in the model.

Residual plots in Figure 109 (top left and bottom left) show that there are no extreme values (no unusual patterns appearing in the plots) and the residuals appear to follow normal distribution (data points clustered around the fitted "blue" line). Also, in the same Figure 109 (top right and bottom right) show that approximately half of the points are above and the other half are below the zero line (with a clear cyclic pattern) indicating that the assumption of error terms having mean zero is valid.

7.5.3 Speed

The following table shows the analysis of variance, model summary, and regression equation that was developed in Minitab. Results are discussed following Table 31 and Figure 110.

Table 31: Minitab Output - Regression Analysis for Model 3 (Speed)

```
-   Analysis of Variance
-   Source               DF   Adj SS   Adj MS  F-Value  P-Value
-   Regression            9  13373.3  1485.92  1561.86    0.000
-     Unconditional       1   1426.0  1426.00  1498.87    0.000
-     Conditional-3min    1    579.1   579.14   608.73    0.000
-     Conditional-5min    1    193.4   193.45   203.33    0.000
-     BRT_NO-TSP          1   1166.8  1166.83  1226.45    0.000
-     BRT_TSP-Uncond      1   3973.4  3973.44  4176.49    0.000
-     BRT_TSP-Con-3min    1   2792.3  2792.26  2934.94    0.000
-     BRT_TSP-Con-5min    1   1937.4  1937.36  2036.36    0.000
-     All                 1   6156.0  6155.96  6470.54    0.000
-     WB                  1   1276.8  1276.75  1342.00    0.000
-   Error              1814   1725.8     0.95
-     Lack-of-Fit        22   1238.4    56.29   206.96    0.000
-     Pure Error       1792    487.4     0.27
-   Total              1823  15099.1
-
-   Model Summary
-          S    R-sq  R-sq(adj)  R-sq(pred)
-   0.975389  88.57%     88.51%      88.44%
-
-   Coefficients
-   Term                 Coef  SE Coef  T-Value  P-Value   VIF
-   Constant          13.7077   0.0722   189.80    0.000
-   Unconditional      3.5368   0.0914    38.72    0.000  1.75
-   Conditional-3min   2.2539   0.0914    24.67    0.000  1.75
-   Conditional-5min   1.3027   0.0914    14.26    0.000  1.75
-   BRT_NO-TSP         3.1993   0.0914    35.02    0.000  1.75
-   BRT_TSP-Uncond     5.9038   0.0914    64.63    0.000  1.75
-   BRT_TSP-Con-3min   4.9491   0.0914    54.18    0.000  1.75
-   BRT_TSP-Con-5min   4.1224   0.0914    45.13    0.000  1.75
-   All                3.6742   0.0457    80.44    0.000  1.00
-   WB                -1.6733   0.0457   -36.63    0.000  1.00
-
-   Regression Equation
-   Speed = 13.7077 + 3.5368 Unconditional + 2.2539 Conditional-3min
            + 1.3027 Conditional-5min + 3.1993 BRT_NO-TSP + 5.9038 BRT_TSP-Uncond
            + 4.9491 BRT_TSP-Con-3min + 4.1224 BRT_TSP-Con-5min + 3.6742 All
            - 1.6733 WB
```

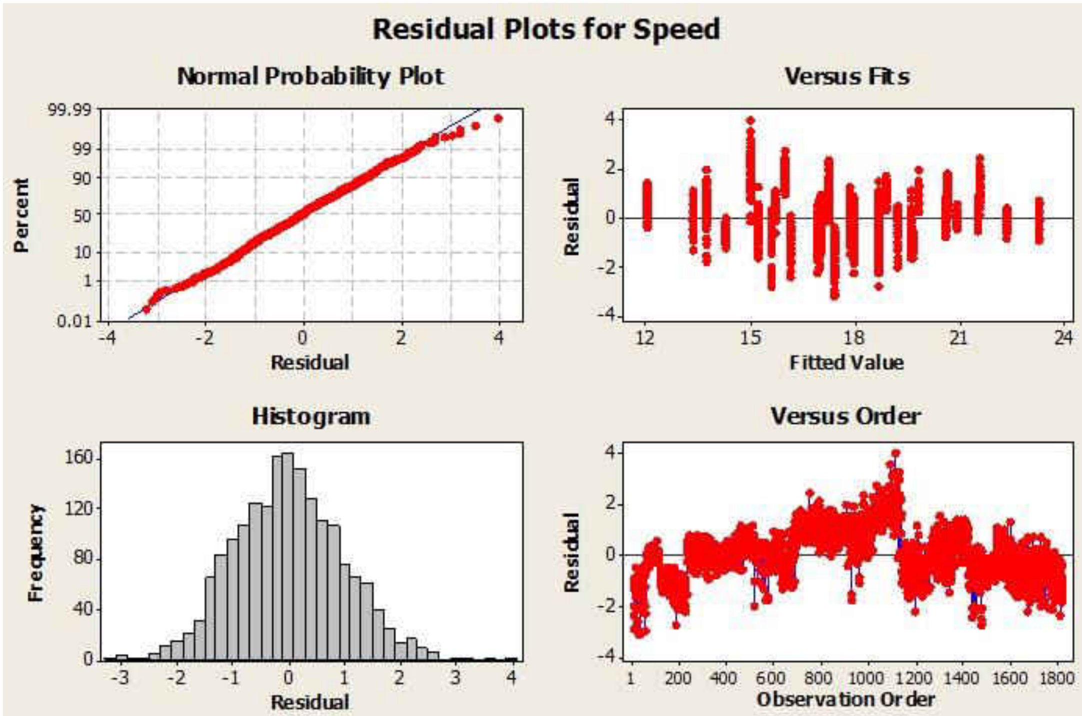


Figure 110: Minitab Output – Residual Plots for Model 3 (Speed)

The generalized regression model developed for <u>speed</u> based on the data of the before (No TSP - No BRT), Unconditional TSP, Conditional TSP 3 Min, and Conditional TSP 5 Min BRT No TSP, Unconditional TSP, Conditional TSP 3 Min, and Conditional TSP 5 Min scenarios listed below:

Speed = 13.7077 + 3.5368 Unconditional + 2.2539 Conditional_3min
+ 1.3027 Conditional_5min + 3.1993 BRT_NO_TSP
+ 5.9038 BRT_TSP_Uncond + 4.9491 BRT_TSP_Cond_3min
+ 4.1224 BRT_TSP_Cond_5min + 3.6742 All - 1.6733 WB

The coefficient of determination (**R^2**) as a measure of goodness of fit listed in the output table was (88.57 %) which implies that about 89% of the sample variation explained by the model.

To determine how useful each predictor variable in the model equation, we test the hypothesis (H_0: $\boldsymbol{\beta_i} = 0$, H_1: $\boldsymbol{\beta_i} \neq 0$). **P-value** associated with the F-value (and t-value) for all terms in the table were

(P-value < 0.05) which indicate that each variable found to be significant (reject the null hypothesis H_0 and accept the alternative hypothesis H_1) and should be included in the model.

Residual plots in Figure 110 (top left and bottom left) show that there are no extreme values (no unusual patterns appearing in the plots) and the residuals appear to follow normal distribution (data points clustered around the fitted “blue” line). Also, in the same Figure 110 (top right and bottom right) show that approximately half of the points are above and the other half are below the zero line (with a clear cyclic pattern) indicating that the assumption of error terms having mean zero is valid.

7.5.4 Number of Stops

The following table shows the analysis of variance, model summary, and regression equation that was developed in Minitab. Results are discussed following Table 32 and Figure 111.

Table 32: Minitab Output - Regression Analysis for Model 3 (Number of Stops)

```
-   Analysis of Variance
-   Source                DF   Adj SS   Adj MS  F-Value  P-Value
-   Regression             9  374.239   41.582   873.52    0.000
-     Unconditional        1  139.199  139.199  2924.17    0.000
-     Conditional-3min     1   15.200   15.200   319.32    0.000
-     Conditional-5min     1    2.401    2.401    50.45    0.000
-     BRT_NO-TSP           1    4.434    4.434    93.14    0.000
-     BRT_TSP-Uncond       1  202.751  202.751  4259.21    0.000
-     BRT_TSP-Con-3min     1   56.230   56.230  1181.23    0.000
-     BRT_TSP-Con-5min     1    9.878    9.878   207.50    0.000
-     All                  1    2.704    2.704    56.81    0.000
-     WB                   1    0.485    0.485    10.19    0.001
-   Error               1814   86.352    0.048
-     Lack-of-Fit         22   28.768    1.308    40.69    0.000
-     Pure Error        1792   57.584    0.032
-   Total               1823  460.591
-
-   Model Summary
-          S    R-sq  R-sq(adj)  R-sq(pred)
-   0.218181  81.25%     81.16%      81.04%
-
-   Coefficients
-   Term                 Coef  SE Coef  T-Value  P-Value   VIF
-   Constant           3.5497   0.0162   219.73    0.000
-   Unconditional     -1.1050   0.0204   -54.08    0.000  1.75
-   Conditional-3min  -0.3652   0.0204   -17.87    0.000  1.75
-   Conditional-5min  -0.1451   0.0204    -7.10    0.000  1.75
-   BRT_NO-TSP        -0.1972   0.0204    -9.65    0.000  1.75
-   BRT_TSP-Uncond    -1.3336   0.0204   -65.26    0.000  1.75
-   BRT_TSP-Con-3min  -0.7023   0.0204   -34.37    0.000  1.75
-   BRT_TSP-Con-5min  -0.2944   0.0204   -14.40    0.000  1.75
-   All                0.0770   0.0102     7.54    0.000  1.00
-   WB                 0.0326   0.0102     3.19    0.001  1.00
-
-   Regression Equation
-   No.Stops = 3.5497 - 1.1050 Unconditional - 0.3652 Conditional-3min
               - 0.1451 Conditional-5min - 0.1972 BRT_NO-TSP
               - 1.3336 BRT_TSP-Uncond - 0.7023 BRT_TSP-Con-3min
               - 0.2944 BRT_TSP-Con-5min + 0.0770 All + 0.0326 WB
```

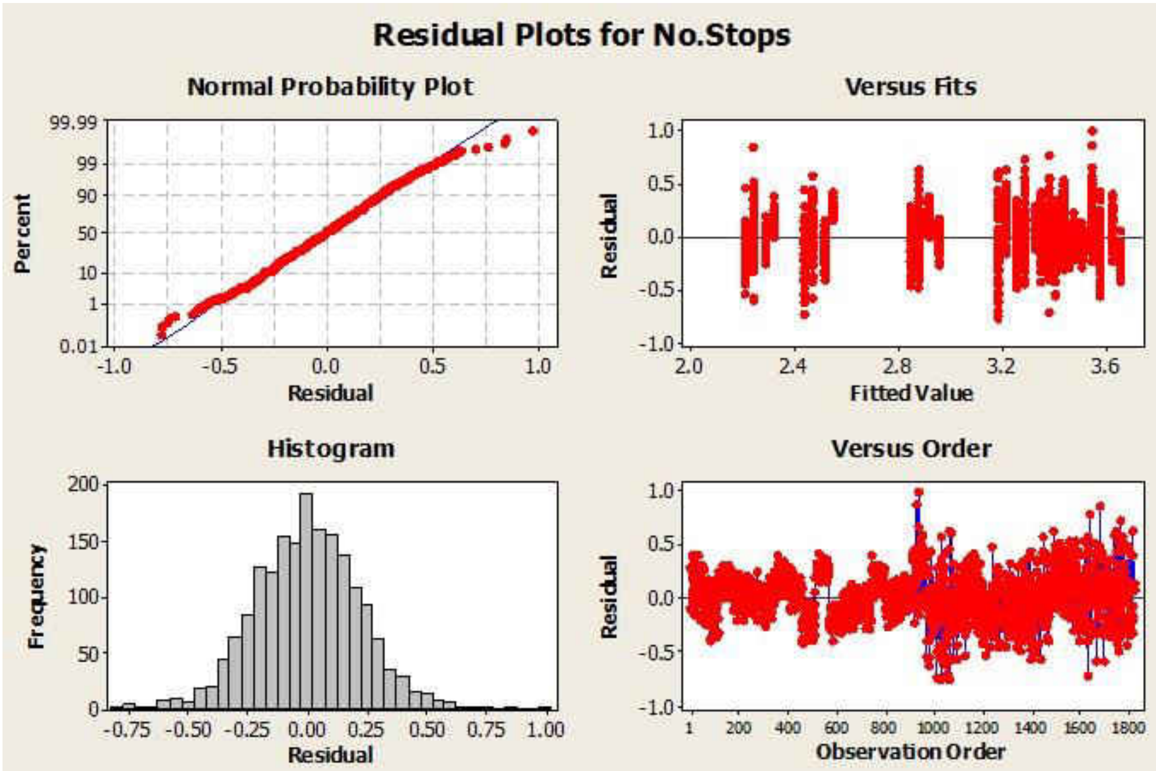


Figure 111: Minitab Output – Residual Plots for Model 3 (Number of Stops)

The generalized regression model developed for number of stops based on the data of the before (No TSP - No BRT), Unconditional TSP, Conditional TSP 3 Min, and Conditional TSP 5, BRT No TSP, BRT Unconditional TSP, BRT Conditional TSP 3 Min, and BRT Conditional TSP 5 Min scenarios listed below:

No.Stops = 3.5497 - 1.1050 Unconditional - 0.3652 Conditional-3min
- 0.1451 Conditional-5min - 0.1972 BRT_NO-TSP
- 1.3336 BRT_TSP-Uncond - 0.7023 BRT_TSP-Con-3min
- 0.2944 BRT_TSP-Con-5min + 0.0770 All + 0.0326 WB

The coefficient of determination (**R^2**) as a measure of goodness of fit listed in the output table was (81.25%) which implies that about 81% of the sample variation explained by the model.

To determine how useful each predictor variable in the model equation, we test the hypothesis (H_0: $\boldsymbol{\beta_i} = 0$, H_1: $\boldsymbol{\beta_i} \neq 0$). **P-value** associated with the F-value (and t-value) for all terms in the table were (P-value < 0.05) which indicate that each variable found to be significant (reject the null hypothesis H_0 and accept the alternative hypothesis H_1) and should be included in the model.

Residual plots in Figure 111 (top left and bottom left) show that there are no extreme values (no unusual patterns appearing in the plots) and the residuals appear to follow normal distribution (data points clustered around the fitted "blue" line). Also, in the same Figure 111 (top right and bottom right) show that approximately half of the points are above and the other half are below the zero line (with a clear cyclic pattern) indicating that the assumption of error terms having mean zero is valid.

7.6 Discussion and Summary

Regression models were developed for the four major MOEs obtained from the VISSIM model analysis (travel times, speed, delays, and number of stops). These categories were sub-divided into more specific groups by direction (eastbound and westbound), and vehicle classification (all vehicles and buses only). The most powerful models for each MOE (y) were in the third criteria (**MODEL 3**). The coefficient of determination (**R^2**) shows the amount of variability explained by the model (goodness of fit) for each model and is listed in the output tables shown in Table 33. These R^2 values were 83.97% for travel time, 94.49% for delay, 88.57% for speed, and 81.25% for number of stops, which indicate that all four MOE models fit the data well.

Tables 33 - 36 and Figures 112 - 115 show the model summary, regression equation, and residual plots for each studied MOE. To determine how useful each predictor variable is in the model equation, the following hypotheses are tested using an F-test.

$$H_0: \boldsymbol{\beta_i} = 0$$

$$H_1: \boldsymbol{\beta_i} \neq 0$$

All terms had p-value < 0.05, which indicates that each variable is significant (reject the null hypothesis H_0 and accept the alternative hypothesis H_1) and should be included in the model. The normal probability plots and histograms shown in Figure 112 (top left and bottom left graphs) show that there are no extreme values and the residuals appear to follow a normal distribution (data points clustered around the fitted "blue" line). Also, the two right plots show that the residuals are randomly distributed and have no pattern, indicating that the assumptions of the error terms having a zero mean and constant variance are valid.

Table 33: Minitab Output Regression Analysis - Travel Time

```
Model Summary
      S    R-sq  R-sq(adj)  R-sq(pred)
22.9235  83.97%     83.89%      83.79%

Coefficients
Term                 Coef  SE Coef  T-Value  P-Value
Constant           447.08     1.70   263.40    0.000
Unconditional      -80.36     2.15   -37.43    0.000
Conditional-3min   -54.07     2.15   -25.19    0.000
Conditional-5min   -36.57     2.15   -17.03    0.000
BRT_NO-TSP         -67.47     2.15   -31.42    0.000
BRT_TSP-Uncond    -109.00     2.15   -50.77    0.000
BRT_TSP-Con-3min   -89.23     2.15   -41.56    0.000
BRT_TSP-Con-5min   -81.20     2.15   -37.82    0.000
All                -77.12     1.07   -71.84    0.000
WB                  30.22     1.07    28.15    0.000

Regression Equation:
Travel Time = 447.08 - 80.36 Unconditional - 54.07 Conditional-3min
                 - 36.57 Conditional-5min - 67.47 BRT_NO-TSP
                 - 109.00 BRT_TSP-Uncond - 89.23 BRT_TSP-Con-3min
                 - 81.20 BRT_TSP-Con-5min - 77.12 All + 30.22 WB
```

Table 34: Minitab Output Regression Analysis - Delay

```
Model Summary
      S    R-sq  R-sq(adj)  R-sq(pred)
8.57798  94.49%     94.46%      94.42%

Coefficients
Term                 Coef  SE Coef  T-Value  P-Value
Constant          178.306    0.635   280.73    0.000
Unconditional     -87.154    0.803  -108.48    0.000
Conditional-3min  -22.642    0.803   -28.18    0.000
Conditional-5min  -10.880    0.803   -13.54    0.000
BRT_NO-TSP         -7.824    0.803    -9.74    0.000
BRT_TSP-Uncond    -96.212    0.803  -119.76    0.000
BRT_TSP-Con-3min  -35.072    0.803   -43.65    0.000
BRT_TSP-Con-5min  -20.375    0.803   -25.36    0.000
All               -17.580    0.402   -43.76    0.000
WB                  4.110    0.402    10.23    0.000

Regression Equation
Delay = 178.306 - 87.154 Unconditional - 22.642 Conditional-3min
          - 10.880 Conditional-5min - 7.824 BRT_NO-TSP - 96.212 BRT_TSP-Uncond
          - 35.072 BRT_TSP-Con-3min - 20.375 BRT_TSP-Con-5min - 17.580 All
          + 4.110 WB
```

Table 35: Minitab Output Regression Analysis - Speed

```
Model Summary
       S    R-sq  R-sq(adj)  R-sq(pred)
0.975389  88.57%     88.51%      88.44%

Coefficients
Term                 Coef  SE Coef  T-Value  P-Value
Constant          13.7077   0.0722   189.80    0.000
Unconditional      3.5368   0.0914    38.72    0.000
Conditional-3min   2.2539   0.0914    24.67    0.000
Conditional-5min   1.3027   0.0914    14.26    0.000
BRT_NO-TSP         3.1993   0.0914    35.02    0.000
BRT_TSP-Uncond     5.9038   0.0914    64.63    0.000
BRT_TSP-Con-3min   4.9491   0.0914    54.18    0.000
BRT_TSP-Con-5min   4.1224   0.0914    45.13    0.000
All                3.6742   0.0457    80.44    0.000
WB                -1.6733   0.0457   -36.63    0.000

Regression Equation
Speed = 13.7077 + 3.5368 Unconditional + 2.2539 Conditional-3min
          + 1.3027 Conditional-5min + 3.1993 BRT_NO-TSP + 5.9038 BRT_TSP-Uncond
          + 4.9491 BRT_TSP-Con-3min + 4.1224 BRT_TSP-Con-5min + 3.6742 All
          - 1.6733 WB
```

Table 36: Minitab Output Regression Analysis - Number of Stops

```
Model Summary
       S    R-sq  R-sq(adj)  R-sq(pred)
0.218181  81.25%     81.16%      81.04%

Coefficients
Term                 Coef  SE Coef  T-Value  P-Value
Constant           3.5497   0.0162   219.73    0.000
Unconditional     -1.1050   0.0204   -54.08    0.000
Conditional-3min  -0.3652   0.0204   -17.87    0.000
Conditional-5min  -0.1451   0.0204    -7.10    0.000
BRT_NO-TSP        -0.1972   0.0204    -9.65    0.000
BRT_TSP-Uncond    -1.3336   0.0204   -65.26    0.000
BRT_TSP-Con-3min  -0.7023   0.0204   -34.37    0.000
BRT_TSP-Con-5min  -0.2944   0.0204   -14.40    0.000
All                0.0770   0.0102     7.54    0.000
WB                 0.0326   0.0102     3.19    0.001

Regression Equation
No.Stops = 3.5497 - 1.1050 Unconditional - 0.3652 Conditional-3min
             - 0.1451 Conditional-5min - 0.1972 BRT_NO-TSP
             - 1.3336 BRT_TSP-Uncond - 0.7023 BRT_TSP-Con-3min
             - 0.2944 BRT_TSP-Con-5min + 0.0770 All + 0.0326 WB
```

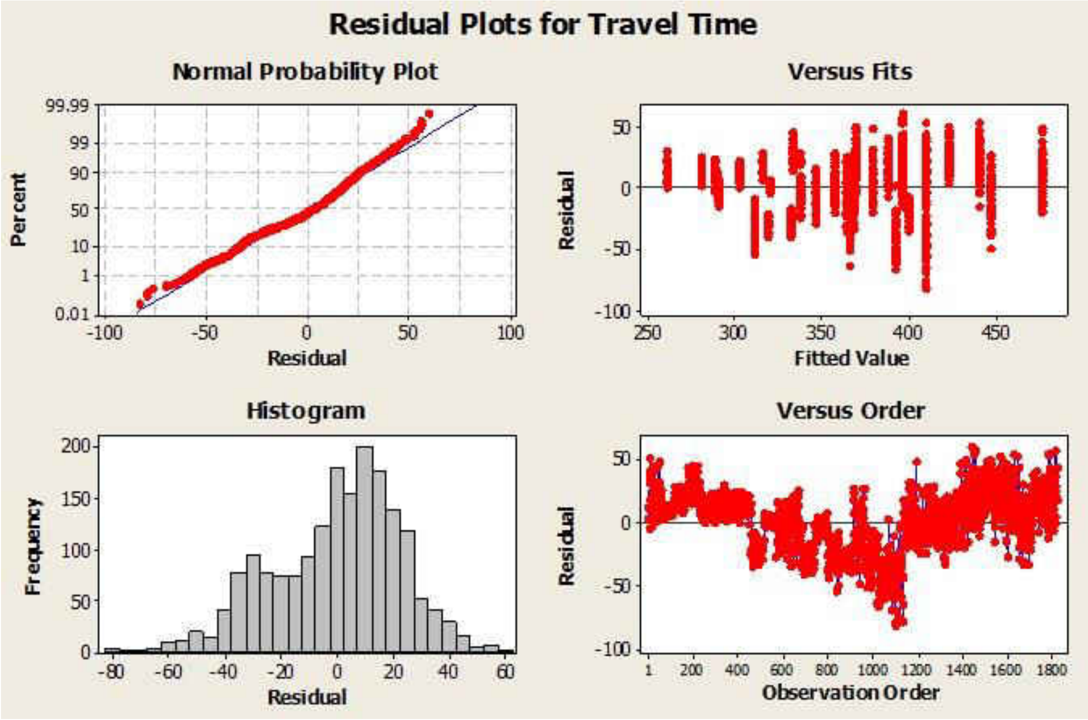


Figure 112: Minitab Output Residual Plots – Travel Time

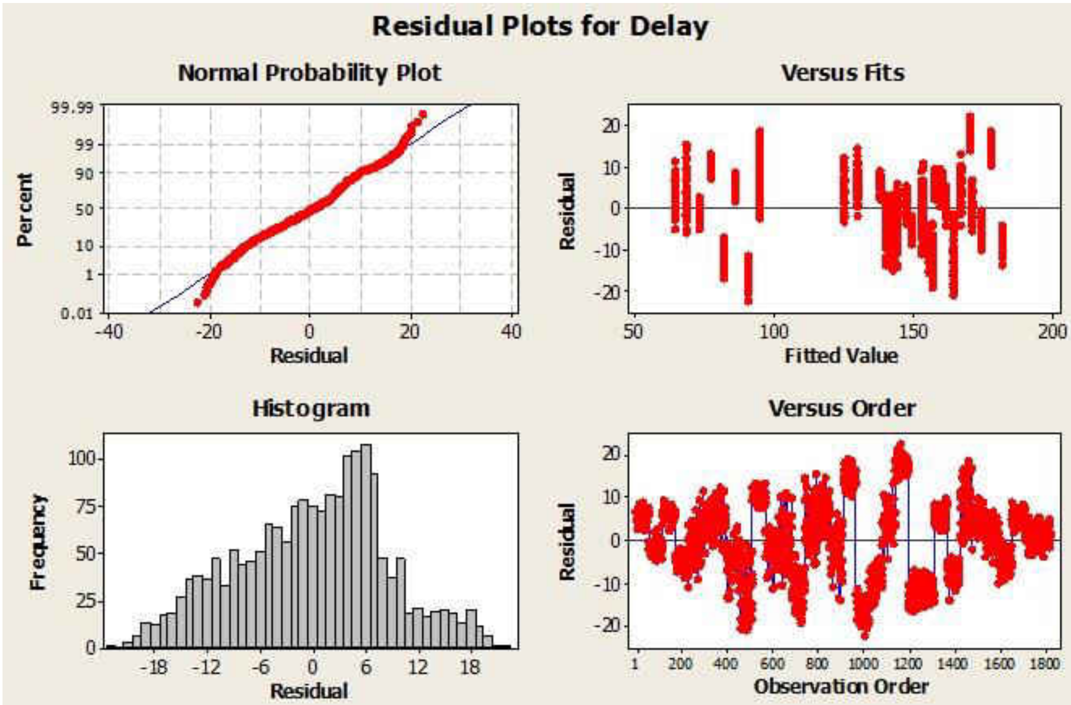


Figure 113: Minitab Output Residual Plots – Delay

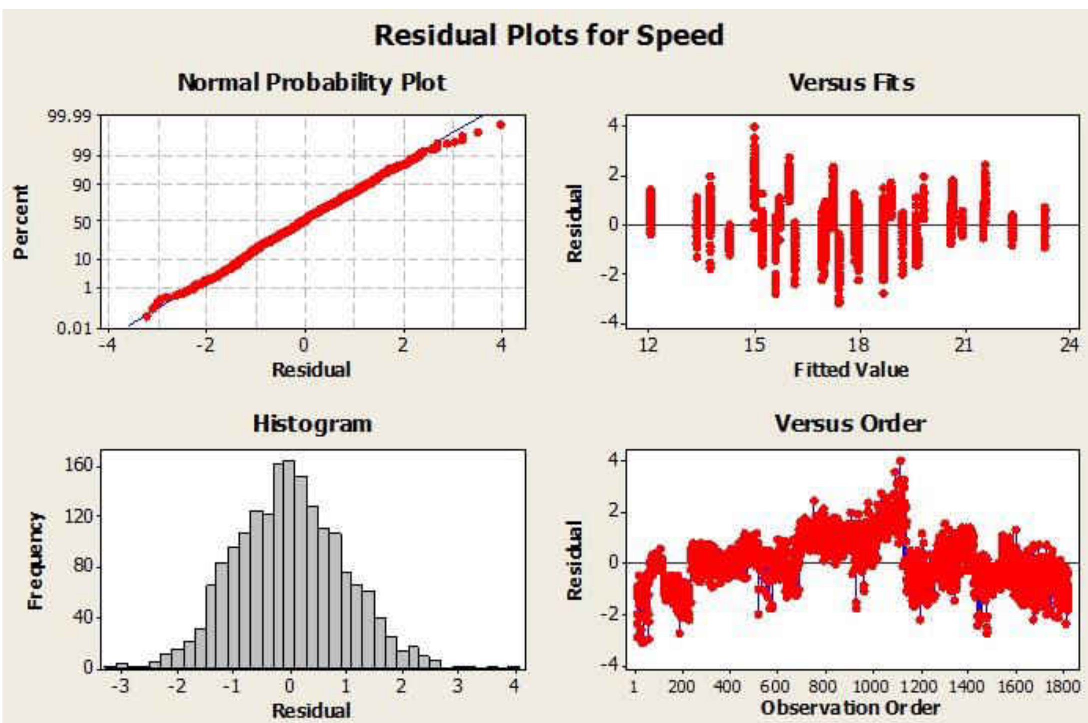


Figure 114: Minitab Output Residual Plots – Speed

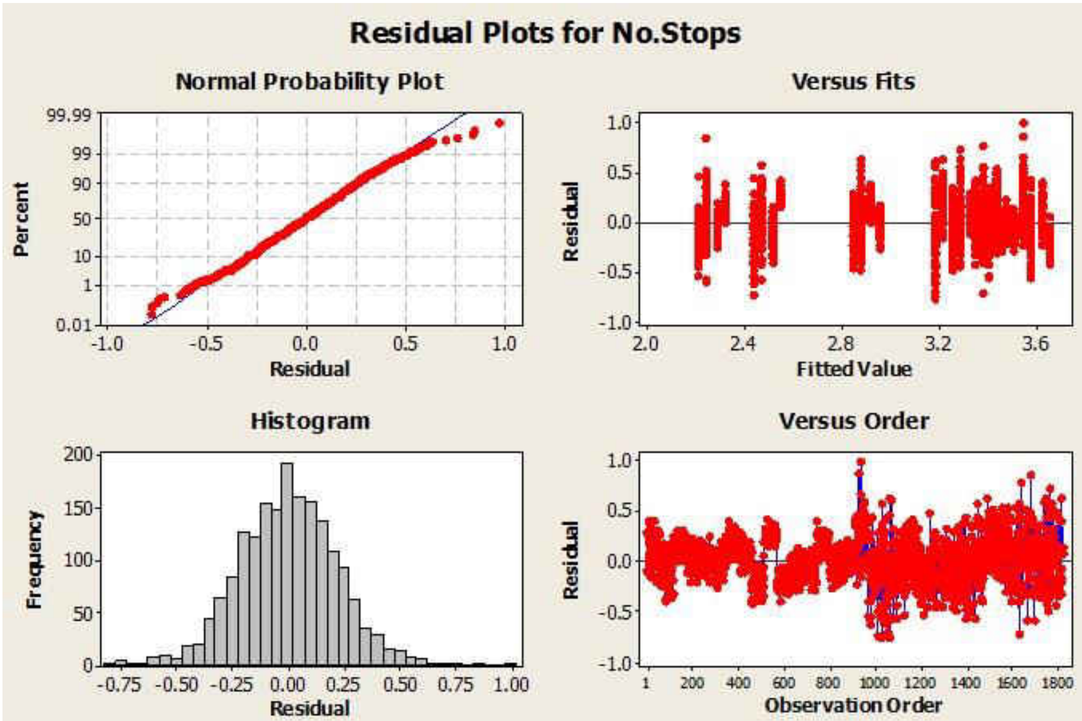


Figure 115: Minitab Output Residual Plots - Number of Stops

The generalized regression models (**MODEL 3**) developed for Travel Time, Delay, Speed, and Number of Stops based on the data of all simulated scenarios are listed below:

**** Travel Time = 447.08 - 80.36 [Unconditional] - 54.07 [Conditional_3min]**

- 36.57 [Conditional_5min] - 67.47 [BRT_NO_TSP]

- 109.00 [BRT_TSP_Uncond] - 89.23 [BRT_TSP_Cond_3min]

- 81.20 [BRT_TSP_Con_5min] - 77.12 [All] + 30.22 [WB]

**** Delay = 178.306 - 87.154 [Unconditional] - 22.642 [Conditional_3min]**

- 10.880 [Conditional_5min] - 7.824 [BRT_NO_TSP]

- 96.212 [BRT_TSP_Uncond] - 35.072 [BRT_TSP_Cond_3min]

- 20.375 [BRT_TSP_Cond_5min] - 17.580 [All] + 4.11 [WB]

**** Speed = 13.7077 + 3.5368 [Unconditional] + 2.2539 [Conditional_3min]**

+ 1.3027 [Conditional_5min] + 3.1993 [BRT_NO_TSP]

+ 5.9038 [BRT_TSP_Uncond] + 4.9491 [BRT_TSP_Cond_3min]

+ 4.1224 [BRT_TSP_Cond_5min] + 3.6742 [All] - 1.6733 [WB]

**** No of Stops = 3.5497 - 1.1050 [Unconditional] - 0.3652 [Conditional-3min]**

- 0.1451 [Conditional-5min] - 0.1972 [BRT_NO-TSP]

- 1.3336 [BRT_TSP-Uncond] - 0.7023 [BRT_TSP-Cond-3min]

- 0.2944 [BRT_TSP-Codn-5min] + 0.0770 [All] + 0.0326 [WB]

To show how the different scenarios can be modeled, the Travel Time model will be used as an example (this same discussion can be stated about the other three models). Estimated travel times for any of the tested scenarios can be computed by changing the values of the appropriate indicators. If all indicators are set to 0, then the model gives the travel time for the base model (No TSP - No BRT), eastbound direction, and buses only.

Travel Time = 447.08 seconds
(*All indicators set to 0*)

To calculate the travel time for *No TSP - No BRT* for *all vehicles* in the *eastbound direction*, all indicators should be set to 0, except for All = 1. Then, the term (- 77.12) will be added to the fitted equation and the estimated travel time is:

Travel Time = 447.08 – 77.12 [All] = 369.96 seconds
(*All = 1, all other indicators = 0*)

To calculate the travel time for *all vehicles* (*westbound direction*) for *BRT Conditional TSP 5-Min* scenario, all indicators should be set to 0 except for (BRT_TSP_Cond_5min = 1, All = 1, and WB

= 1). Then, the terms (- 81.20, - 77.12, and + 30.22) will be added to the fitted equation and the estimated travel time is:

Travel Time = 447.08 - 81.20 [BRT_TSP_Cond_5min] - 77.12 [All] + 30.22 [WB]
= 318.98 seconds
(*BRT_TSP_Cond_5min = 1, All = 1, WB = 1, all other indicators = 0*)

The performance of each scenario compared to the base scenario is indicated by the values of the respective indicators. The positive and negative signs for each term inside the model and the value of their coefficients indicate the relationship between each term and the studied MOE. For example, in travel time model, the *Conditional TSP 3 Minutes behind* coefficient (-54.07) has a negative sign, indicating that this scenario reduces the travel time compared to the base scenario by 54.07 seconds. With these regression models, the performance of each scenario for each direction and vehicle type can be predicted for each studied MOE.

The studied corridor has only one set of intersections. The model, therefore, has limited applicability. The intention in this research is to show how a linear regression can be developed. Further research can be performed to extend the model if more multiple data points are available. Since the developed models were based on real world data, they can provide accurate estimates of BRT and TSP performance. These models can also be used for further sensitivity analysis on a larger network concerning the upcoming regional expansion of TSP and BRT in Central Florida. Accurately evaluating BRT with and without TSP is important in order for these systems to be an effective part of the regional multimodal public transportation network. Finally, since this research demonstrated the operational functionality and effectiveness of BRT and TSP systems in this critical corridor in Central Florida, these systems' accomplishments can be expanded throughout the state of Florida to provide greater benefits to transit passengers.

CHAPTER 8 INTERSECTION ANALYSIS

8.1 Introduction

Although the main purpose is to study the corridor at network level, the effects of BRT have to be investigated along I-Drive corridor before and after at the intersection level and their results will guide the analysis and give more to the big picture as a whole. This chapter introduces Level of Service (LOS) analysis before and after BRT conditions. The intersections modeled based on real life data for the before and after TSP and BRT to determine their LOS.

FHWA (Traffic Analysis Toolbox-Volume VI) mentioned in their tools evaluation for traffic analysis MOEs (these tools include HCS, Synchro, SimTraffic, CORSIM, VISSIM, Q-Paramics, and Aimsun) that "HCS reports HCM level of service letter grades. The other tools report MOEs that users may be tempted to convert into HCM LOS grades" (Dowling R., 2007). Also, they said that "all micro-simulation tools (such as VISSIM) tally approach delay for the links approaching the intersection. Also, HCM control delay excludes vehicles not going through the intersection that become entangled in the queue for the intersection" (Dowling R., 2007).

Based on the above, the intersections LOS will be evaluated using the Highway Capacity Software™ (HCS2010) that was built based on the Highway Capacity Manual (HCM 2010) procedures for urban streets and signalized intersections. This analysis will compare the before scenario and the after BRT scenario (which was completed by the end of 2014). Each intersection analyzed for its LOS for the before and after BRT conditions. The intersections modeled based on real life data for the before and after BRT to determine their LOS.

Table 37 shows the LOS (thresholds) criteria established for automobiles at signalized intersections (HCM, 2010). Level of service ranges from grade “A” with less than or equal 10 seconds/vehicle up to grade “F” with more than 80 seconds/vehicle. LOS “D” is the upper desired boundary for most drivers.

Table 37: Level of Service (LOS) Criteria at Signalized Intersection (HCM 2010)

Control Delay (Second/Vehicle)	LOS by Volume to Capacity Ratio	
	≤ 1.0	> 1.0
≤ 10	A	F
> 10 – 20	B	F
> 20 – 35	C	F
> 35 – 55	D	F
> 55 – 80	E	F
> 80	F	F

8.2 Data Collection after BRT

As previously discussed, the selected test corridor contains the six following major signalized intersections (see I-Drive corridor in Figure 17 and the detailed aerial photos for each intersection in Figures 18 - 23):

- Universal Boulevard (T1),
- Kirkman Road (T2),
- Grand National Drive (T3),
- Municipal Drive (T4),
- Del Verde Way (T5), and
- Fun Spot Way (T6).

The most important collected and used field data for this type of analysis are geometric data, control data, and traffic data. These data were collected before and after the implementation of TSP and BRT systems. The before data were explained in details back in Chapter 4. Table 38 shows the main geometric data collected from the field for each intersection on the corridor after BRT construction. Additional detailed geometric, signing, and pavement marking plans after completion of the BRT lanes are shown in **Appendix C**.

Table 38: Intersections Characteristics after the BRT Construction

Intersection	Control Type	Number of lanes				Lane Width (ft)				Number of Approaches
		EB	WB	NB	SB	EB	WB	NB	SB	
T1	Traffic Signal	4	5	3	6	11	11	11	11	4
T2		5	6	5	6	11	11	11	11	4
T3		5	4	2	3	11	11	11	11	4
T4		4	4	2	2	11	11	11	11	4
T5		2	-	4	4	11	-	10	10	3
T6		2	3	4	5	11	11	10	10	4

Manual traffic counts (MTC) after completion of the BRT were also conducted to obtain entering traffic volumes, turning movements, and vehicle classifications at the intersection locations shown in Figure 29 back in Chapter 4. These data were captured using digital camera recorders (Figure 31 in Chapter 4) during the peak PM periods on working days in spring 2015. From the MTC, the peak hour factor (PHF) was calculated for each intersection (Equations 1 and 2 in Chapter 4).

Tables 39 through 45 show the peak hour volume in vehicles/hour (VPH), peak hour factor, and heavy vehicle (HV) and bus percentages for each intersection on the corridor. Also, Figures 112 through 117 show the traffic volumes for the corridor intersections during the PM peak hour.

Table 39: Peak Hour Volume Calculation Results for Intersection T1 after BRT

Peak Hour Volume (VPH)		EB			WB			NB			SB		
		584			1062			863			800		
17:00 - 18:00	TOTAL	175	347	62	169	549	344	98	606	159	217	375	208
Total	PHF	0.74	0.92	0.86	0.77	0.83	0.83	0.68	0.89	0.92	0.82	0.74	0.80
3309	HV & BUS %	3%	4%	2%	5%	3%	3%	1%	3%	6%	6%	6%	3%

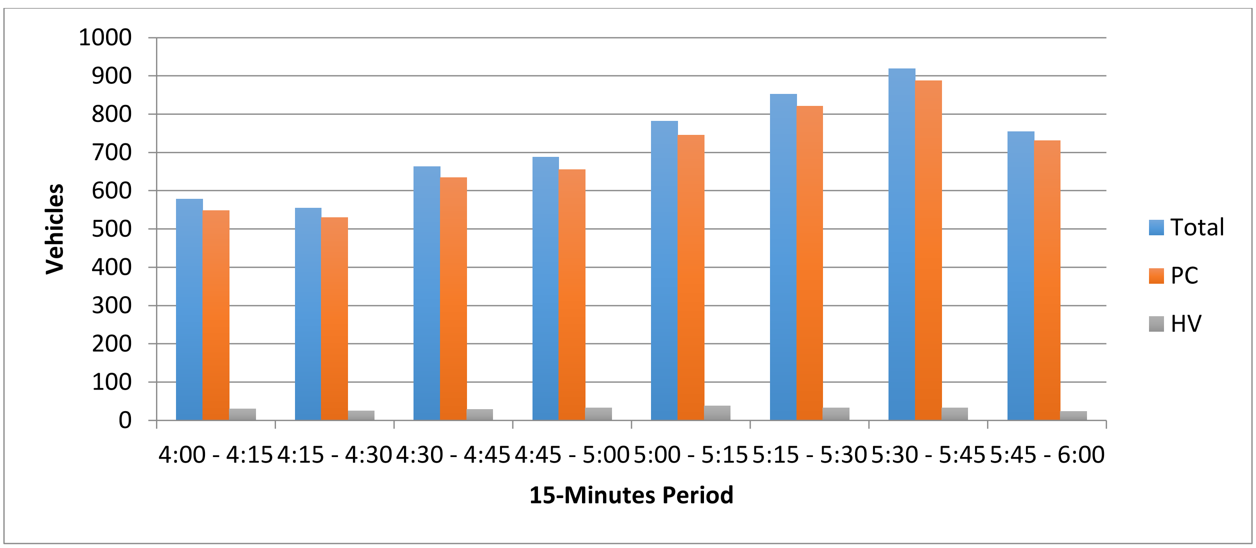


Figure 112: 15-Minutes Period Turning Movements on Intersection T1 after BRT

Table 40: Peak Hour Volume Calculation Results for Intersection T2 after BRT

Peak Hour Volume (VPH)		EB			WB			NB			SB		
		721			1451			2024			1275		
16:45 - 17:45	TOTAL	148	483	90	236	451	764	75	1764	185	403	671	201
Total	PHF	0.86	0.91	0.78	0.97	0.85	0.88	0.72	0.86	0.91	0.93	0.93	0.87
5471	HV & BUS %	4%	3%	8%	0%	4%	1%	1%	1%	3%	3%	3%	12%

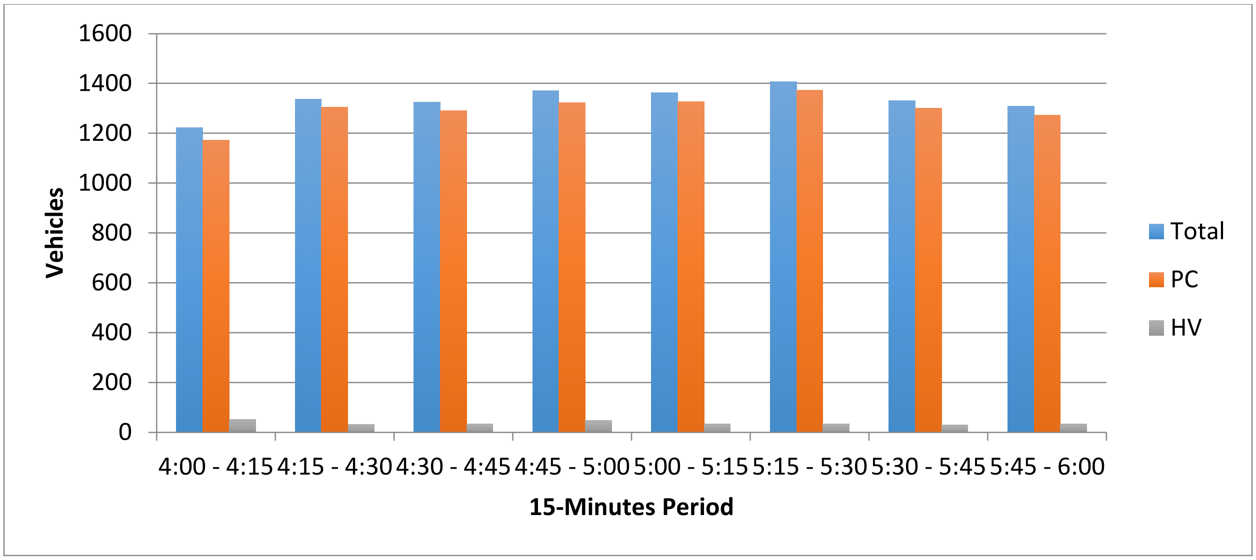


Figure 113: 15-Minutes Period Turning Movements on Intersection T2 after BRT

Table 41: Peak Hour Volume Calculation Results for Intersection T3 after BRT

Peak Hour Volume (VPH)		EB			WB			NB			SB		
		1002			816			399			551		
17:00 - 18:00	TOTAL	216	735	51	22	768	26	192	167	40	24	96	431
Total 2768	PHF	0.89	0.90	0.91	0.61	0.97	0.65	0.77	0.75	0.71	0.75	0.83	0.84
	HV & BUS %	0%	2%	0%	0%	2%	0%	0%	2%	3%	4%	2%	0%

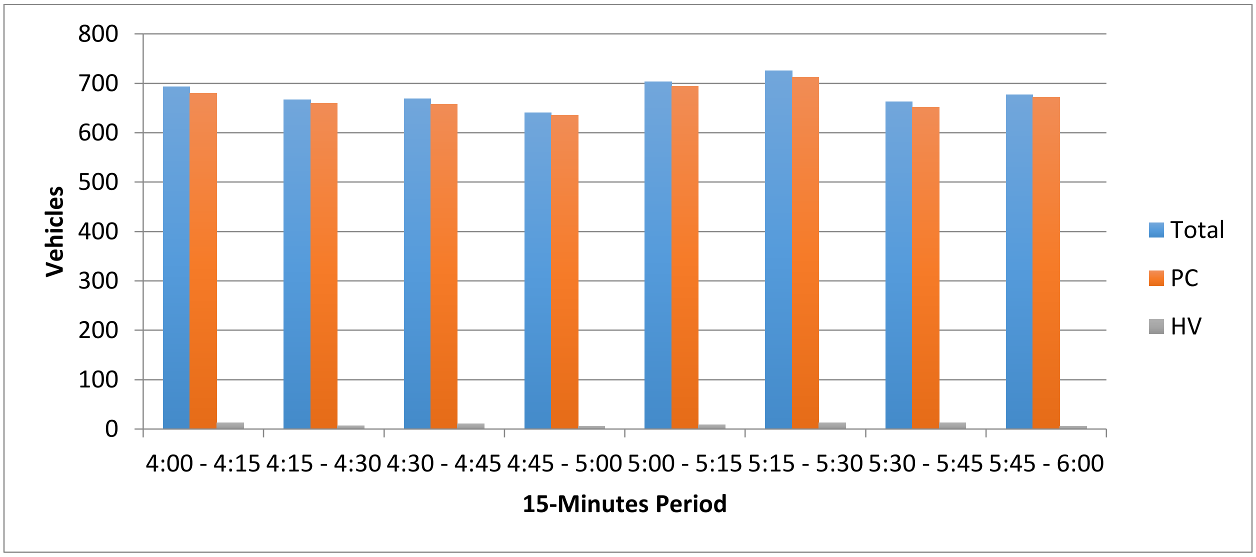


Figure 114: 15-Minutes Period Turning Movements on Intersection T3 after BRT

Table 42: Peak Hour Volume Calculation Results for Intersection T4 after BRT

Peak Hour Volume (VPH)		EB			WB			NB			SB		
		772			818			337			0		
16:30 - 17:30	TOTAL	13	673	86	125	691	2	108	10	219	0	0	0
Total 1936	PHF	0.54	0.93	0.72	0.87	0.89	0.25	0.82	0.83	0.90	0.00	0.00	0.00
	HV & BUS %	8%	2%	3%	1%	2%	0%	4%	0%	0%	0%	0%	0%

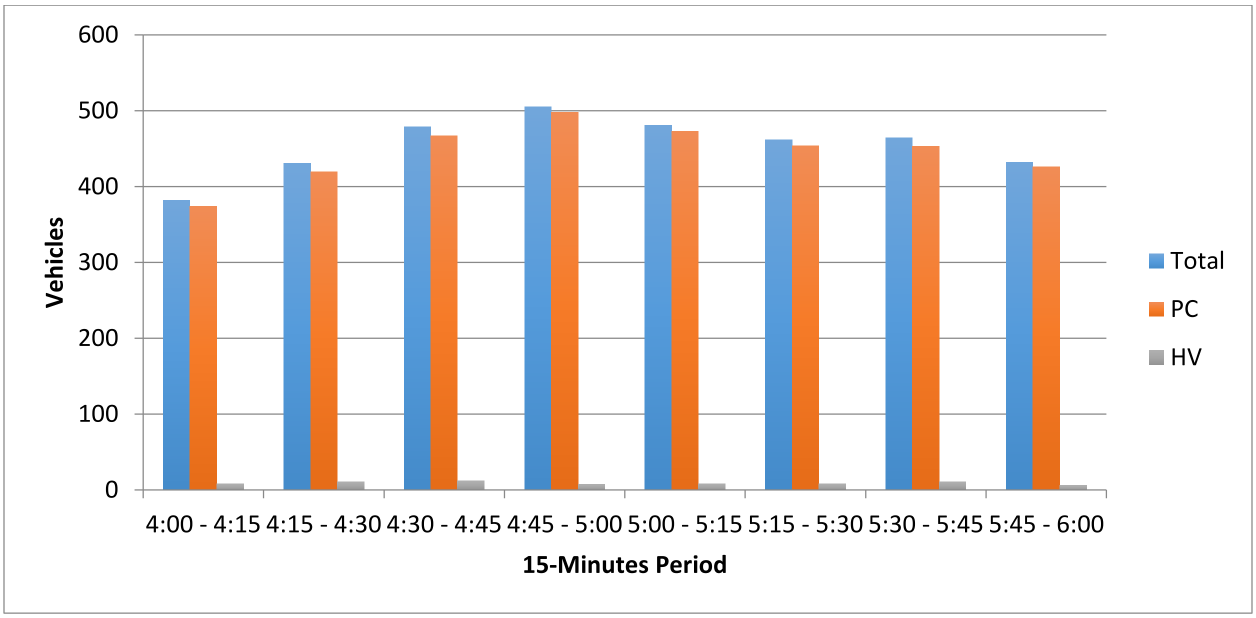


Figure 115: 15-Minutes Period Turning Movements on Intersection T4 after BRT

Table 43: Peak Hour Volume Calculation Results for Intersection T5 after BRT

Peak Hour Volume (VPH)		EB			WB			NB			SB		
		25			0			940			794		
16:15 - 17:15	TOTAL	16	0	8	0	0	0	36	904	0	0	775	9
Total 1759	PHF	0.50	0.00	0.50	0.00	0.00	0.00	0.75	0.95	0.00	0.00	0.86	0.45
	HV & BUS %	0%	0%	0%	0%	0%	0%	3%	1%	0%	0%	2%	44%

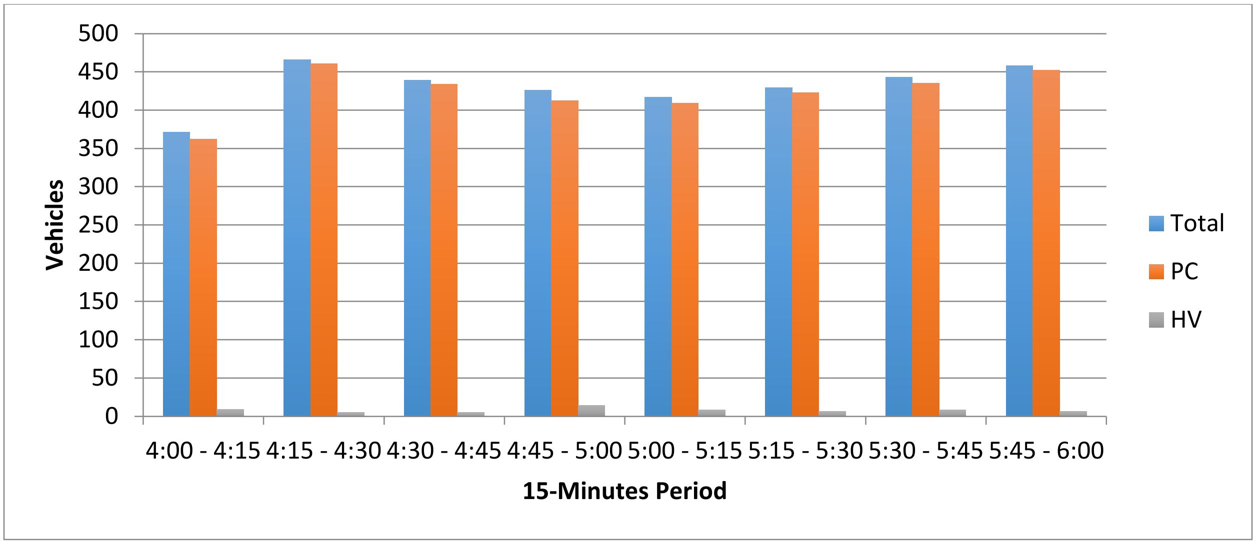


Figure 116: 15-Minutes Period Turning Movements on Intersection T5 after BRT

Table 44: Peak Hour Volume Calculation Results for Intersection T6 after BRT

Peak Hour Volume (VPH)		EB			WB			NB			SB		
		106			20			958			709		
16:45 - 17:45	TOTAL	40	5	61	14	3	3	99	807	52	11	661	37
Total 1793	PHF	0.59	0.63	0.90	0.88	0.38	0.38	0.85	0.96	0.81	0.69	0.90	0.84
	HV & BUS %	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	1%	0%

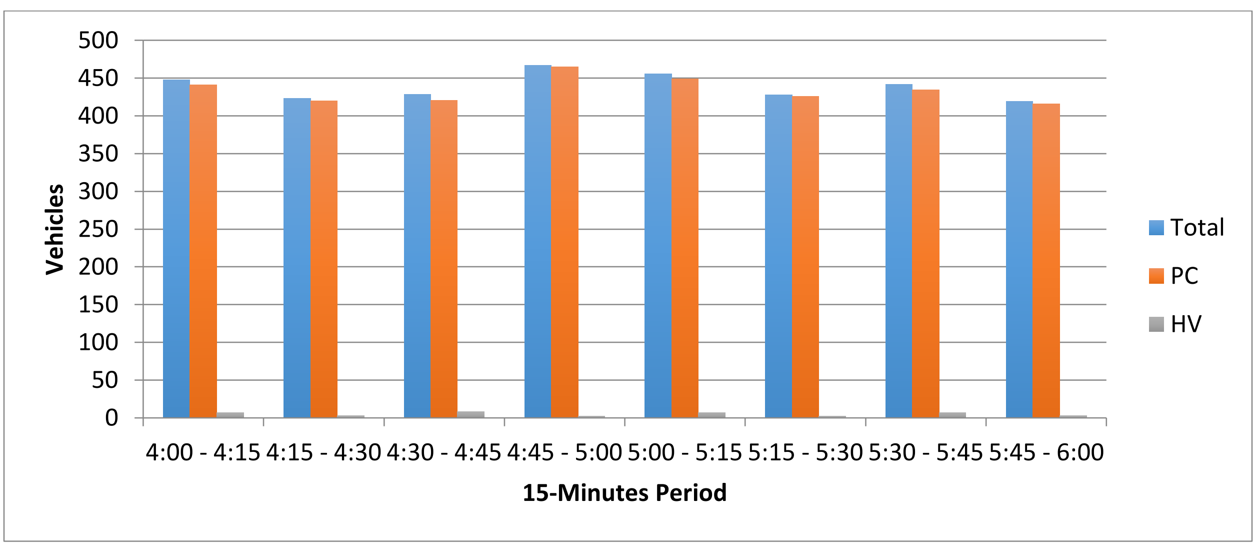


Figure 117: 15-Minutes Period Turning Movements on Intersection T6 after BRT

Figure 118 summarizes the peak hour volumes (in VPH) on the corridor. Kirkman Intersection (T2) had the highest peak hour volume with 5471 VPH and then the Universal Intersection (T1) with 3309 VPH. Detailed information on the turning movements corridor after the BRT construction is shown in **Appendix H**.

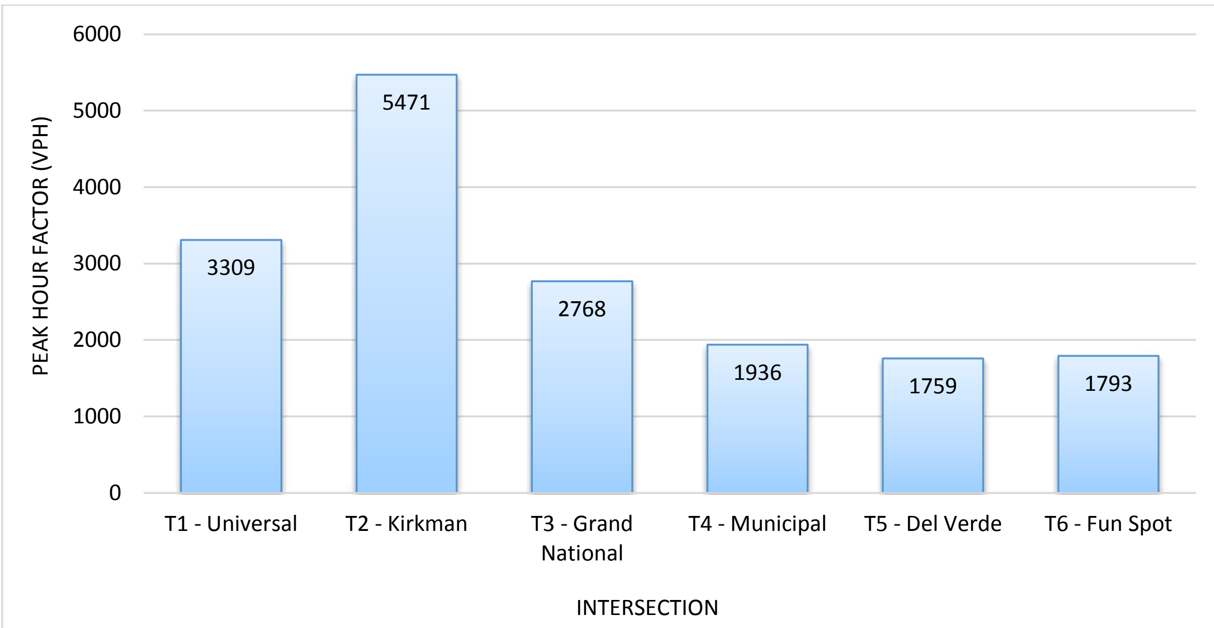


Figure 118: Summary of the Peak Hour Volume on the Corridor after BRT

8.3 HCS Analysis and Results

Intersection analysis evaluates the intersection area plus the extended backward distance from the stop line at the traffic light to an adequate amount of distance that can be affected by the formed queue during the study period (on each intersection leg). The study period should contain the peak hour for credible HCM and HCS2010 analysis (HCM, 2010).

There are three levels of analysis generally used for signalized intersection depending on the details that are needed for each study: operational, design, and planning. This chapter will follow the operational analysis which is the most detailed level that requires traffic characteristics, geometric design, and signal control data. Table 45 shows the required input data for the signalized intersection methodology in HCM 2010.

Table 45: Input Data Requirements for Signalized Intersections (HCM, 2010)

Data Category	*Input Data Element*	*Basis*
Traffic Characteristics	Demand flow rate	Movement
	Right-turn-on-red flow rate	Approach
	Percent heavy vehicles	Movement Group
	Intersection peak hour factor	Intersection
	Platoon ratio	Movement Group
	Upstream filtering adjustment factor	Movement Group
	Initial queue	Movement Group
	Base saturation flow rate	Movement Group
	Lane utilization adjustment factor	Movement Group
	Pedestrian flow rate	Approach
	Bicycle flow rate	Approach
	On-street parking maneuver rate	Movement Group
	Local bus stopping rate	Approach
Geometric Design	Number of lanes	Movement Group
	Average lane width	Movement Group
	Number of receiving lanes	Approach
	Turn bay length	Movement Group
	Presence of on-street parking	Movement Group
	Approach grade	Approach
Signal Control	Type of signal control	Intersection
	Phase sequence	Intersection
	Left-turn operational mode	Approach
	Passage time (if actuated)	Phase
	Maximum green (or green duration if pre-timed)	Phase
	Minimum green	Phase
	Yellow change	Phase
	Red clearance	Phase
	Walk	Phase
	Pedestrian clear	Phase
	Phase recall	Phase
	Simultaneous gap-out (if actuated)	Approach
Other	Analysis period duration	Intersection
	Speed limit	Approach
	Stop-line detector length and detection mode	Movement Group
	Area type	Intersection

As previously mentioned in Table 37, the performance measure used in this analysis is the level of service (LOS) criteria that was established for automobile at signalized intersections. LOS categories shown in Table 37 depend on the control delay values for each turning movement (lane groups), each approach, and finally for the entire intersection.

LOS is an "indication of the acceptability of delay levels to motorists at the intersection. Plus, it can indicate an unacceptable oversaturated operation for individual lane groups." (HCM, 2010). Using real observations before and after BRT implementation, HCS2010 was used to perform LOS at corridor intersections. Tables 46 to 51 below show the intersection's control delay (seconds per vehicle) and the level of service (LOS) analysis results.

Table 46: Intersection LOS Analysis Summary for (T1) - Universal Blvd

(T1) Universal Blvd		Eastbound (EB)	Westbound (WB)	Northbound (NB)	Southbound (SB)
Approach Control Delay (Sec/Veh) and LOS	Before	28.6 (C)	29.5 (C)	27.6 (C)	21.6 (C)
	After	25.1 (C)	26.0 (C)	26.8 (C)	19.6 (C)
Intersection Delay (Sec/Veh) and LOS	Before	26.7 (C)			
	After	25.1 (C)			

Table 47: Intersection LOS Analysis Summary for (T2) - Kirkman Road

(T2) Kirkman Road		Eastbound (EB)	Westbound (WB)	Northbound (NB)	Southbound (SB)
Approach Control Delay (Sec/Veh) and LOS	Before	75.6 (E)	63.7 (E)	52.7 (E)	43.1 (D)
	After	65.5 (E)	61.0 (E)	48.1 (E)	36.7 (D)
Intersection Delay (Sec/Veh) and LOS	Before	60.1 (E)			
	After	49.3 (E)			

Table 48: Intersection LOS Analysis Summary for (T3) - Grand National Drive

(T3) Grand National Drive		Eastbound (EB)	Westbound (WB)	Northbound (NB)	Southbound (SB)
Approach Control Delay (Sec/Veh) and LOS	Before	18.6 (B)	25.2 (C)	70.0 (E)	32.0 (C)
	After	17.8 (B)	20.4 (C)	52.8 (D)	27.0 (C)
Intersection Delay (Sec/Veh) and LOS	Before	33.2 (C)			
	After	27.1 (C)			

Table 49: Intersection LOS Analysis Summary for (T4) - Municipal Drive

(T4) Municipal Drive		Eastbound (EB)	Westbound (WB)	Northbound (NB)	Southbound (SB)
Approach Control Delay (Sec/Veh) and LOS	Before	13.9 (B)	11.6 (B)	18.6 (B)	-
	After	11.9 (B)	8.5 (A)	17.4 (B)	-
Intersection Delay (Sec/Veh) and LOS	Before	13.6 (B)			
	After	11.1 (B)			

Table 50: Intersection LOS Analysis Summary for (T5) - Del Verde Way

(T5) Del Verde Way		Eastbound (EB)	Westbound (WB)	Northbound (NB)	Southbound (SB)
Approach Control Delay (Sec/Veh) and LOS	Before	17.8 (B)	-	3.2 (A)	3.1 (A)
	After	17.6 (B)	-	3.0 (A)	2.5 (B)
Intersection Delay (Sec/Veh) and LOS	Before	3.5 (A)			
	After	2.9 (A)			

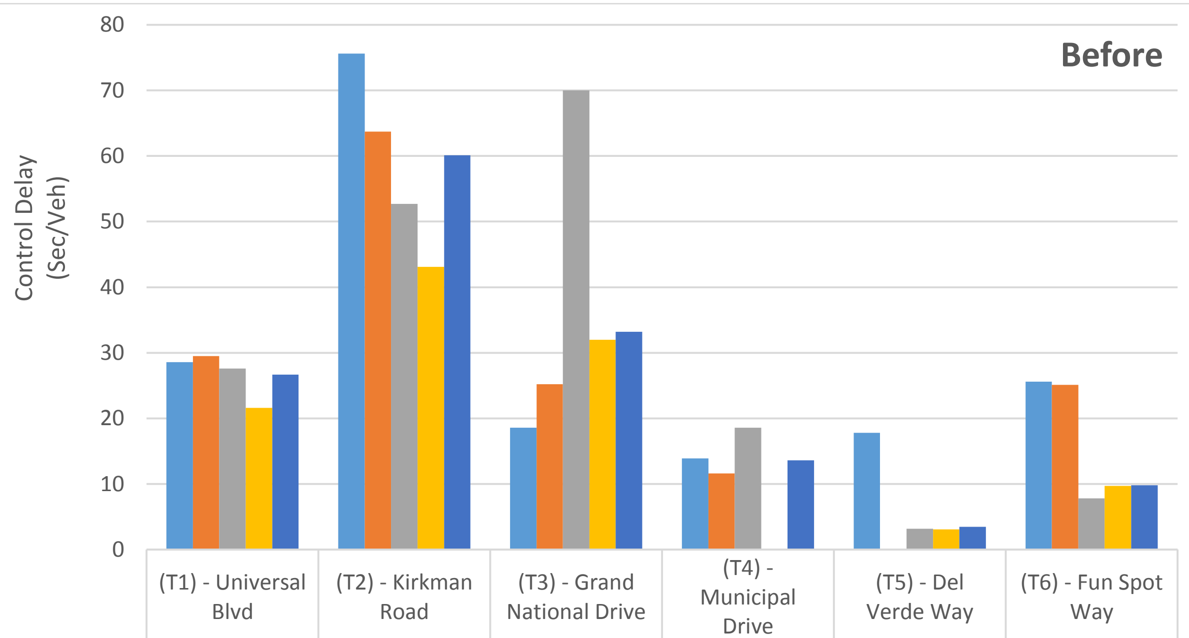
Table 51: Intersection LOS Analysis Summary for (T6) - Fun Spot Way

(T6) Fun Spot Way		Eastbound (EB)	Westbound (WB)	Northbound (NB)	Southbound (SB)
Approach Control Delay (Sec/Veh) and LOS	Before	25.6 (C)	25.1 (C)	7.8 (A)	9.7 (A)
	After	18.9 (B)	18.6 (B)	7.8 (A)	8.7 (A)
Intersection Delay (Sec/Veh) and LOS	Before	9.8 (A)			
	After	8.7 (A)			

The LOS analysis indicated that although there was no change in LOS at the intersection level, the LOS for several approaches improved after BRT was implemented. The majority of intersections operated with an overall LOS "C" or better except for T2 (Kirkman Road with LOS "E") that had the highest traffic volumes (Figures 39 and 118) before and after BRT construction. Examples of intersection approaches that showed a change in LOS before and after BRT implementation are T3-NB, T4-WB, T5-SB, T6-EB, and T6-WB.

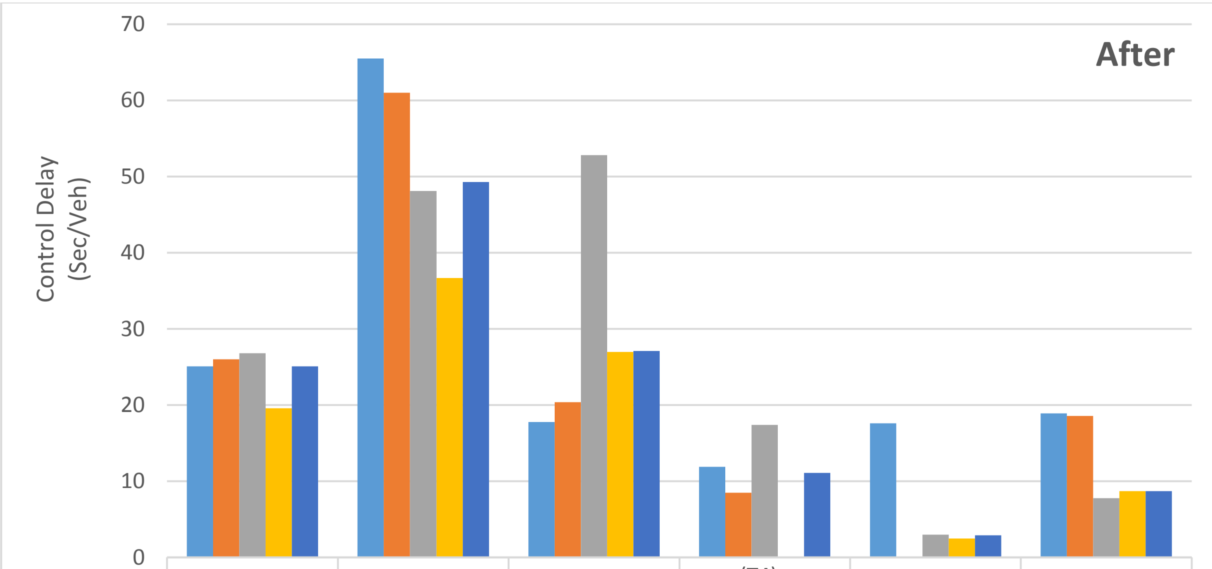
The LOS analysis also shows control delay and LOS on crossing streets in the study corridor. It should be noted that crossing street approaches for each intersection are: T1 (NB, and SB), T2 (NB, and SB), T3 (NB, and SB), T4 (NB, and SB), T5 (EB only), and T6 (EB, and WB). There is a reduction in control delay for every crossing street approach. Also, the majority of crossing street approaches had no change in their LOS and there are 3 approaches that had their LOS enhanced; T3-NB (from E to D), T6-EB (from C to B), and T6-WB (from C to B).

Figures 119 and 120 show the control delay (seconds per vehicle) analysis comparison for each intersection before and after BRT construction. Results showed that BRT improved (reduced) the control delays on all corridor intersections.



	(T1) - Universal Blvd	(T2) - Kirkman Road	(T3) - Grand National Drive	(T4) - Municipal Drive	(T5) - Del Verde Way	(T6) - Fun Spot Way
(EB)	28.6	75.6	18.6	13.9	17.8	25.6
(WB)	29.5	63.7	25.2	11.6	0	25.1
(NB)	27.6	52.7	70	18.6	3.2	7.8
(SB)	21.6	43.1	32	0	3.1	9.7
Total	26.7	60.1	33.2	13.6	3.5	9.8

Figure 119: Control Delay (Seconds/Vehicle) Analysis Summary - (The Before)



	(T1) - Universal Blvd	(T2) - Kirkman Road	(T3) - Grand National Drive	(T4) - Municipal Drive	(T5) - Del Verde Way	(T6) - Fun Spot Way
(EB)	25.1	65.5	17.8	11.9	17.6	18.9
(WB)	26	61	20.4	8.5	0	18.6
(NB)	26.8	48.1	52.8	17.4	3	7.8
(SB)	19.6	36.7	27	0	2.5	8.7
Total	25.1	49.3	27.1	11.1	2.9	8.7

Figure 120: Control Delay (Seconds/Vehicle) Analysis Summary - (The After)

Even though the HCS2010 results did not demonstrate a change in LOS at the intersection level, control delays reduced on all corridor intersections after BRT was implemented. The major reason behind these improvements is that there was one lane added to both directions (eastbound and westbound) on the main corridor (I-Drive) to accommodate the new exclusive bus lane. This BRT implementation strategy kept the current number of lanes for general traffic and added an extra lane for busses only to avoid excessive traffic congestion.

Another significant issue that can explain the improved delay is the shared right turn movement for general traffic on the bus only (BRT) lane for intersections that have no exclusive right turn movement. Figure 121 shows this shared right turn movement with the through buses only traffic lane. Because there is no exclusive lane for the right turn movements on the main corridor (I-Drive) for some intersections, the general traffic is allowed to use the bus lane at intersections with no exclusive right turn lane. Adding an extra lane with a good amount of traffic storage has caused a positive effect as demonstrated in the HCS results. It worked well to minimize the right turn queue effect on the through and left turn queued traffic. At the end, this was a win-win situation for both bus and general traffic.

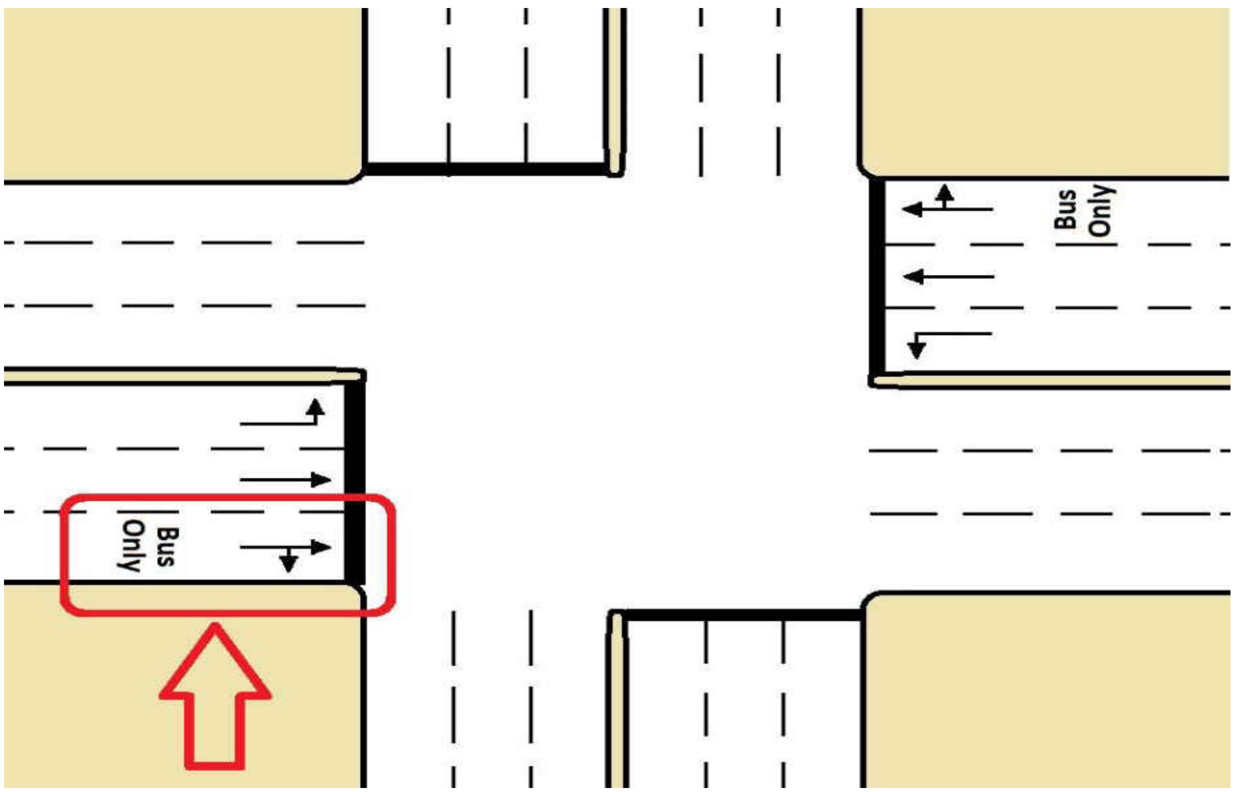


Figure 120: Shared Right Turn Movement on the Straight Bus Only Lane

Generally, transit service influence was positive after BRT construction with adding a new dedicated curb-side bus lane in each direction and implementing a TSP system at the corridor intersections. This chapter aimed to demonstrate a consistent and objective criteria for BRT (before and after the construction) by performing LOS analysis on the intersection level. To make the analysis consistent along the corridor, the control delay (seconds per vehicle) was used as a measure of effectiveness for the signalized intersection analysis.

This type of analysis used variety of field data before and after the construction of BRT; these data were useful in understanding the traffic behavior during peak hour along the corridor. HCS analysis results showed that while BRT did not cause a change in the overall intersection LOS but it did reduce control delay for several intersection approaches along I-Drive corridor. Furthermore, BRT improved the control delay and sometimes LOS on crossing streets along the main corridor. While this seems to be counterintuitive, it is a valid result due to the capacity enhancement strategy of implementing BRT and also TSP together. Since BRT provides better travel time and less delay for both buses and general traffic, it does offer an attractive mode of travel choice that reduced the out of pocket cost for automobile travelers which eventually increase bus ridership in the future.

CHAPTER 9 CONCLUSIONS

Understanding the combined impact of TSP and BRT on network traffic operations can be challenging. Previous studies showed conflicting results. A holistic and well organized approach is needed. This research presented a new approach that utilizes microscopic simulation along with hierarchical design and multiple linear regression to analyze simulation results for various strategies (scenarios) and present them in an organized manner that is easy for decision makers to understand. The robust methodology developed in this research applied on I-Drive corridor for the sake of demonstrating the new approach. However, this methodology can be applied to any corridor to understand the combined TSP and BRT effects on traffic performance. Presenting the results in a simplified and organized manner can help decision makers in their public transit investment decisions.

This research evaluated various practical BRT with TSP scenario options for application on International Drive (I-Drive) in Orlando, FL, by comparing the before and after effects of implementing BRT with TSP using the microscopic simulation software VISSIM. This evaluation included the following scenarios:

- Existing Scenario without TSP and BRT (The base scenario).
- TSP Scenarios: TSP Unconditional, TSP Conditional with 3 minutes behind schedule, and TSP Conditional with 5 minutes behind schedule.
- BRT Scenarios: BRT with No TSP, BRT with Unconditional TSP, BRT with Conditional TSP (3 minutes behind schedule), and BRT with Conditional TSP (5 minutes behind schedule).

A vast quantity of field data was collected; these data were useful in understanding the traffic behavior along the corridor and developing the VISSIM model. The VISSIM model was developed, calibrated, and utilized to determine the average speeds, average travel times, average total delay per vehicle, and average number of stops per vehicle for through traffic, including both all vehicle and buses only, as well as the average delay per vehicle on crossing streets for all of the tested scenarios.

Nested sets (hierarchical design) were used in the statistical analysis of the VISSIM model. Simulation results regarding the main through movement on the I-Drive corridor showed TSP and BRT scenarios were effective in reducing travel times (up to 26 %) and delays (up to 64%), as well as increasing the speed (up to 47%), compared to the base scenario. The most effective scenarios were achieved by combining BRT and TSP. BRT with Unconditional TSP provided the best travel time, speed, number of stops and delay enhancements along I-Drive. However, this scenario had a significant negative impact on side street traffic delays, especially at major intersections with high traffic demand. Therefore, this scenario is impractical for application in the corridor.

Since the BRT with Unconditional TSP scenario causes large increases in side street delays, especially on side streets with high traffic demands (such as Kirkman and Grand National), it was concluded that BRT with Conditional TSP 3 minutes behind was the most effective scenario. This scenario reduced travel times and delays for I-Drive more than BRT with Conditional TSP 5 minutes behind without remarkably increasing side street delays. The results showed that BRT with Conditional TSP 3 minutes behind significantly improved travel times (17 – 26%), average speed (30 – 39%), and average total delay per vehicle (11 – 32%) for the main corridor through movements compared with the base scenario. Therefore, this is the best scenario for implementation in the I-Drive corridor. The methodology and results of this research can be utilized in other urban settings for the purpose of selecting the most practical scenario for implementation of BRT and TSP.

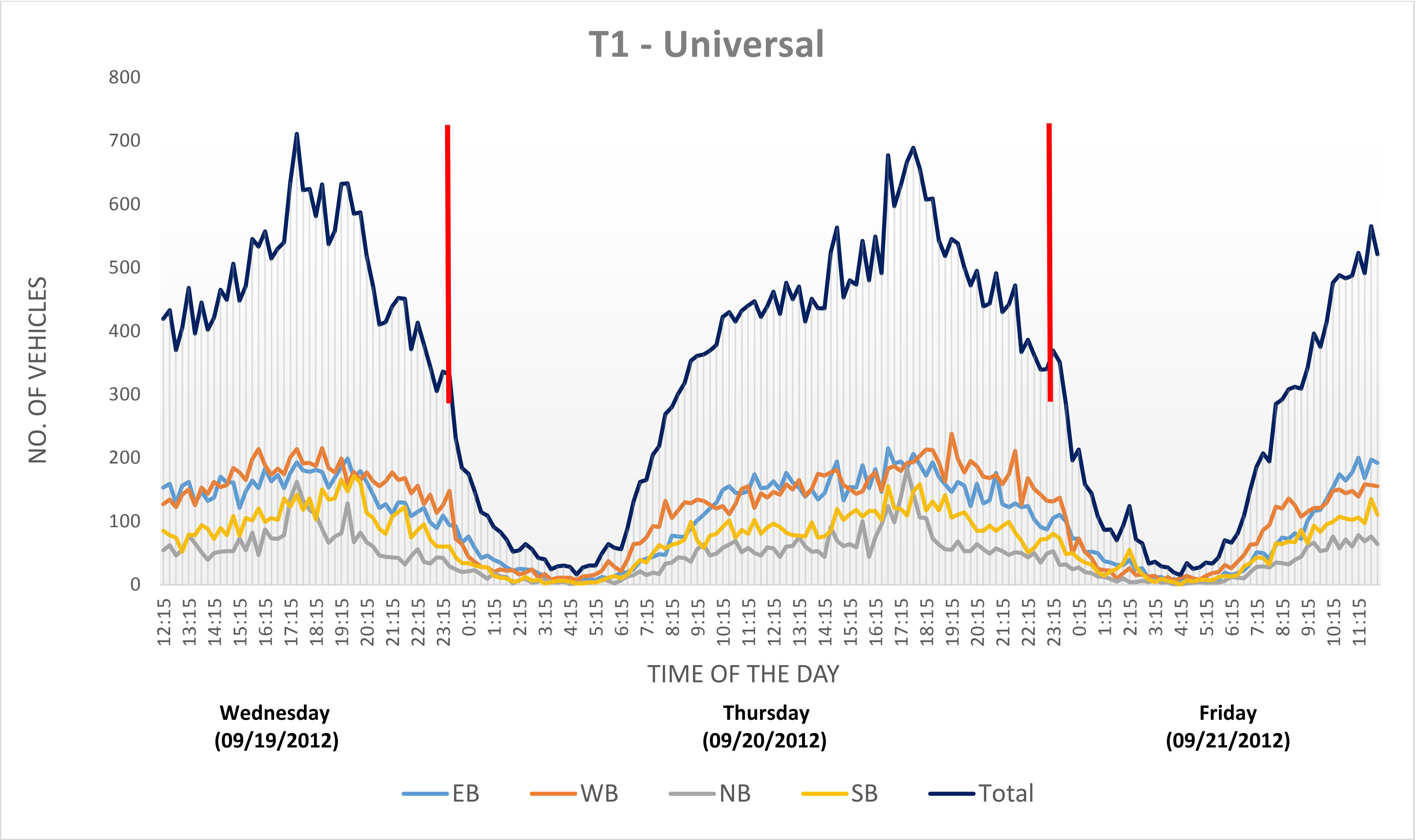
Since the developed regression models were based on real world data, they can provide accurate estimates of BRT and TSP performance. These models can also be used for further sensitivity analysis on a larger network concerning the upcoming regional expansion of TSP and BRT in Central Florida. Accurately evaluating BRT with and without TSP is important in order for these systems to be an effective part of the regional multimodal public transportation network. Finally, since this research demonstrated the operational functionality and effectiveness of BRT and TSP systems in this critical corridor in Central Florida, these systems' accomplishments can be expanded throughout the state of Florida to provide greater benefits to transit passengers.

This research established an objective investigation criteria for BRT (before and after the construction) by performing LOS analysis at the intersection level too using the control delay (seconds per vehicle) as a measure of effectiveness. This type of analysis used variety of field data before and after the construction of BRT; these data were useful in understanding the traffic behavior during peak hour along the corridor. HCS analysis results showed that while BRT did not cause a change in the overall intersection LOS but it did reduce control delay for several intersection approaches along I-Drive corridor. Furthermore, BRT improved the control delay and sometimes LOS on crossing streets along the main corridor. While this seems to be counterintuitive, it is a valid result due to the capacity enhancement strategy of implementing BRT and also TSP together. Since BRT provides better travel time and less delay for both buses and general traffic, it does offer an attractive mode of travel choice that reduced the out of pocket cost for automobile travelers which eventually increase bus ridership in the future.

Future work to continue this research may include application of the microscopic simulation along with hierarchical design and multiple linear regression for light rail transit (LRT) on this corridor. This future evaluation would also be beneficial because Central Florida is going through continuous expansions of the new SunRail LRT system. This model could utilize an exclusive LRT lane in both directions along the corridor in addition to the other traffic. The methodology and analysis in this research can be extended to evaluate traffic operational improvements before and after the implementation of TSP, BRT, LRT, or any combination of transit scenarios in any corridor.

APPENDIX A: TUBE COUNTS PEAK HOURLY VOLUMES

Intersection (T1)

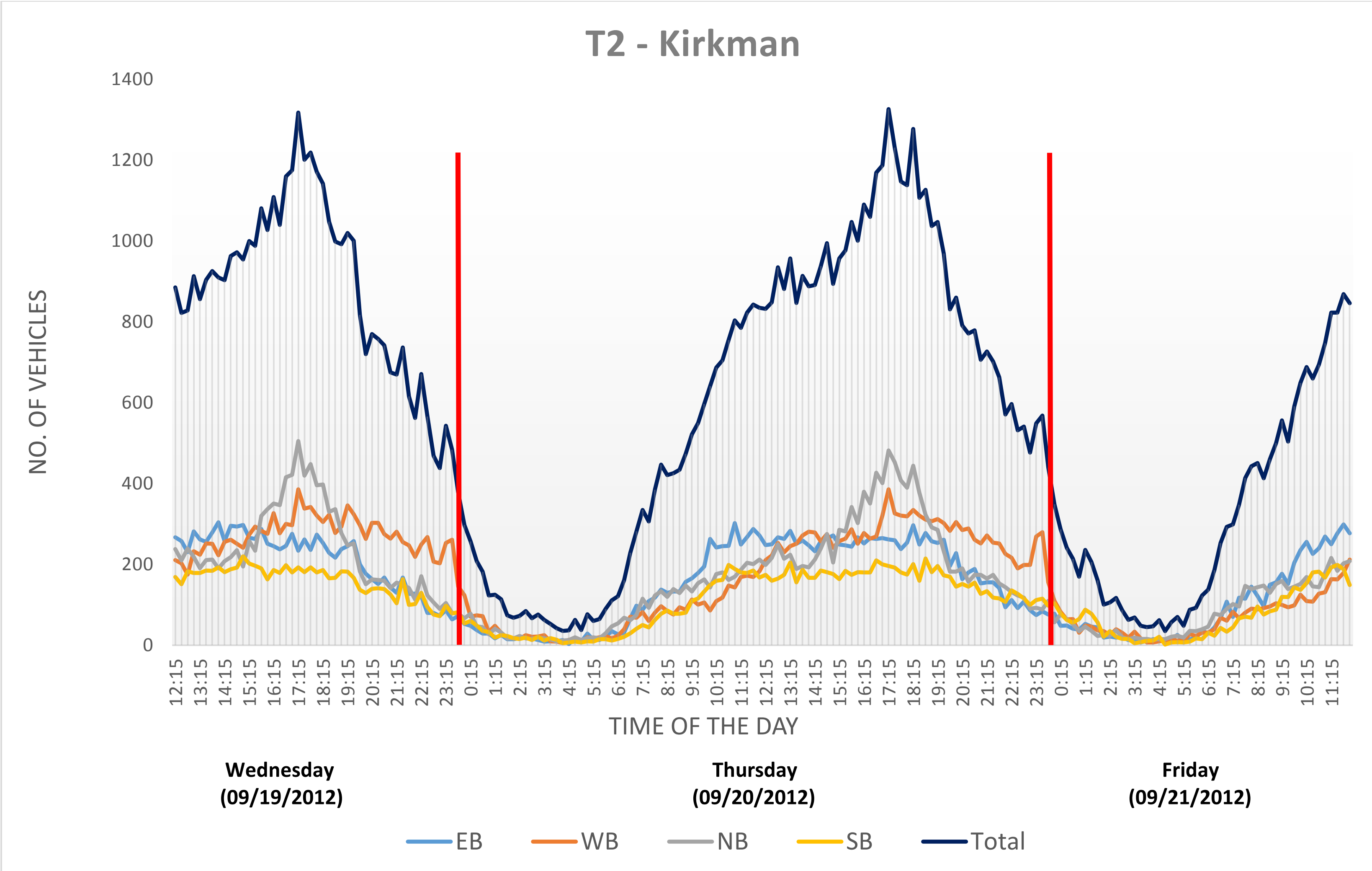


Daily Traffic Volumes on T1 – Universal Intersection

Peak Hourly Volumes on T1 – Universal Intersection

Peak Hours	EB			WB			NB			SB			TOTAL		
	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri
AM Peak	-	11:15-12:15	11:15-12:15	-	11:00-12:00	11:15-12:15	-	10:15-11:15	11:15-12:15	-	10:15-11:15	11:15-12:15	-	11:00-12:00	11:00-12:00
Volume (VPH)	-	626	757	-	571	609	-	241	286	-	352	448	-	1741	2100
PM Peak	19-15-20:15	16:45-17:45	-	17:15-18:15	17:45-18:45	-	17:15-18:15	17:15-18:15	-	19:15-20:15	17:45-18:45	-	17:15-18:15	**17:15-18:15**	-
Volume (VPH)	733	783	-	798	821	-	548	570	-	645	553	-	2592	**2642**	-

Intersection (T2)

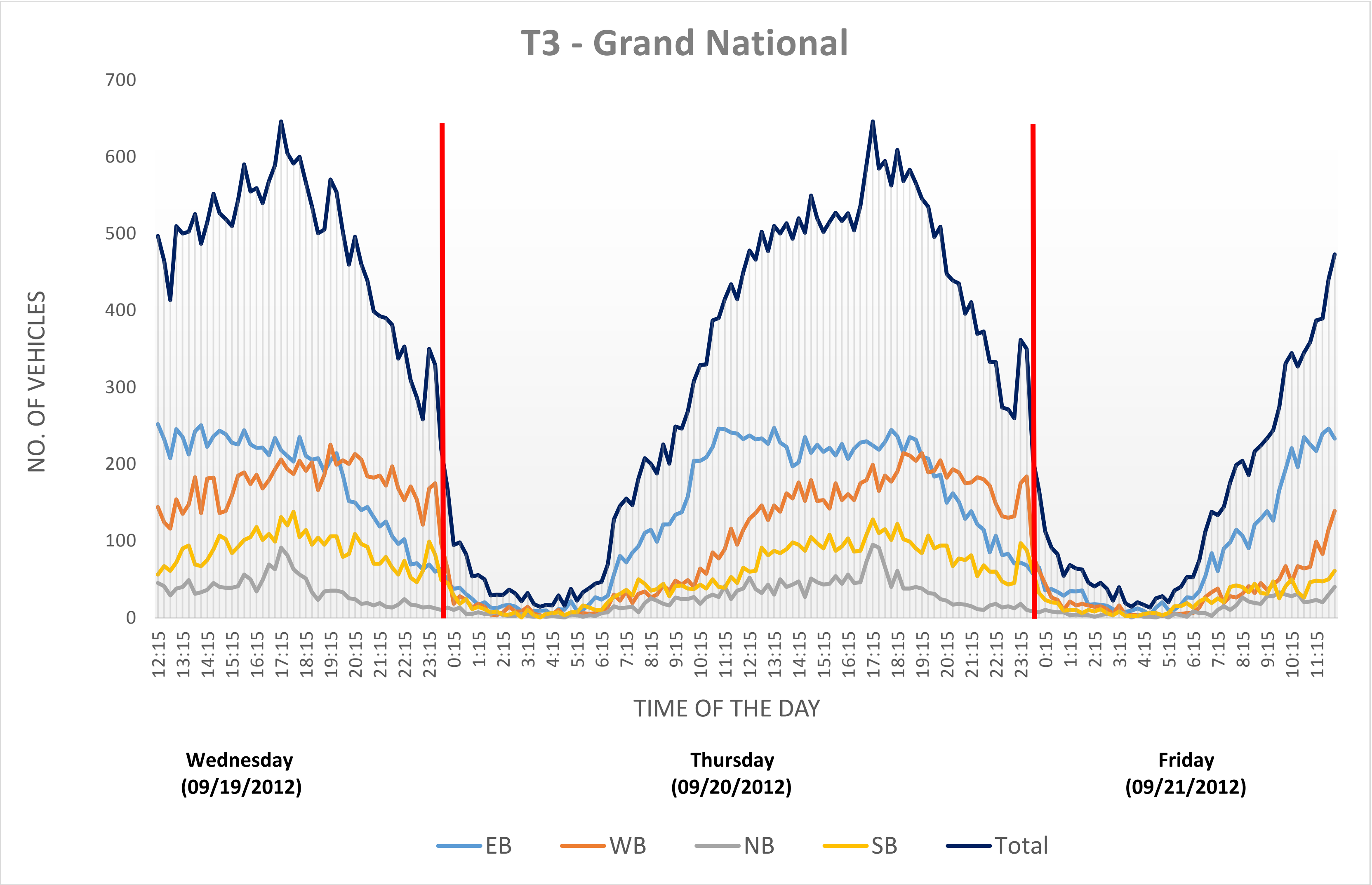


Daily Traffic Volumes on T2 – Kirkman Intersection

Peak Hourly Volumes on T2 – Kirkman Intersection

Peak Hours	EB			WB			NB			SB			TOTAL		
	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri
AM Peak	-	11:00-12:00	11:15-12:15	-	11:15-12:15	11:15-12:15	-	11:15-12:15	11:15-12:15	-	10:45-11:45	11:00-12:00	-	11:15-12:15	11:15-12:15
Volume (VPH)	-	1107	1103	-	693	718	-	804	811	-	747	748	-	3286	3361
PM Peak	14:30-15:30	18:15-19:15	-	17:15-18:15	17:00-18:00	-	17:00-18:00	16:45-17:45	-	14:45-15:45	16:45-17:45	-	17:00-18:00	16:45-17:45	-
Volume (VPH)	1154	1081	-	1387	1354	-	1795	1763	-	811	798	-	4915	4913	-

Intersection (T3)

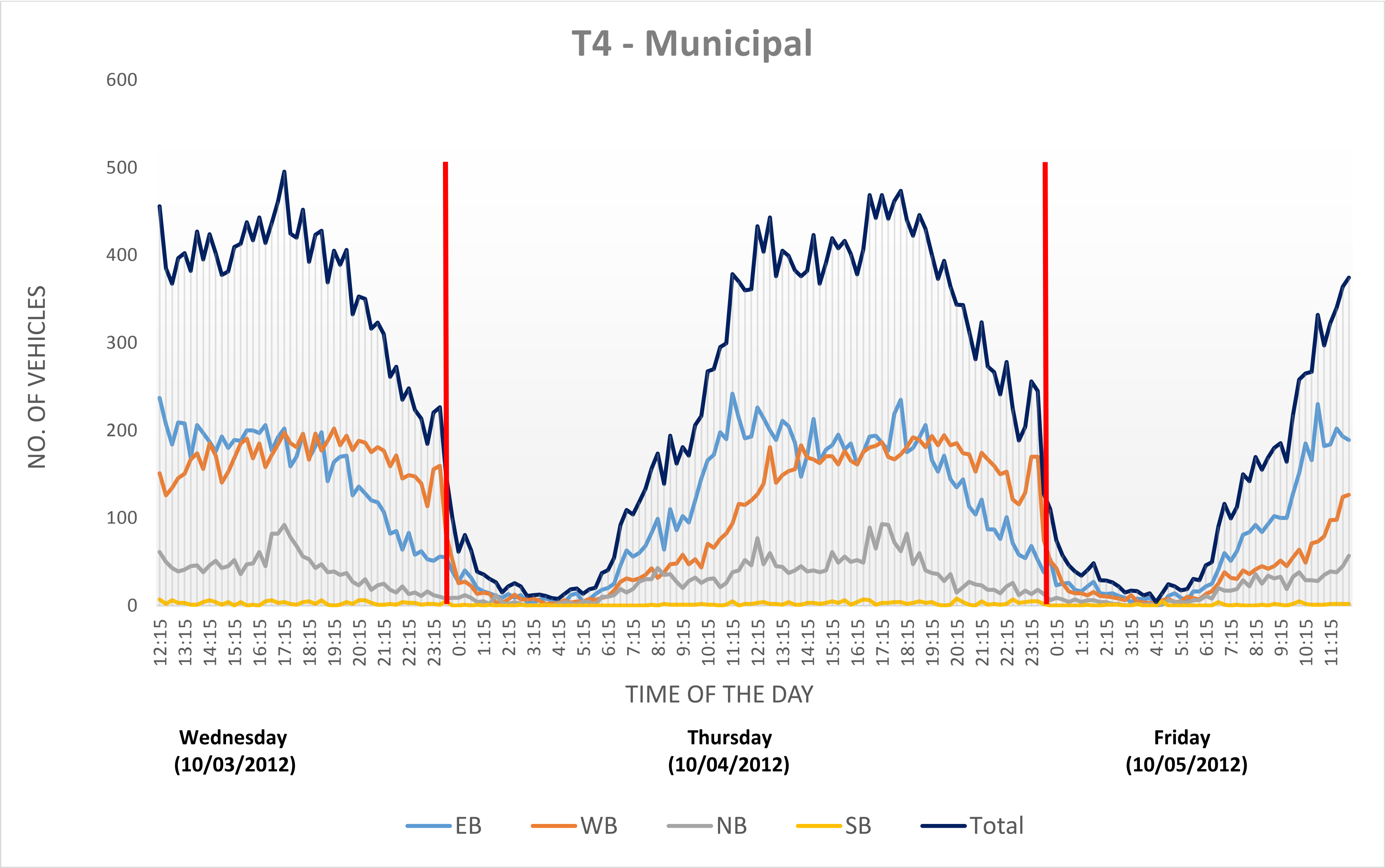


Daily Traffic Volumes on T3 – Grand National Intersection

Peak Hourly Volumes on T3 – Grand National Intersection

Peak Hours	EB			WB			NB			SB			TOTAL		
	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri
AM Peak	-	11:00-12:00	11:15-12:15	-	11:15-12:15	11:15-12:15	-	11:15-12:15	9:45-10:45	-	11:15-12:15	11:15-12:15	-	11:15-12:15	11:15-12:15
Volume (VPH)	-	972	936	-	414	436	-	138	122	-	202	206	-	1712	1691
PM Peak	13:45-14:45	12:30-13:30	-	19:15-20:15	18:30-19:30	-	16:45-17:45	17:00-18:00	-	17:15-18:15	17:00-18:00	-	**17:15-18:15**	17:00-18:00	-
Volume (VPH)	952	939	-	829	843	-	304	325	-	494	461	-	**2442**	2415	-

Intersection (T4)

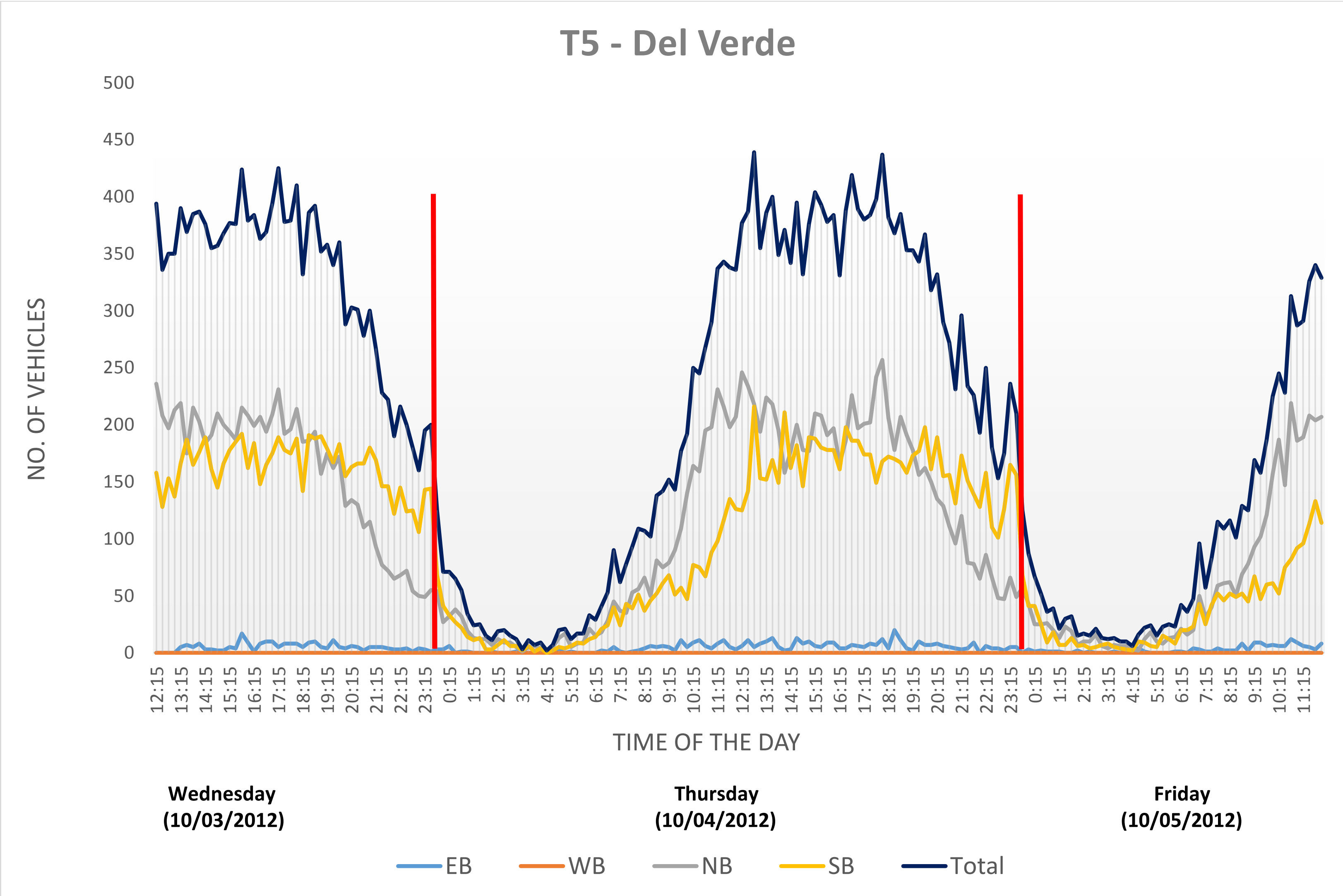


Daily Traffic Volumes on T4 – Municipal Intersection

Peak Hourly Volumes on T4 – Municipal Intersection

Peak Hours	EB			WB			NB			SB			TOTAL		
	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri
AM Peak	-	10:45-11:45	10:45-11:45	-	11:15-12:15	11:15-12:15	-	11:15-12:15	11:15-12:15	-	11:15-12:15	9:45-10:45	-	11:15-12:15	11:15-12:15
Volume (VPH)	-	844	798	-	445	446	-	176	179	-	9	10	-	1470	1401
PM Peak	12:15-13:15	12:15-13:15	-	19:00-20:00	18:30-19:30	-	16:45-17:45	16:45-17:45	-	12:15-13:15	22:30-23:30	-	16:45-17:45	17:15-18:15	-
Volume (VPH)	837	829	-	767	756	-	334	339	-	18	19	-	1818	1846	-

Intersection (T5)

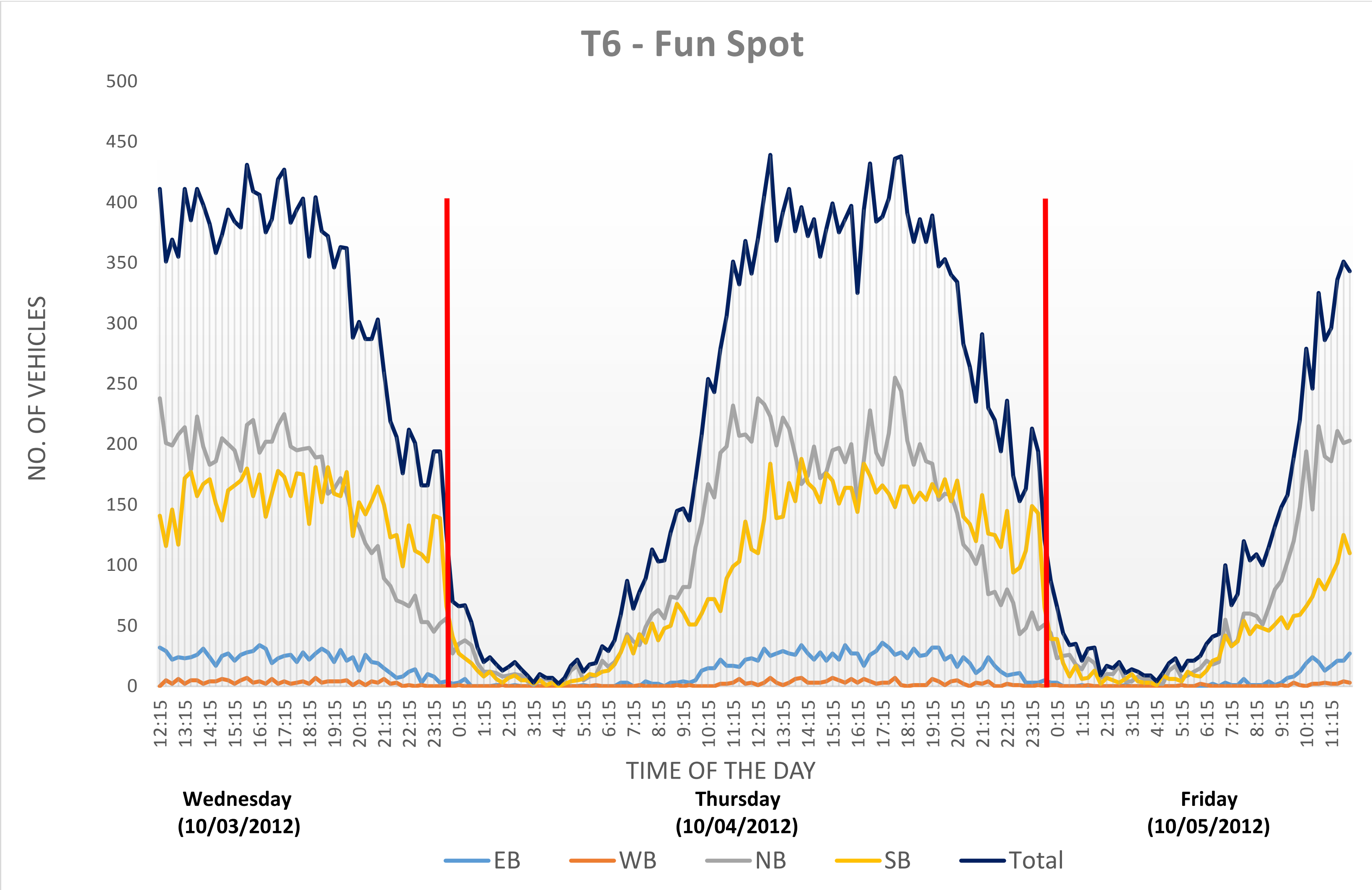


Daily Traffic Volumes on T5 – Del Verde Intersection

Peak Hourly Volumes on T5 – Del Verde Intersection

Peak Hours	EB			WB			NB			SB			TOTAL		
	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri
AM Peak	-	9:45-10:45	10:15-11:15	-	-	-	-	11:15-12:15	11:15-12:15	-	11:15-12:15	11:15-12:15	-	11:15-12:15	11:15-12:15
Volume (VPH)	-	36	33	-	-	-	-	852	808	-	475	456	-	1354	1286
PM Peak	15:15-16:15	18:00-19:00	-	-	-	-	12:15-13:15	17:30-18:30	-	18:30-19:30	16:30-17:30	-	17:15-18:15	17:30-18:30	-
Volume (VPH)	35	47	-	-	-	-	854	907	-	748	744	-	1592	1601	-

Intersection (T6)



Daily Traffic Volumes on T6 – Fun Spot Intersection

Peak Hourly Volumes on T6 – Fun Spot Intersection

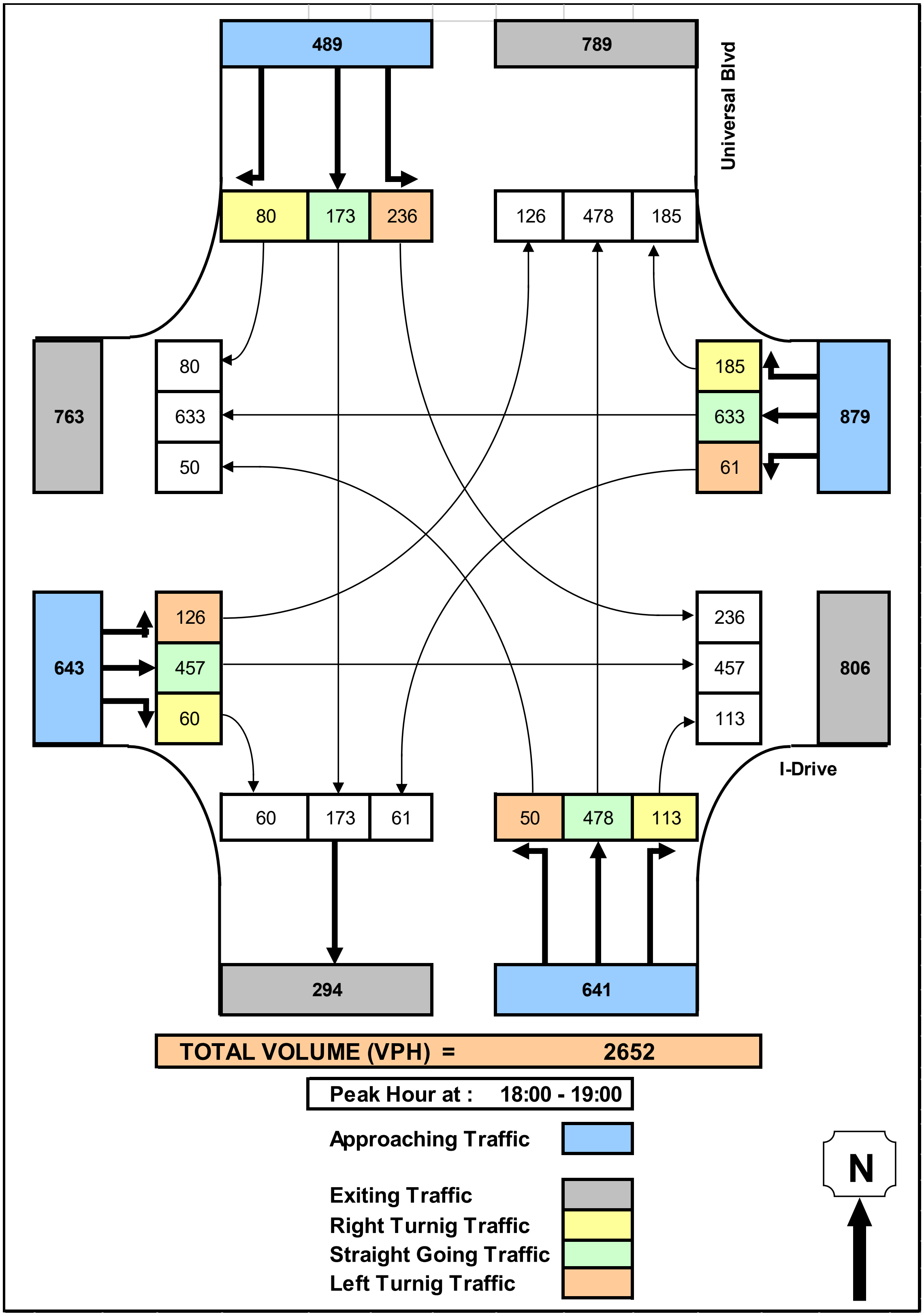
Peak Hours	EB			WB			NB			SB			TOTAL		
	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri	Wed	Thu	Fri
AM Peak	-	11:15-12:15	11:15-12:15	-	11:15-12:15	11:00-12:00	-	11:15-12:15	10:45-11:45	-	11:15-12:15	11:15-12:15	-	11:15-12:15	11:15-12:15
Volume (VPH)	-	78	86	-	14	11	-	849	802	-	451	428	-	1392	1326
PM Peak	15:45-16:45	16:45-17:45	-	14:15-15:15	15:15-16:15	-	12:15-13:15	17:30-18:30	-	17:00-18:00	16:30-17:30	-	15:30-16:30	17:30-18:30	-
Volume (VPH)	122	123	-	19	21	-	846	911	-	684	684	-	1625	1668	-

APPENDIX B: DETAILED INTERSECTION TRAFFIC MOVEMENTS

BEFORE BRT

Turning Movement Counts on Intersection T1

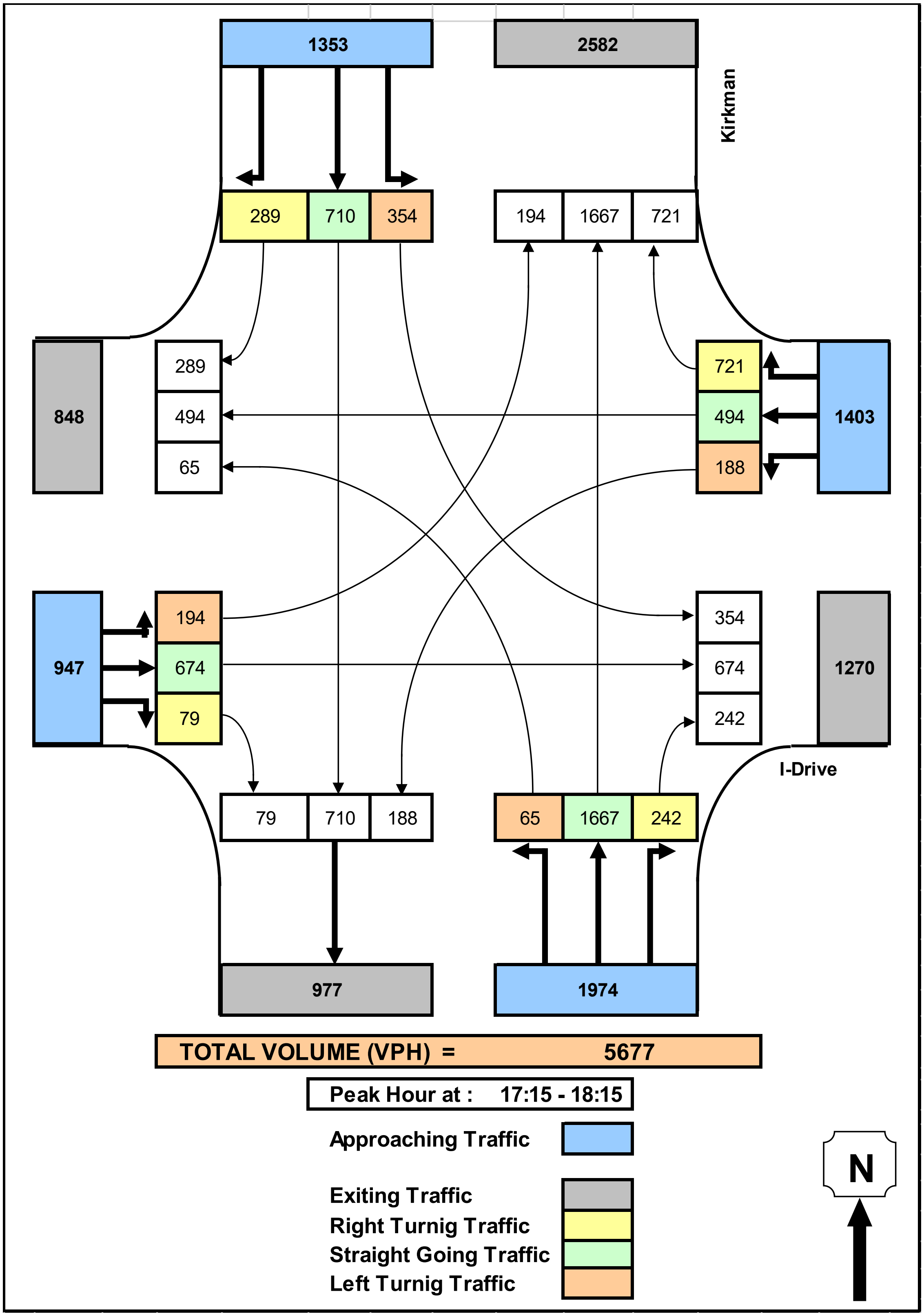
		International Dr						Universal Blvd						TOTAL
		EB			WB			NB			SB			
		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
3:00 - 3:15	PC	15	124	16	10	157	34	14	51	33	32	25	19	530
	HV	1	3	1	1	4	1	0	0	1	1	0	0	13
SUM		16	127	17	11	161	35	14	51	34	33	25	19	543
3:15 - 3:30	PC	13	130	12	12	184	41	7	72	31	45	29	32	608
	HV	1	2	0	0	3	1	1	1	0	1	1	1	12
SUM		14	132	12	12	187	42	8	73	31	46	30	33	620
3:30 - 3:45	PC	10	102	7	21	177	33	11	39	21	36	25	20	502
	HV	0	1	0	1	2	0	0	1	1	0	0	0	6
SUM		10	103	7	22	179	33	11	40	22	36	25	20	508
3:45 - 4:00	PC	8	117	11	8	165	40	13	77	23	52	29	34	577
	HV	0	2	1	1	2	0	0	0	2	1	1	0	10
SUM		8	119	12	9	167	40	13	77	25	53	30	34	587
1		Total PC		565	Total PC		882	Total PC		392	Total PC		378	
		Totl HV		12	Totl HV		16	Totl HV		7	Totl HV		6	
4:00 - 4:15	PC	13	133	14	14	198	46	8	71	28	43	47	30	645
	HV	1	2	0	0	5	1	0	2	0	0	0	0	11
SUM		14	135	14	14	203	47	8	73	28	43	47	30	656
4:15 - 4:30	PC	21	119	17	10	214	35	10	90	20	38	34	28	636
	HV	1	2	1	0	2	1	0	0	0	1	1	0	9
SUM		22	121	18	10	216	36	10	90	20	39	35	28	645
4:30 - 4:45	PC	14	69	16	6	58	29	9	69	28	50	33	32	413
	HV	1	3	0	0	5	0	0	3	1	1	2	1	17
SUM		15	72	16	6	63	29	9	72	29	51	35	33	430
4:45 - 5:00	PC	28	85	18	21	96	64	6	29	18	52	43	28	488
	HV	1	3	2	1	1	3	0	1	1	1	0	1	15
SUM		29	88	20	22	97	67	6	30	19	53	43	29	503
2		Total PC		547	Total PC		791	Total PC		386	Total PC		458	
		Totl HV		17	Totl HV		19	Totl HV		8	Totl HV		8	
5:00 - 5:15	PC	41	127	21	20	129	74	15	51	27	54	69	27	655
	HV	0	6	4	1	5	1	1	1	0	1	1	1	22
SUM		41	133	25	21	134	75	16	52	27	55	70	28	677
5:15 - 5:30	PC	37	138	21	24	97	55	13	68	28	46	61	31	619
	HV	0	10	2	1	2	1	0	1	1	0	3	0	21
SUM		37	148	23	25	99	56	13	69	29	46	64	31	640
5:30 - 5:45	PC	12	131	18	22	91	69	12	90	37	43	27	32	584
	HV	0	7	2	0	3	3	0	1	2	0	1	1	20
SUM		12	138	20	22	94	72	12	91	39	43	28	33	604
5:45 - 6:00	PC	28	127	18	18	125	66	6	73	38	44	46	33	622
	HV	1	10	2	1	3	2	0	0	0	1	0	0	20
SUM		29	137	20	19	128	68	6	73	38	45	46	33	642
3		Total PC		719	Total PC		790	Total PC		458	Total PC		513	
		Totl HV		44	Totl HV		23	Totl HV		7	Totl HV		9	
6:00 - 6:15	PC	27	88	6	16	118	45	10	130	11	67	62	29	609
	HV	3	5	1	0	4	0	0	4	2	0	0	0	19
SUM		30	93	7	16	122	45	10	134	13	67	62	29	628
6:15 - 6:30	PC	31	108	14	16	102	56	16	140	43	79	43	21	669
	HV	0	2	1	1	2	1	0	2	0	2	0	0	11
SUM		31	110	15	17	104	57	16	142	43	81	43	21	680
6:30 - 6:45	PC	34	130	21	14	187	42	14	101	35	51	37	18	684
	HV	0	2	0	0	3	2	0	2	1	1	1	0	12
SUM		34	132	21	14	190	44	14	103	36	52	38	18	696
6:45 - 7:00	PC	29	121	17	13	215	38	10	97	21	34	29	12	636
	HV	2	1	0	1	2	1	0	2	0	2	1	0	12
SUM		31	122	17	14	217	39	10	99	21	36	30	12	648
4		Total PC		626	Total PC		862	Total PC		628	Total PC		482	
		Totl HV		17	Totl HV		17	Totl HV		13	Totl HV		7	
Total		373	1910	264	254	2361	785	176	1269	454	779	651	431	9707
			2547			3400			1899			1861		
		5947						3760						



Graphic Summary of Intersection T1 Movements during the Peak Hour

Turning Movement Counts on Intersection T2

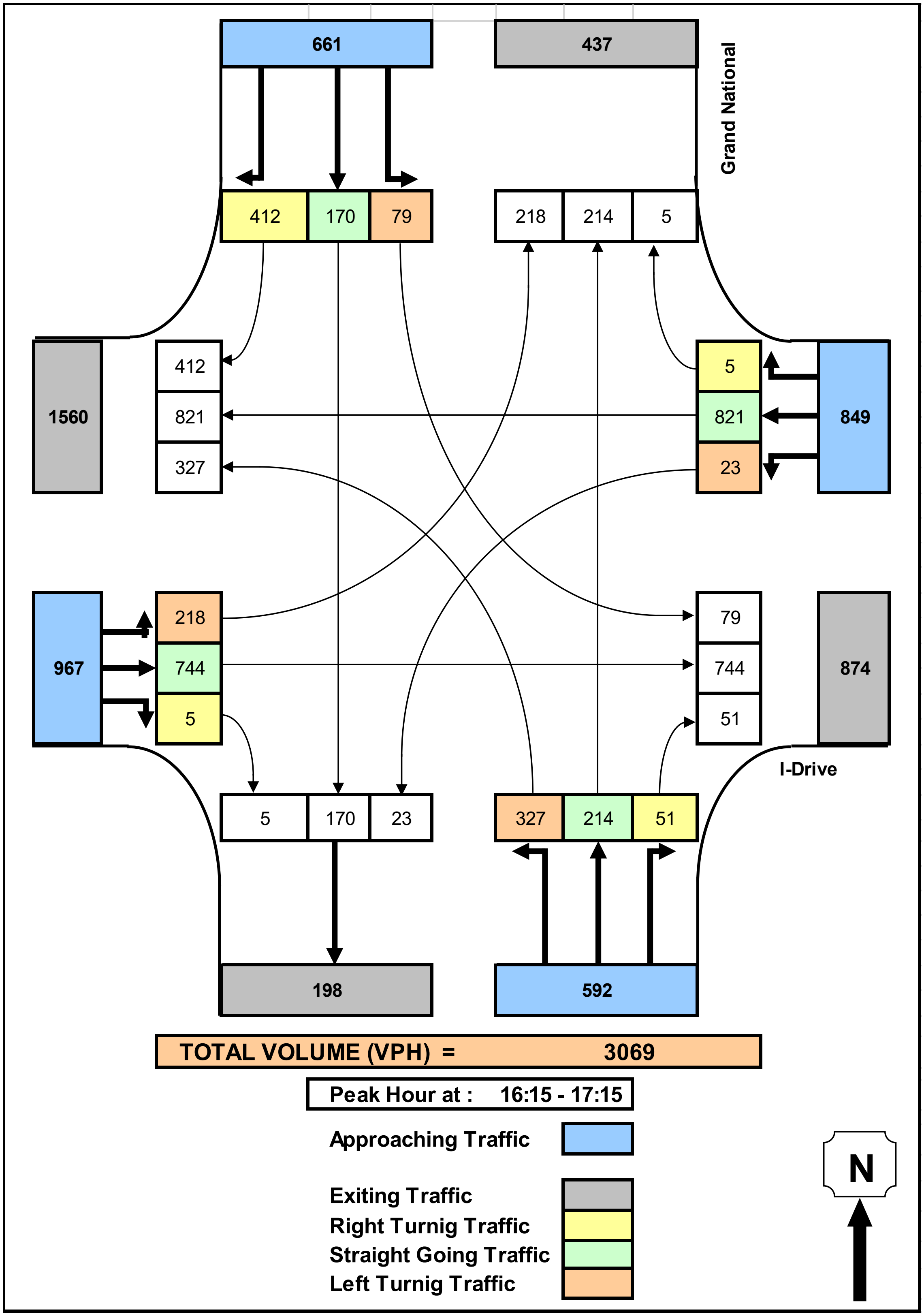
		International Dr						Kirkman						TOTAL
		EB			WB			NB			SB			
		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
3:00 - 3:15	PC	44	107	14	30	241	110	7	195	41	53	162	66	1070
	HV	3	3	0	1	3	0	0	5	0	0	2	0	17
SUM		**47**	**110**	**14**	**31**	**244**	**110**	**7**	**200**	**41**	**53**	**164**	**66**	**1087**
3:15 - 3:30	PC	40	122	12	43	81	126	9	204	51	75	175	73	1011
	HV	2	1	0	1	4	0	0	7	2	0	3	1	21
SUM		**42**	**123**	**12**	**44**	**85**	**126**	**9**	**211**	**53**	**75**	**178**	**74**	**1032**
3:30 - 3:45	PC	43	108	9	34	93	132	4	197	38	101	158	75	992
	HV	1	8	1	0	4	1	0	4	0	1	3	2	25
SUM		**44**	**116**	**10**	**34**	**97**	**133**	**4**	**201**	**38**	**102**	**161**	**77**	**1017**
3:45 - 4:00	PC	45	146	8	37	121	101	9	362	44	45	170	69	1157
	HV	5	3	0	0	4	2	1	5	2	5	6	0	33
SUM		**50**	**149**	**8**	**37**	**125**	**103**	**10**	**367**	**46**	**50**	**176**	**69**	**1190**
1		**Total PC**		**698**	**Total PC**		**1149**	**Total PC**		**1161**	**Total PC**		**1222**	
		Totl HV		**27**	**Totl HV**		**20**	**Totl HV**		**26**	**Totl HV**		**23**	
4:00 - 4:15	PC	51	112	11	36	83	102	13	378	33	101	195	69	1184
	HV	5	1	1	3	8	2	0	7	0	3	8	3	41
SUM		**56**	**113**	**12**	**39**	**91**	**104**	**13**	**385**	**33**	**104**	**203**	**72**	**1225**
4:15 - 4:30	PC	57	133	13	31	102	19	19	329	47	87	138	73	1048
	HV	1	4	1	1	3	3	3	6	1	2	4	1	30
SUM		**58**	**137**	**14**	**32**	**105**	**22**	**22**	**335**	**48**	**89**	**142**	**74**	**1078**
4:30 - 4:45	PC	43	154	6	32	115	13	13	312	51	95	162	74	1070
	HV	3	1	0	0	2	0	0	8	0	1	3	0	18
SUM		**46**	**155**	**6**	**32**	**117**	**13**	**13**	**320**	**51**	**96**	**165**	**74**	**1088**
4:45 - 5:00	PC	37	110	15	26	161	19	19	455	54	97	174	71	1238
	HV	1	6	0	0	2	0	0	9	0	1	5	4	28
SUM		**38**	**116**	**15**	**26**	**163**	**19**	**19**	**464**	**54**	**98**	**179**	**75**	**1266**
2		**Total PC**		**742**	**Total PC**		**739**	**Total PC**		**1723**	**Total PC**		**1336**	
		Totl HV		**24**	**Totl HV**		**24**	**Totl HV**		**34**	**Totl HV**		**35**	
5:00 - 5:15	PC	37	114	13	50	203	15	15	426	42	105	150	73	1243
	HV	3	1	0	0	0	1	1	7	0	2	5	1	21
SUM		**40**	**115**	**13**	**50**	**203**	**16**	**16**	**433**	**42**	**107**	**155**	**74**	**1264**
5:15 - 5:30	PC	45	186	20	45	139	275	20	448	52	82	171	82	1565
	HV	1	3	0	2	4	1	1	4	2	1	5	0	24
SUM		**46**	**189**	**20**	**47**	**143**	**276**	**21**	**452**	**54**	**83**	**176**	**82**	**1589**
5:30 - 5:45	PC	44	155	22	47	132	173	13	436	75	72	200	68	1437
	HV	2	4	1	1	6	2	0	10	0	3	1	1	31
SUM		**46**	**159**	**23**	**48**	**138**	**175**	**13**	**446**	**75**	**75**	**201**	**69**	**1468**
5:45 - 6:00	PC	48	137	12	47	88	104	21	412	66	85	173	73	1266
	HV	2	0	0	1	2	2	0	2	0	1	3	0	13
SUM		**50**	**137**	**12**	**48**	**90**	**106**	**21**	**414**	**66**	**86**	**176**	**73**	**1279**
3		**Total PC**		**833**	**Total PC**		**1318**	**Total PC**		**2026**	**Total PC**		**1334**	
		Totl HV		**17**	**Totl HV**		**22**	**Totl HV**		**27**	**Totl HV**		**23**	
6:00 - 6:15	PC	51	182	24	43	120	164	10	351	46	108	153	63	1315
	HV	1	7	0	2	3	0	0	4	1	2	4	2	26
SUM		**52**	**189**	**24**	**45**	**123**	**164**	**10**	**355**	**47**	**110**	**157**	**65**	**1341**
6:15 - 6:30	PC	46	132	7	52	115	149	14	357	48	92	117	86	1215
	HV	1	3	0	0	3	2	0	2	0	1	1	3	16
SUM		**47**	**135**	**7**	**52**	**118**	**151**	**14**	**359**	**48**	**93**	**118**	**89**	**1231**
6:30 - 6:45	PC	41	115	14	49	109	97	17	305	41	69	154	75	1086
	HV	0	5	0	0	1	1	0	2	0	2	3	3	17
SUM		**41**	**120**	**14**	**49**	**110**	**98**	**17**	**307**	**41**	**71**	**157**	**78**	**1103**
6:45 - 7:00	PC	52	128	7	36	141	131	27	267	50	89	124	84	1136
	HV	1	1	0	0	0	1	1	0	0	2	0	1	7
SUM		**53**	**129**	**7**	**36**	**141**	**132**	**28**	**267**	**50**	**91**	**124**	**85**	**1143**
4		**Total PC**		**799**	**Total PC**		**1206**	**Total PC**		**1533**	**Total PC**		**1214**	
		Totl HV		**19**	**Totl HV**		**13**	**Totl HV**		**10**	**Totl HV**		**24**	
Total		**756**	**2192**	**211**	**650**	**2093**	**1748**	**237**	**5516**	**787**	**1383**	**2632**	**1196**	**19401**
		3159			**4491**			**6540**			**5211**			
		7650						**11751**						



Graphic Summary of Intersection T2 Movements during the Peak Hour

Turning Movement Counts on Intersection T3

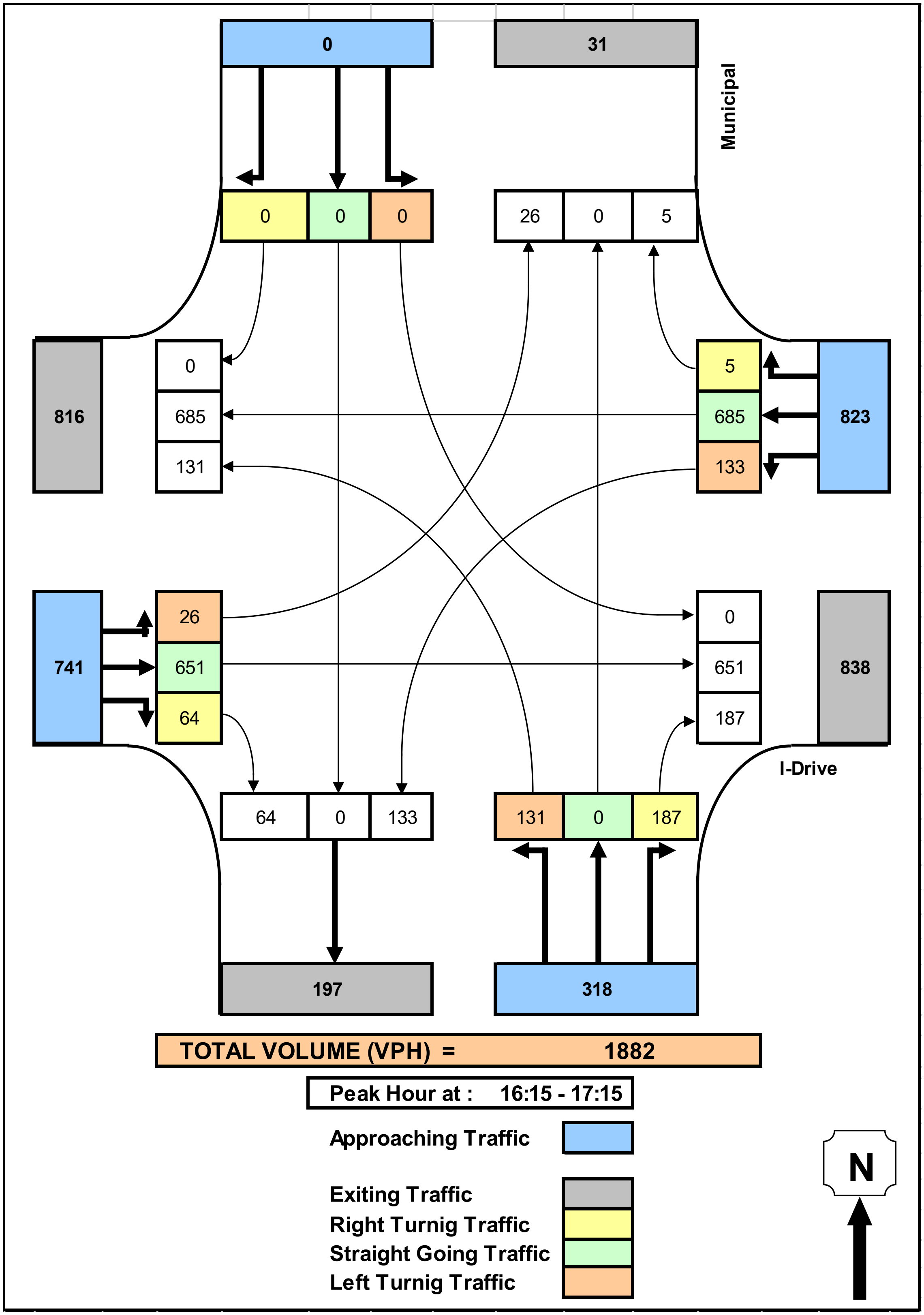
		International Dr						Grand National						TOTAL
		EB			WB			NB			SB			
		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
3:00 - 3:15	PC	21	108	0	6	177	0	35	16	9	10	25	102	509
	HV	0	0	0	0	2	0	0	0	0	0	0	2	4
SUM		21	108	0	6	179	0	35	16	9	10	25	104	513
3:15 - 3:30	PC	50	188	1	5	175	5	46	22	16	12	28	112	660
	HV	1	2	0	0	3	0	0	0	0	0	0	3	9
SUM		51	190	1	5	178	5	46	22	16	12	28	115	669
3:30 - 3:45	PC	53	210	0	7	191	0	56	42	8	14	32	65	678
	HV	1	5	0	0	3	0	0	0	0	1	0	4	14
SUM		54	215	0	7	194	0	56	42	8	15	32	69	692
3:45 - 4:00	PC	44	189	0	9	186	5	49	39	7	22	23	73	646
	HV	0	3	0	0	4	0	0	0	0	0	0	3	10
SUM		44	192	0	9	190	5	49	39	7	22	23	76	656
1		Total PC		864	Total PC		766	Total PC		345	Total PC		518	
		Totl HV		12	Totl HV		12	Totl HV		0	Totl HV		13	
4:00 - 4:15	PC	37	192	1	6	176	1	51	56	12	12	29	118	691
	HV	1	6	2	0	4	0	0	0	0	0	1	2	16
SUM		38	198	3	6	180	1	51	56	12	12	30	120	707
4:15 - 4:30	PC	47	181	4	8	180	1	76	63	12	23	46	109	750
	HV	0	4	0	0	2	0	1	1	0	0	1	3	12
SUM		47	185	4	8	182	1	77	64	12	23	47	112	762
4:30 - 4:45	PC	67	180	0	3	205	2	68	49	12	30	48	98	762
	HV	0	3	0	0	1	0	0	1	0	0	1	2	8
SUM		67	183	0	3	206	2	68	50	12	30	49	100	770
4:45 - 5:00	PC	49	200	1	5	208	1	91	51	10	8	28	73	725
	HV	3	1	0	0	6	0	0	2	0	0	0	3	15
SUM		52	201	1	5	214	1	91	53	10	8	28	76	740
2		Total PC		959	Total PC		796	Total PC		551	Total PC		622	
		Totl HV		20	Totl HV		13	Totl HV		5	Totl HV		13	
5:00 - 5:15	PC	51	170	0	7	215	1	91	47	17	18	46	118	781
	HV	1	5	0	0	4	0	0	0	0	0	0	6	16
SUM		52	175	0	7	219	1	91	47	17	18	46	124	797
5:15 - 5:30	PC	47	201	2	16	171	3	72	33	17	7	28	106	703
	HV	0	2	0	0	2	0	1	0	0	1	0	1	7
SUM		47	203	2	16	173	3	73	33	17	8	28	107	710
5:30 - 5:45	PC	39	204	1	10	224	7	47	38	14	4	25	88	701
	HV	1	5	0	0	1	0	0	1	0	0	1	2	11
SUM		40	209	1	10	225	7	47	39	14	4	26	90	712
5:45 - 6:00	PC	37	209	0	8	173	6	59	21	8	8	24	81	634
	HV	0	7	0	0	4	0	1	0	0	0	0	2	14
SUM		37	216	0	8	177	6	60	21	8	8	24	83	648
3		Total PC		961	Total PC		841	Total PC		464	Total PC		553	
		Totl HV		21	Totl HV		11	Totl HV		3	Totl HV		13	
6:00 - 6:15	PC	46	192	1	9	167	2	51	29	8	18	31	91	645
	HV	0	4	0	1	3	1	0	0	0	0	0	1	10
SUM		46	196	1	10	170	3	51	29	8	18	31	92	655
6:15 - 6:30	PC	32	191	0	8	165	4	45	33	6	14	18	86	602
	HV	0	2	0	0	2	0	0	0	0	0	0	0	4
SUM		32	193	0	8	167	4	45	33	6	14	18	86	606
6:30 - 6:45	PC	37	202	0	7	160	2	30	23	5	9	15	75	565
	HV	0	3	0	0	3	0	0	0	0	0	0	0	6
SUM		37	205	0	7	163	2	30	23	5	9	15	75	571
6:45 - 7:00	PC	28	166	0	5	157	3	37	39	7	13	18	71	544
	HV	0	4	0	0	2	0	0	0	0	0	0	0	6
SUM		28	170	0	5	159	3	37	39	7	13	18	71	550
4		Total PC		895	Total PC		689	Total PC		313	Total PC		459	
		Totl HV		13	Totl HV		12	Totl HV		0	Totl HV		1	
Total		693	3039	13	120	2976	44	907	606	168	224	468	1500	10758
		3745			3140			1681			2192			
		6885						3873						



Graphic Summary of Intersection T3 Movements during the Peak Hour

Turning Movement Counts on Intersection T4

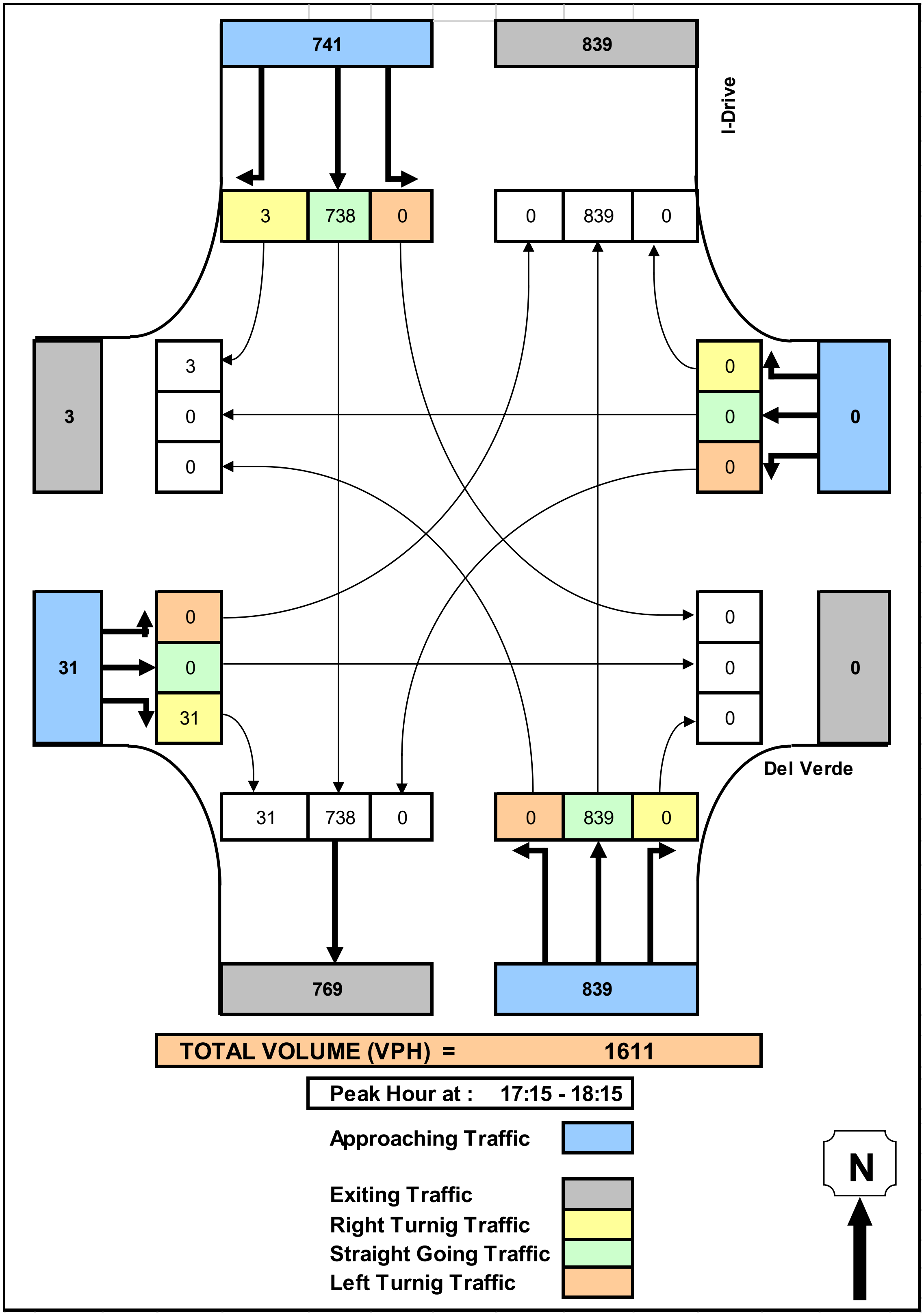
		International Dr						Municipal						TOTAL
		EB			WB			NB			SB			
		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
3:00 - 3:15	PC	4	180	5	20	132	0	17	1	28	0	0	0	387
	HV	0	4	0	0	3	0	0	0	0	0	0	0	7
SUM		4	184	5	20	135	0	17	1	28	0	0	0	394
3:15 - 3:30	PC	6	156	9	31	169	1	24	2	39	0	0	0	437
	HV	0	3	0	0	2	0	0	0	0	0	0	0	5
SUM		6	159	9	31	171	1	24	2	39	0	0	0	442
3:30 - 3:45	PC	10	153	11	25	149	1	12	2	28	0	0	0	391
	HV	0	3	0	0	2	0	0	0	0	0	0	0	5
SUM		10	156	11	25	151	1	12	2	28	0	0	0	396
3:45 - 4:00	PC	4	129	9	23	130	1	7	0	19	0	0	0	322
	HV	0	4	0	0	4	0	0	0	1	0	0	0	9
SUM		4	133	9	23	134	1	7	0	20	0	0	0	331
1		Total PC		676	Total PC		682	Total PC		179	Total PC		0	
		Totl HV		14	Totl HV		11	Totl HV		1	Totl HV		0	
4:00 - 4:15	PC	4	149	12	35	158	2	14	1	28	0	0	0	403
	HV	0	2	0	1	1	0	0	0	0	0	0	0	4
SUM		4	151	12	36	159	2	14	1	28	0	0	0	407
4:15 - 4:30	PC	8	158	11	20	185	3	22	0	52	0	0	0	459
	HV	0	4	1	0	1	0	1	0	1	0	0	0	8
SUM		8	162	12	20	186	3	23	0	53	0	0	0	467
4:30 - 4:45	PC	8	155	20	43	154	0	22	0	37	0	0	0	439
	HV	0	2	0	0	2	0	0	0	0	0	0	0	4
SUM		8	157	20	43	156	0	22	0	37	0	0	0	443
4:45 - 5:00	PC	8	174	18	30	150	2	35	0	58	0	0	0	475
	HV	0	4	1	0	5	0	1	0	0	0	0	0	11
SUM		8	178	19	30	155	2	36	0	58	0	0	0	486
2		Total PC		725	Total PC		782	Total PC		269	Total PC		0	
		Totl HV		14	Totl HV		10	Totl HV		3	Totl HV		0	
5:00 - 5:15	PC	2	152	13	40	186	0	50	0	39	0	0	0	482
	HV	0	2	0	0	2	0	0	0	0	0	0	0	4
SUM		2	154	13	40	188	0	50	0	39	0	0	0	486
5:15 - 5:30	PC	5	141	12	35	164	0	29	0	43	0	0	0	429
	HV	0	3	2	0	0	0	1	0	0	0	0	0	6
SUM		5	144	14	35	164	0	30	0	43	0	0	0	435
5:30 - 5:45	PC	6	185	18	27	170	1	20	0	31	0	0	0	458
	HV	0	2	1	0	0	0	0	0	1	0	0	0	4
SUM		6	187	19	27	170	1	20	0	32	0	0	0	462
5:45 - 6:00	PC	6	170	12	41	177	0	11	0	29	0	0	0	446
	HV	0	3	3	0	3	0	2	0	2	0	0	0	13
SUM		6	173	15	41	180	0	13	0	31	0	0	0	459
3		Total PC		722	Total PC		841	Total PC		252	Total PC		0	
		Totl HV		16	Totl HV		5	Totl HV		6	Totl HV		0	
6:00 - 6:15	PC	6	162	16	33	156	1	16	0	31	0	0	0	421
	HV	0	7	1	0	7	0	0	0	0	0	0	0	15
SUM		6	169	17	33	163	1	16	0	31	0	0	0	436
6:15 - 6:30	PC	4	153	10	28	161	0	13	0	37	0	0	0	406
	HV	0	2	0	0	2	0	0	0	0	0	0	0	4
SUM		4	155	10	28	163	0	13	0	37	0	0	0	410
6:30 - 6:45	PC	6	167	9	25	152	0	12	0	29	0	0	0	400
	HV	0	1	0	0	0	0	0	0	0	0	0	0	1
SUM		6	168	9	25	152	0	12	0	29	0	0	0	401
6:45 - 7:00	PC	7	173	15	26	160	1	14	1	33	0	0	0	430
	HV	0	3	0	0	2	0	0	0	0	0	0	0	5
SUM		7	176	15	26	162	1	14	1	33	0	0	0	435
4		Total PC		728	Total PC		743	Total PC		186	Total PC		0	
		Totl HV		14	Totl HV		11	Totl HV		0	Totl HV		0	
Total		94	2606	209	483	2589	13	323	7	566	0	0	0	6890
		2909			3085			896			0			
		5994						896						



Graphic Summary of Intersection T4 Movements during the Peak Hour

Turning Movement Counts on Intersection T5

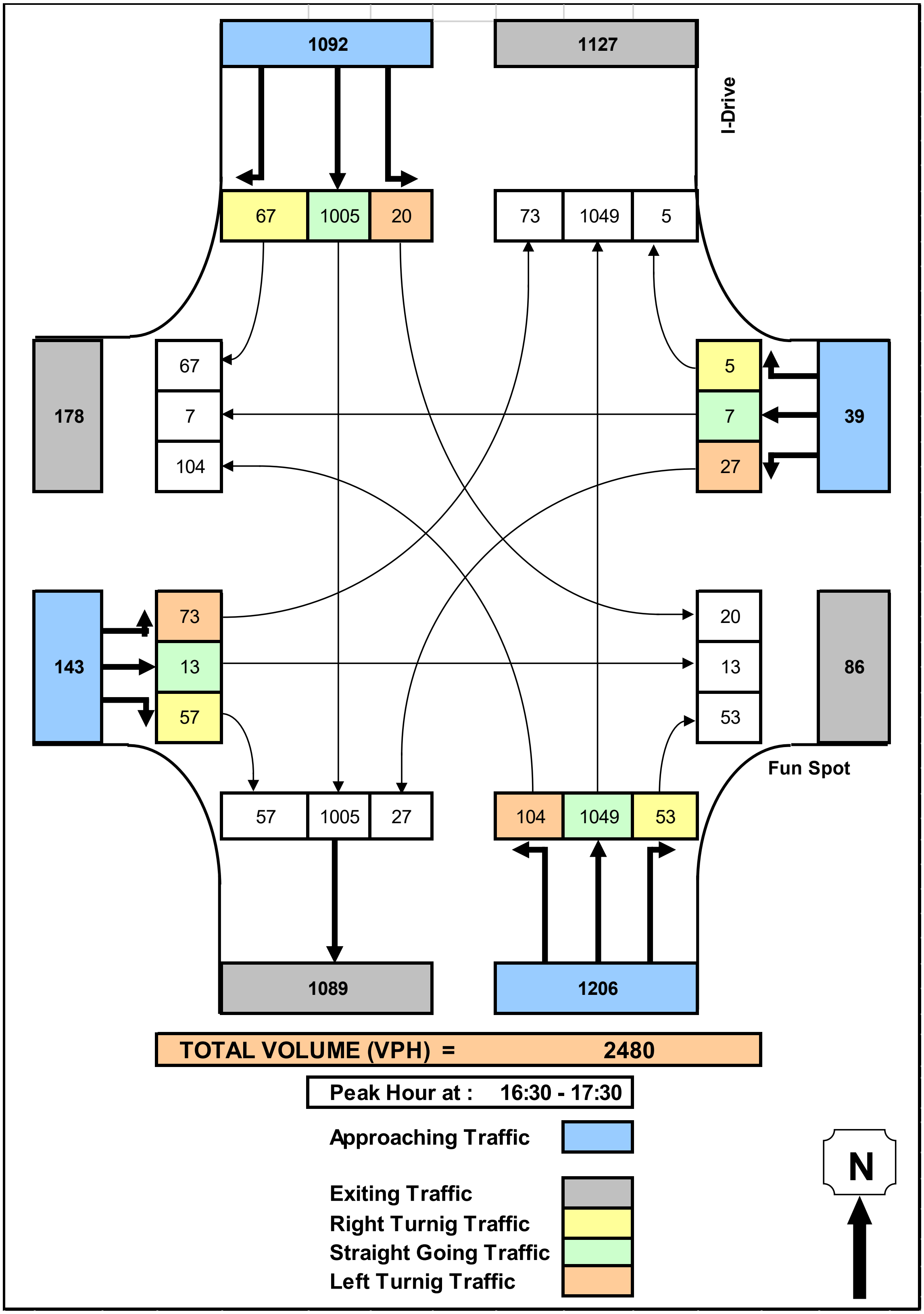
		Del Verde						International Dr						TOTAL
		EB			WB			NB			SB			
		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
3:00 - 3:15	PC	0		10				0	200			166	1	377
	HV	0		0				0	2			0	0	2
SUM		0	0	10	0	0	0	0	202	0	0	166	1	379
3:15 - 3:30	PC	0		6				0	194			178	0	378
	HV	0		0				0	0			2	0	2
SUM		0	0	6	0	0	0	0	194	0	0	180	0	380
3:30 - 3:45	PC	0		5				0	187			185	2	379
	HV	0		0				0	3			4	0	7
SUM		0	0	5	0	0	0	0	190	0	0	189	2	386
3:45 - 4:00	PC	0		9				0	215			192	2	418
	HV	0		0				0	2			0	1	3
SUM		0	0	9	0	0	0	0	217	0	0	192	3	421
1		Total PC		30	Total PC		0	Total PC		796	Total PC		726	
		Totl HV		0	Totl HV		0	Totl HV		7	Totl HV		7	
4:00 - 4:15	PC	0		4				0	208			162	0	374
	HV	0		0				0	2			3	0	5
SUM		0	0	4	0	0	0	0	210	0	0	165	0	379
4:15 - 4:30	PC	0		4				0	199			184	0	387
	HV	0		0				0	1			2	0	3
SUM		0	0	4	0	0	0	0	200	0	0	186	0	390
4:30 - 4:45	PC	0		7				0	207			148	0	362
	HV	0		0				0	0			2	0	2
SUM		0	0	7	0	0	0	0	207	0	0	150	0	364
4:45 - 5:00	PC	0		6				0	194			165	2	367
	HV	0		0				0	2			2	1	5
SUM		0	0	6	0	0	0	0	196	0	0	167	3	372
2		Total PC		21	Total PC		0	Total PC		808	Total PC		661	
		Totl HV		0	Totl HV		0	Totl HV		5	Totl HV		10	
5:00 - 5:15	PC	0		5				0	209			175	0	389
	HV	0		0				0	2			3	0	5
SUM		0	0	5	0	0	0	0	211	0	0	178	0	394
5:15 - 5:30	PC	0		8				0	231			189	0	428
	HV	0		0				0	2			2	0	4
SUM		0	0	8	0	0	0	0	233	0	0	191	0	432
5:30 - 5:45	PC	0		7				0	192			178	0	377
	HV	0		0				0	1			2	0	3
SUM		0	0	7	0	0	0	0	193	0	0	180	0	380
5:45 - 6:00	PC	0		12				0	196			175	1	384
	HV	0		0				0	1			2	0	3
SUM		0	0	12	0	0	0	0	197	0	0	177	1	387
3		Total PC		32	Total PC		0	Total PC		828	Total PC		718	
		Totl HV		0	Totl HV		0	Totl HV		6	Totl HV		9	
6:00 - 6:15	PC	0		4				0	214			188	1	407
	HV	0		0				0	2			2	1	5
SUM		0	0	4	0	0	0	0	216	0	0	190	2	412
6:15 - 6:30	PC	0		20				0	185			142	0	347
	HV	0		0				0	2			1	0	3
SUM		0	0	20	0	0	0	0	187	0	0	143	0	350
6:30 - 6:45	PC	0		11				0	186			191	0	388
	HV	0		0				0	2			3	0	5
SUM		0	0	11	0	0	0	0	188	0	0	194	0	393
6:45 - 7:00	PC	0		5				0	194			188	0	387
	HV	0		0				0	1			2	0	3
SUM		0	0	5	0	0	0	0	195	0	0	190	0	390
4		Total PC		40	Total PC		0	Total PC		779	Total PC		710	
		Totl HV		0	Totl HV		0	Totl HV		7	Totl HV		9	
Total		0	0	123	0	0	0	0	3236	0	0	2838	12	6209
		123			0			3236			2850			
		123						6086						



Graphic Summary of Intersection T5 Movements during the Peak Hour

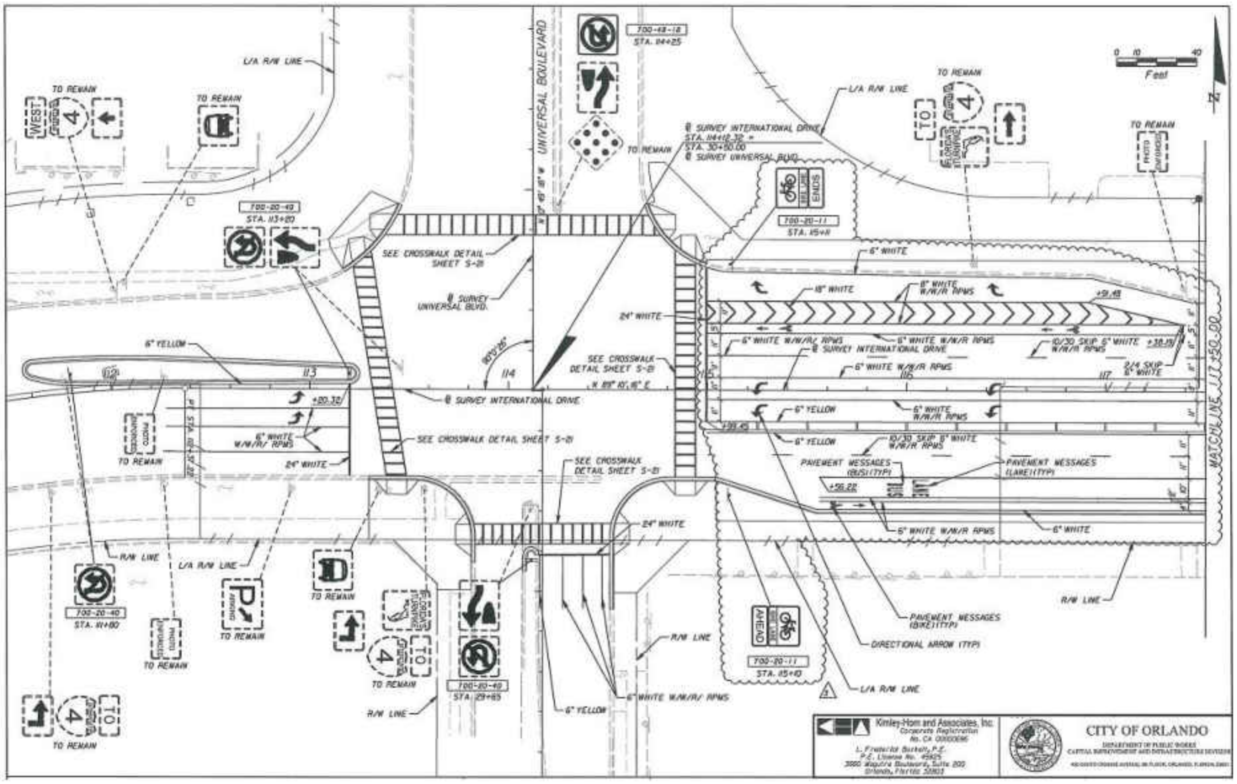
Turning Movement Counts on Intersection T6

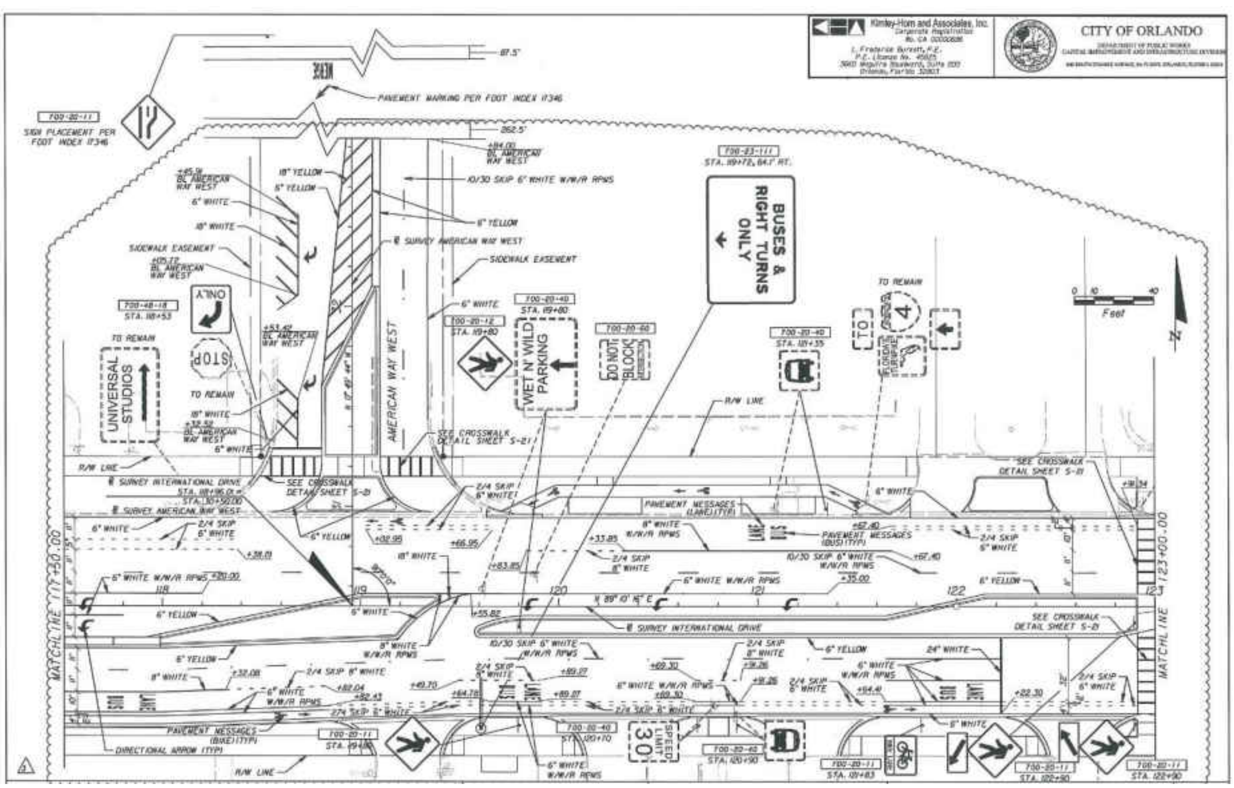
		Fun Spot						International Dr						TOTAL
		EB			WB			NB			SB			
		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
3:00 - 3:15	PC	5	0	8	4	1	1	20	169	5	3	142	4	362
	HV	0	0	0	0	0	0	0	0	0	0	3	0	3
SUM		5	0	8	4	1	1	20	169	5	3	145	4	365
3:15 - 3:30	PC	10	0	9	5	2	2	29	165	7	2	155	7	393
	HV	0	0	0	0	0	0	0	5	0	0	5	0	10
SUM		10	0	9	5	2	2	29	170	7	2	160	7	403
3:30 - 3:45	PC	20	3	21	1	0	5	25	214	3	6	127	8	433
	HV	0	0	0	0	0	0	0	0	0	0	5	0	5
SUM		20	3	21	1	0	5	25	214	3	6	132	8	438
3:45 - 4:00	PC	8	1	17	1	1	3	27	233	5	5	189	12	502
	HV	0	0	0	0	0	0	0	5	1	0	1	0	7
SUM		8	1	17	1	1	3	27	238	6	5	190	12	509
1		Total PC		102	Total PC		26	Total PC		902	Total PC		660	
		Totl HV		0	Totl HV		0	Totl HV		11	Totl HV		14	
4:00 - 4:15	PC	13	2	8	3	1	5	18	250	16	0	201	16	533
	HV	0	0	1	0	0	0	0	6	0	0	6	0	13
SUM		13	2	9	3	1	5	18	256	16	0	207	16	546
4:15 - 4:30	PC	16	4	20	5	3	7	29	246	11	3	244	8	596
	HV	0	0	0	0	0	0	0	2	0	0	6	0	8
SUM		16	4	20	5	3	7	29	248	11	3	250	8	604
4:30 - 4:45	PC	11	10	8	7	6	0	26	264	5	4	256	18	615
	HV	0	0	0	0	0	0	0	4	0	0	3	0	7
SUM		11	10	8	7	6	0	26	268	5	4	259	18	622
4:45 - 5:00	PC	15	1	20	3	1	2	27	266	18	3	246	21	623
	HV	0	0	0	0	0	0	0	3	0	0	3	0	6
SUM		15	1	20	3	1	2	27	269	18	3	249	21	629
2		Total PC		128	Total PC		43	Total PC		1176	Total PC		1020	
		Totl HV		1	Totl HV		0	Totl HV		15	Totl HV		18	
5:00 - 5:15	PC	18	1	13	6	0	0	23	255	11	8	245	15	595
	HV	0	0	0	0	0	0	0	3	0	0	5	0	8
SUM		18	1	13	6	0	0	23	258	11	8	250	15	603
5:15 - 5:30	PC	28	1	16	11	0	3	28	249	19	5	241	13	614
	HV	1	0	0	0	0	0	0	5	0	0	6	0	12
SUM		29	1	16	11	0	3	28	254	19	5	247	13	626
5:30 - 5:45	PC	25	0	21	6	1	4	33	266	10	8	198	21	593
	HV	0	0	0	0	0	0	0	3	1	0	0	0	4
SUM		25	0	21	6	1	4	33	269	11	8	198	21	597
5:45 - 6:00	PC	19	0	17	1	1	3	20	248	10	6	188	14	527
	HV	0	0	0	0	0	0	0	5	1	0	1	0	7
SUM		19	0	17	1	1	3	20	253	11	6	189	14	534
3		Total PC		159	Total PC		36	Total PC		1172	Total PC		962	
		Totl HV		1	Totl HV		0	Totl HV		18	Totl HV		12	
6:00 - 6:15	PC	22	0	11	4	1	0	33	218	4	10	180	17	500
	HV	0	0	0	0	0	0	0	5	0	0	4	0	9
SUM		22	0	11	4	1	0	33	223	4	10	184	17	509
6:15 - 6:30	PC	10	0	14	1	0	2	23	238	8	4	169	20	489
	HV	0	0	0	0	0	0	0	3	0	0	2	0	5
SUM		10	0	14	1	0	2	23	241	8	4	171	20	494
6:30 - 6:45	PC	8	0	12	2	2	1	26	205	12	3	175	15	461
	HV	0	0	0	0	0	0	0	4	0	0	3	0	7
SUM		8	0	12	2	2	1	26	209	12	3	178	15	468
6:45 - 7:00	PC	6	0	11	0	1	1	20	216	10	2	162	12	441
	HV	0	0	0	0	0	0	0	0	0	0	1	0	1
SUM		6	0	11	0	1	1	20	216	10	2	163	12	442
4		Total PC		94	Total PC		15	Total PC		1013	Total PC		769	
		Totl HV		0	Totl HV		0	Totl HV		12	Totl HV		10	
Total		235	23	227	60	21	39	407	3755	157	72	3172	221	8389
		485			120			4319			3465			
		605						7784						

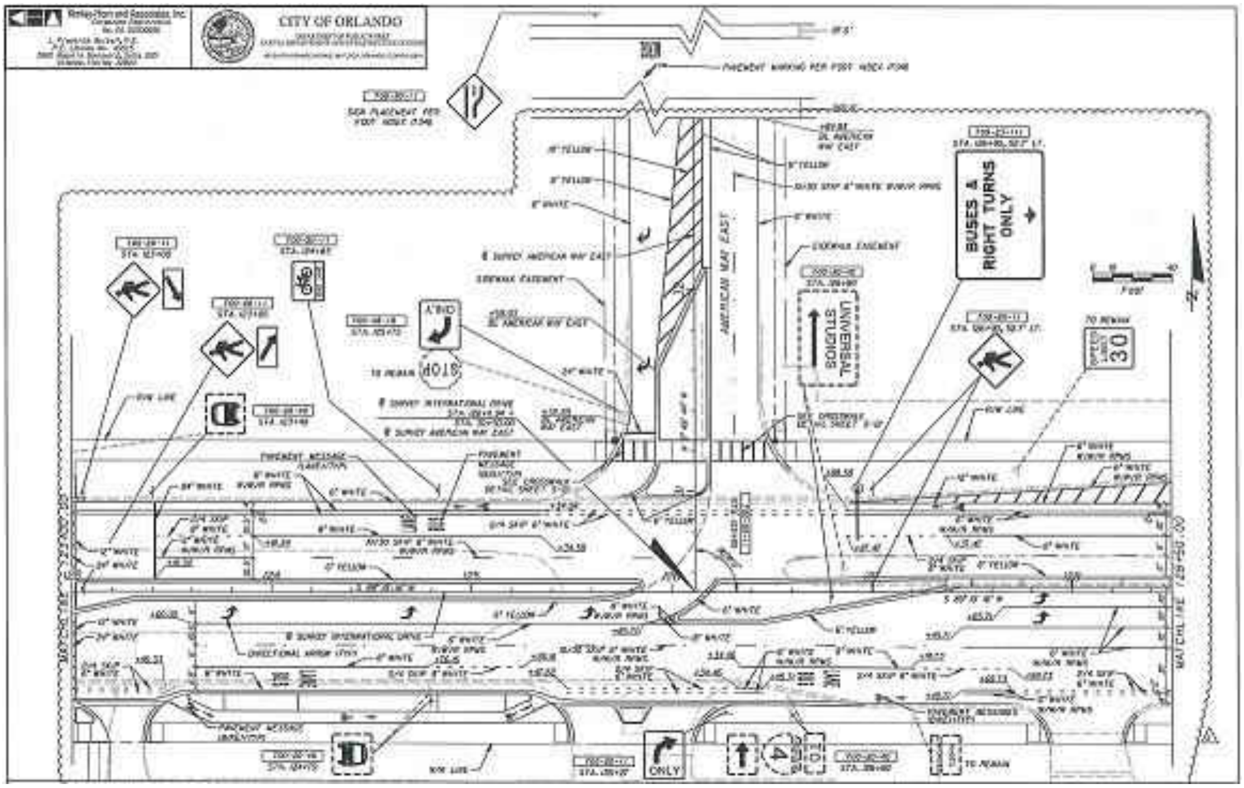


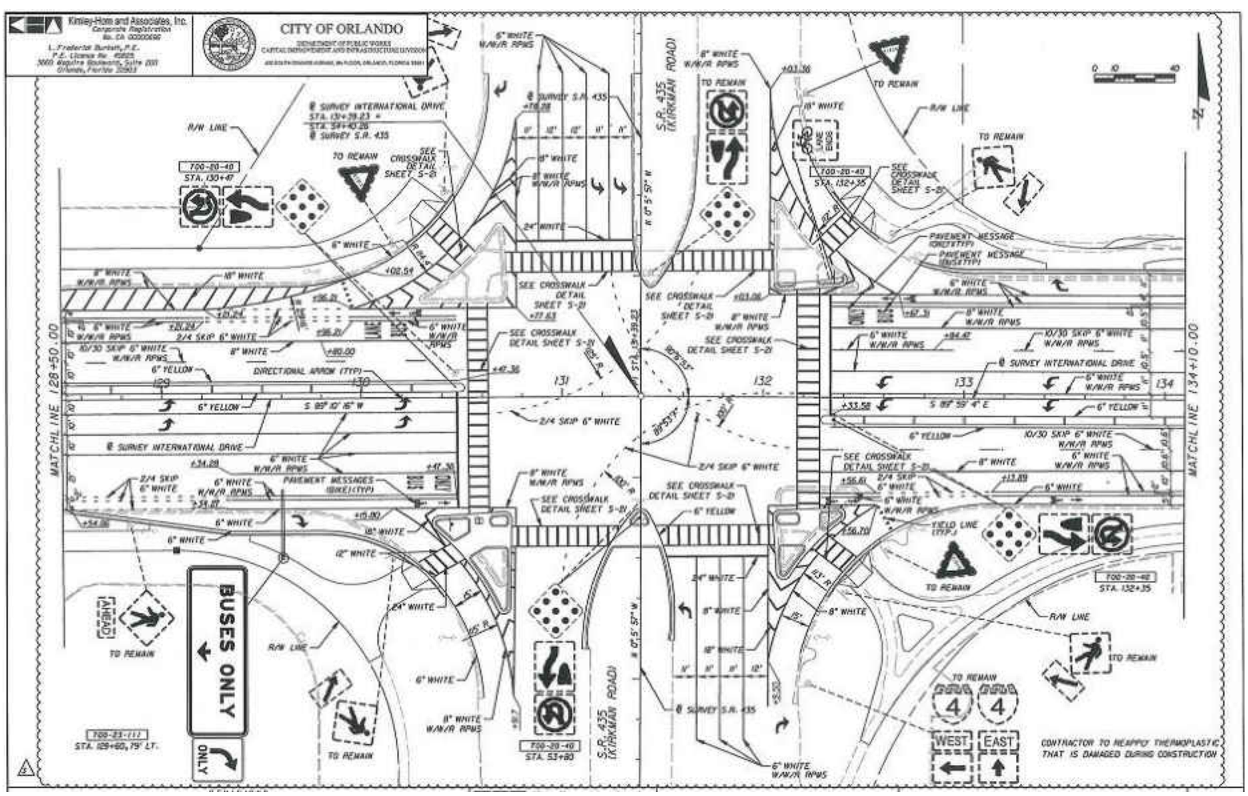
Graphic Summary of Intersection T6 Movements during the Peak Hour

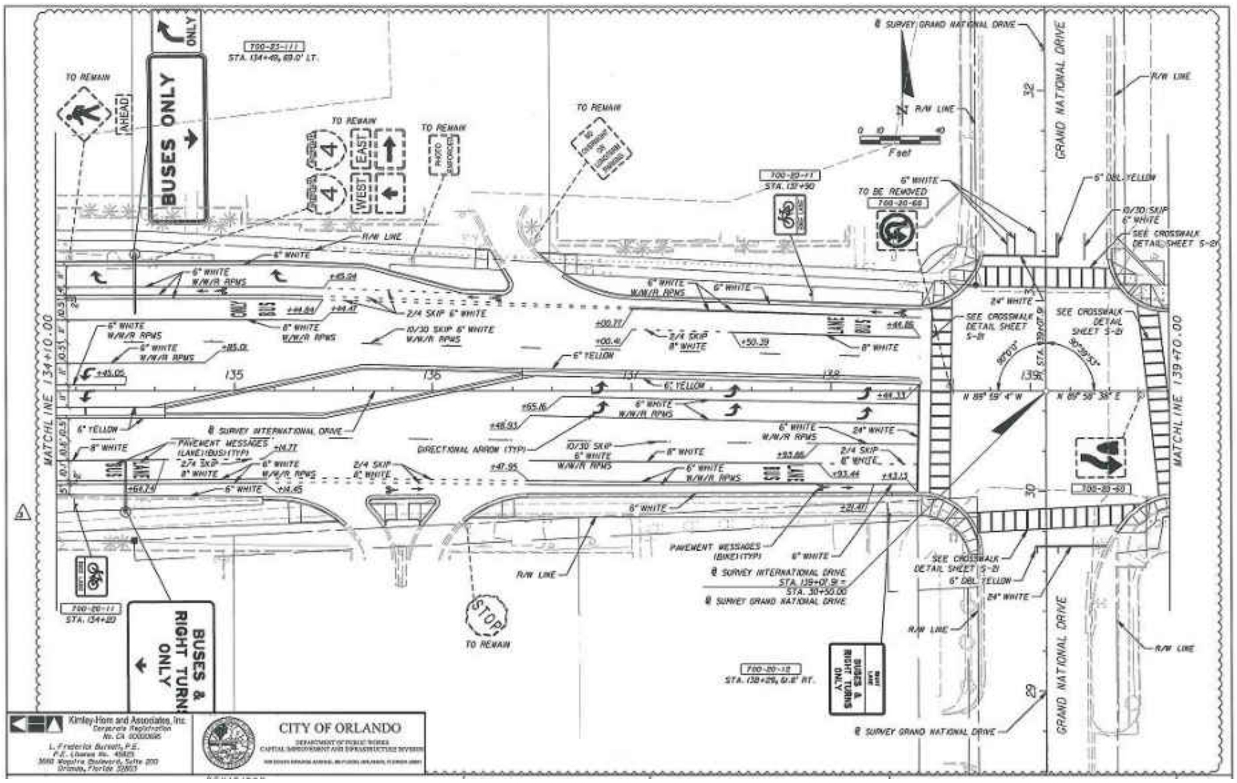
APPENDIX C: GEOMETRIC, SIGNING, AND PAVEMENT MARKING PLAN FOR BRT

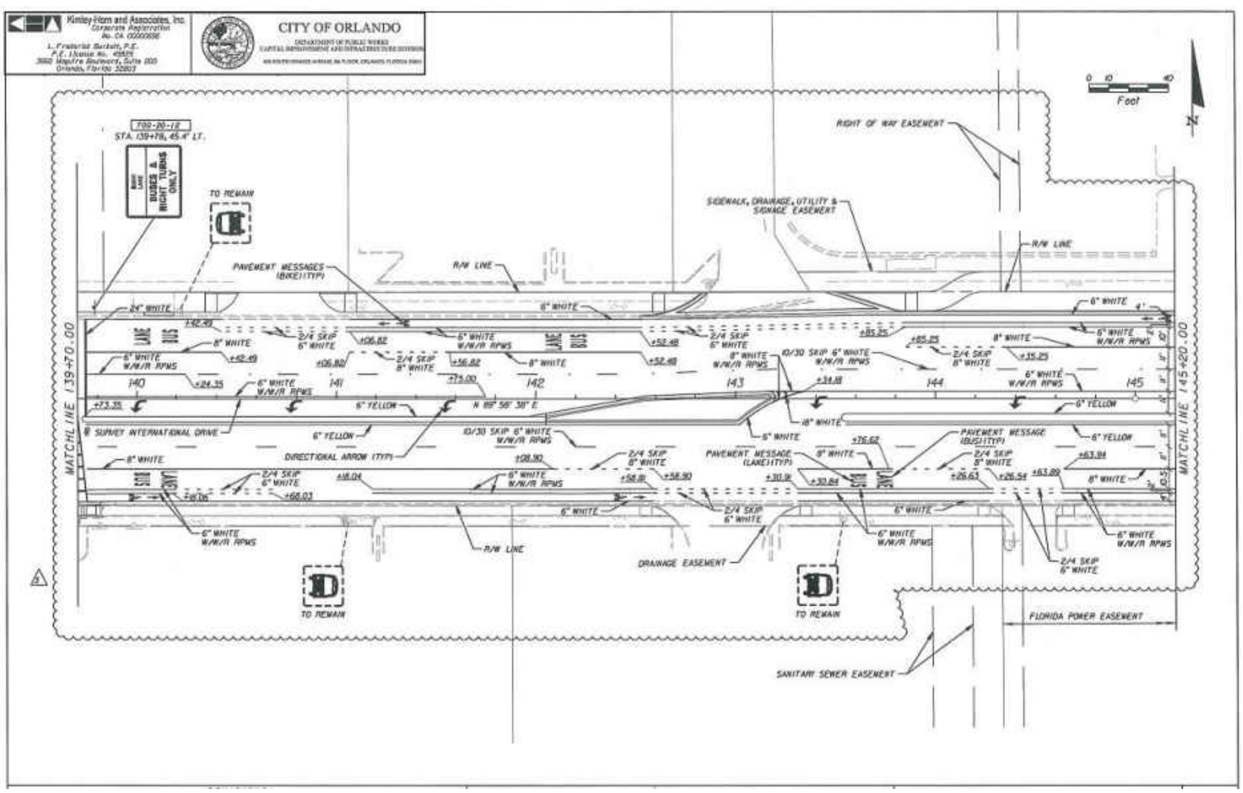

UNIVERSAL BOULEVARD
TO REMAIN
L/A R/W LINE
SEE CROSSWALK DETAIL SHEET S-21
℄ SURVEY UNIVERSAL BLVD.
℄ SURVEY INTERNATIONAL DRIVE
6" YELLOW
24" WHITE
18" WHITE
6" WHITE
R/W LINE
PAVEMENT MESSAGES (BIKE)(TYP)
DIRECTIONAL ARROW (TYP)
PAVEMENT MESSAGES (BUS)(TYP)
PAVEMENT MESSAGES (LANE)(TYP)
Feet
Kimley-Horn and Associates, Inc.
CITY OF ORLANDO

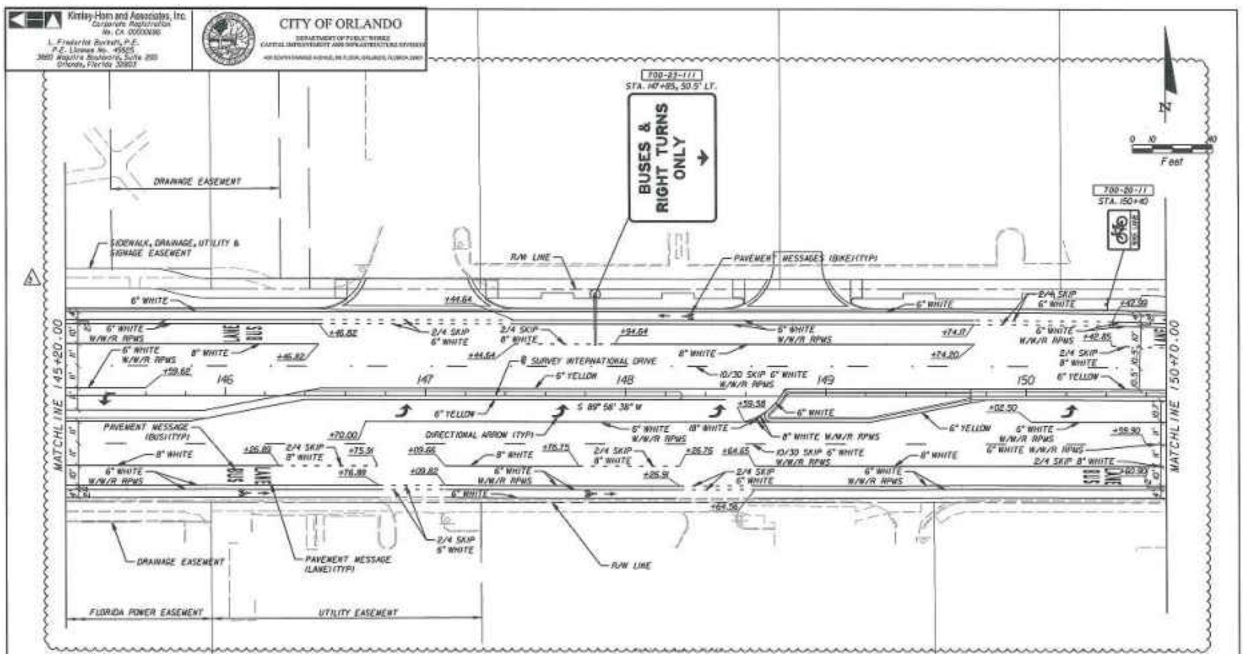

Kimley-Horn and Associates, Inc.
CITY OF ORLANDO
PAVEMENT MARKING PER FDOT INDEX 17346
SIGN PLACEMENT PER FDOT INDEX 17346
BUSES & RIGHT TURNS ONLY
AMERICAN WAY WEST
SIDEWALK EASEMENT
UNIVERSAL STUDIOS
STOP
ONLY
WET N' WILD PARKING
DO NOT BLOCK
SEE CROSSWALK DETAIL SHEET S-21
℄ SURVEY INTERNATIONAL DRIVE
℄ SURVEY AMERICAN WAY WEST
PAVEMENT MESSAGES (BIKE)(TYP)
DIRECTIONAL ARROW (TYP)
R/W LINE
SPEED LIMIT 30
Feet

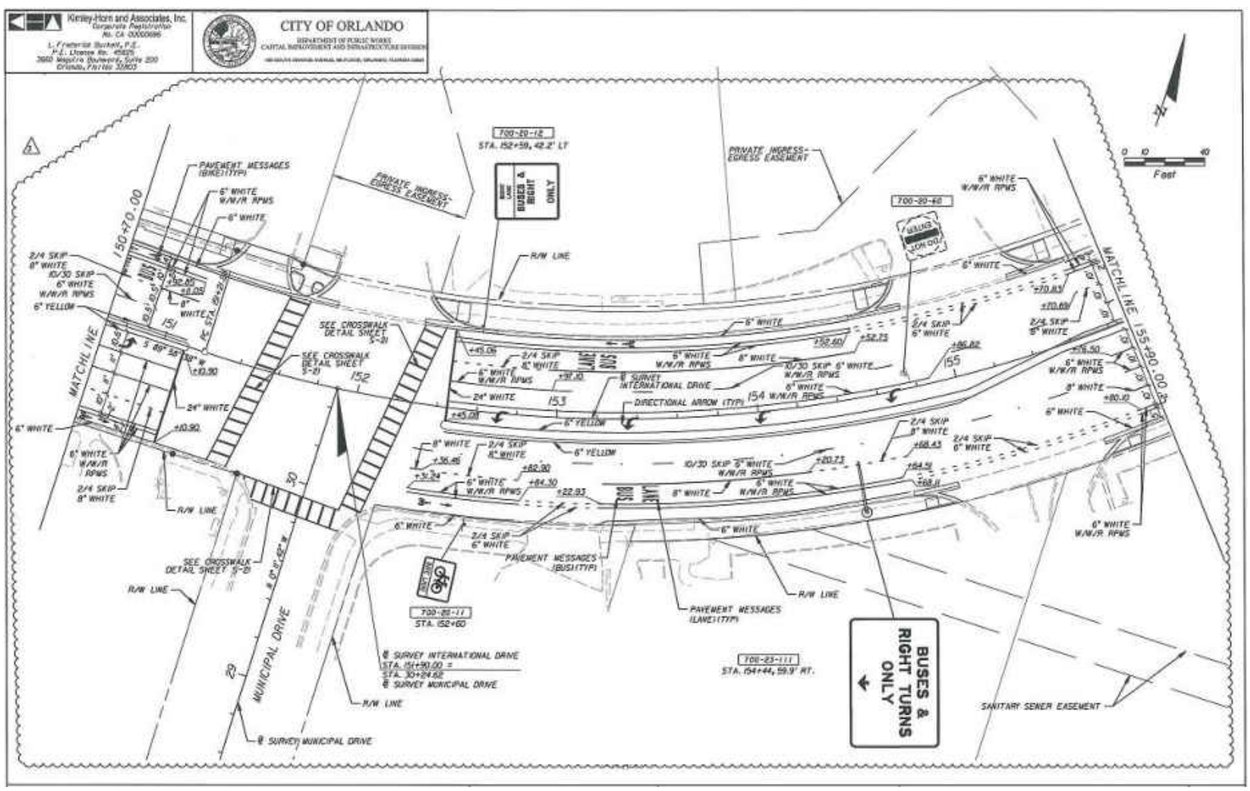

Kimley-Horn and Associates, Inc.
CITY OF ORLANDO
BUSES & RIGHT TURNS ONLY
UNIVERSAL STUDIOS
AMERICAN WAY EAST
STOP
ONLY
SPEED LIMIT 30
MATCHLINE 128+50.00

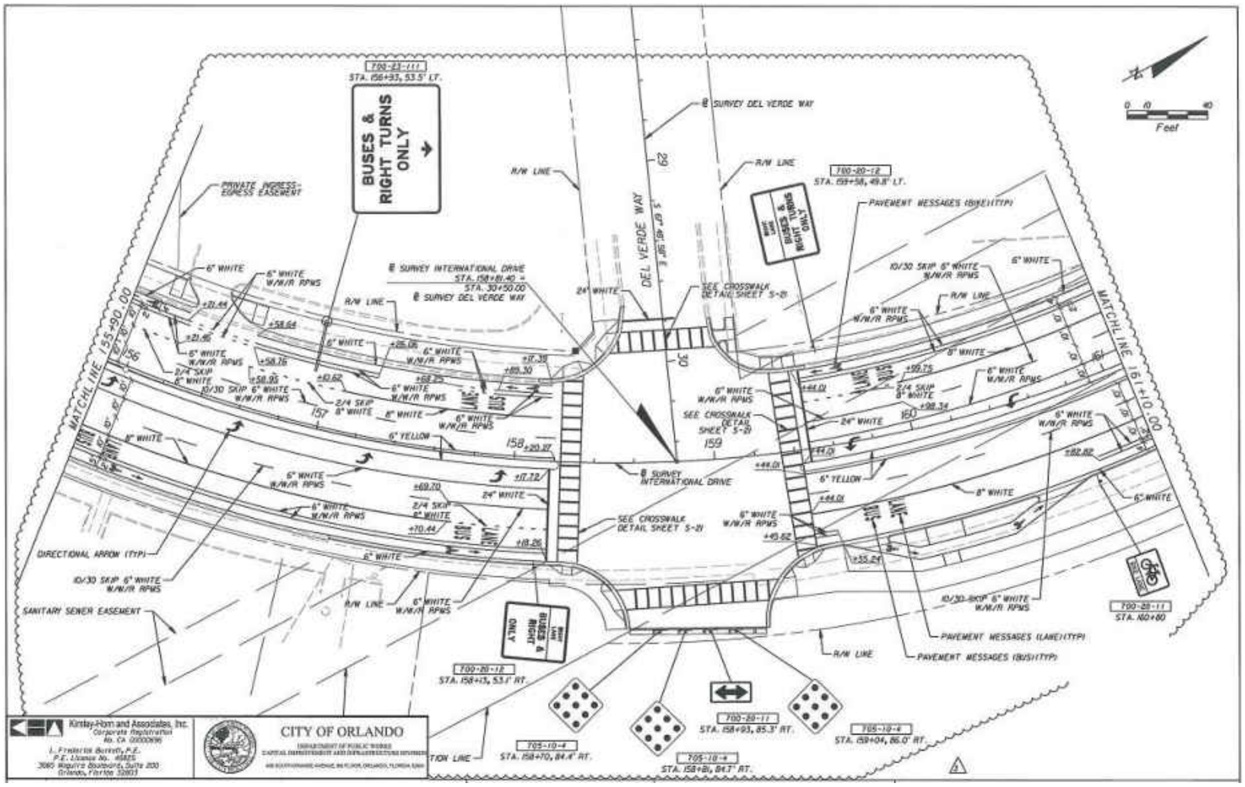

Kimley-Horn and Associates, Inc.
CITY OF ORLANDO
S.R. 435 (KIRKMAN ROAD)
BUSES ONLY
ONLY
AHEAD
WEST
EAST
MATCHLINE 128+50.00
MATCHLINE 134+10.00
CONTRACTOR TO REAPPLY THERMOPLASTIC THAT IS DAMAGED DURING CONSTRUCTION

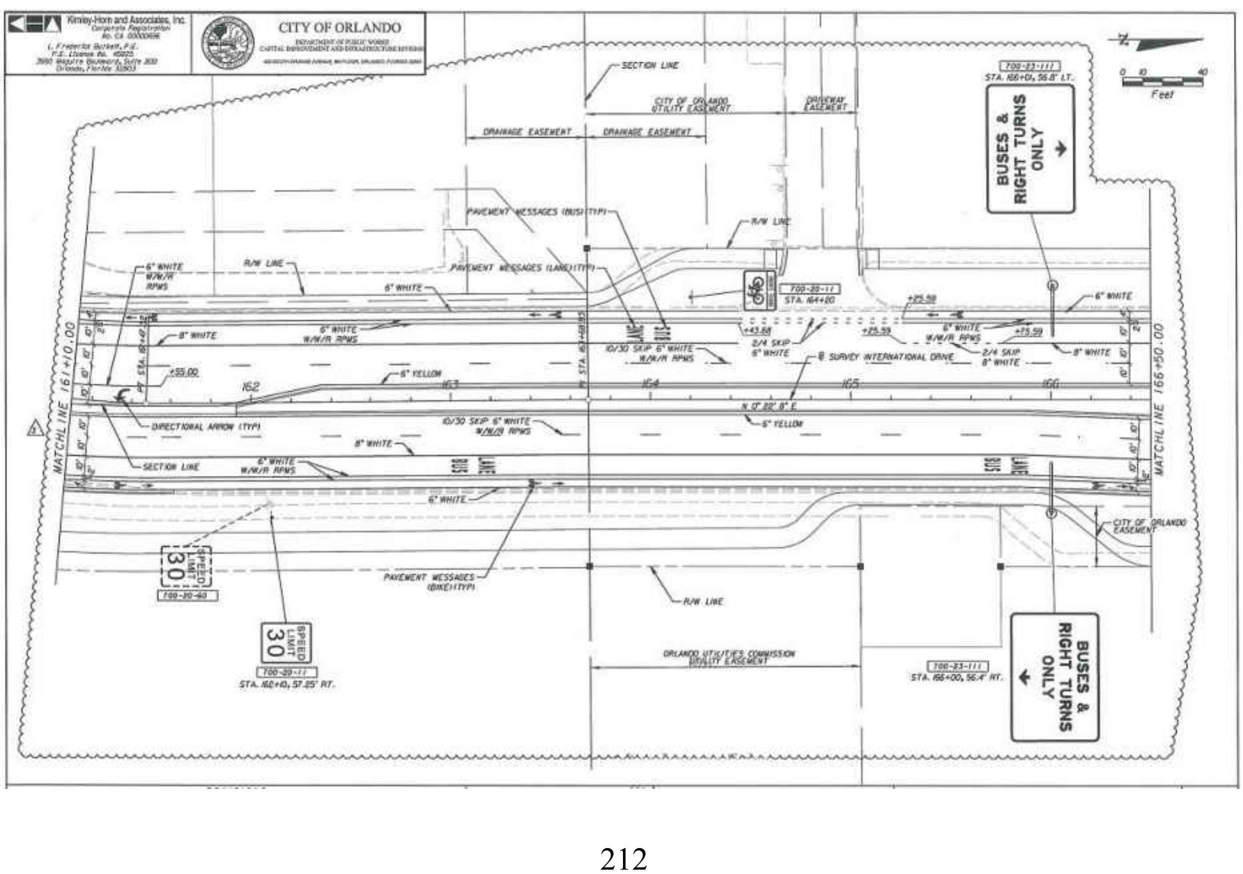

BUSES ONLY
TO REMAIN
GRAND NATIONAL DRIVE
MATCHLINE 134+10.00
MATCHLINE 139+70.00
BUSES & RIGHT TURNS ONLY
Kimley-Horn and Associates, Inc.
CITY OF ORLANDO

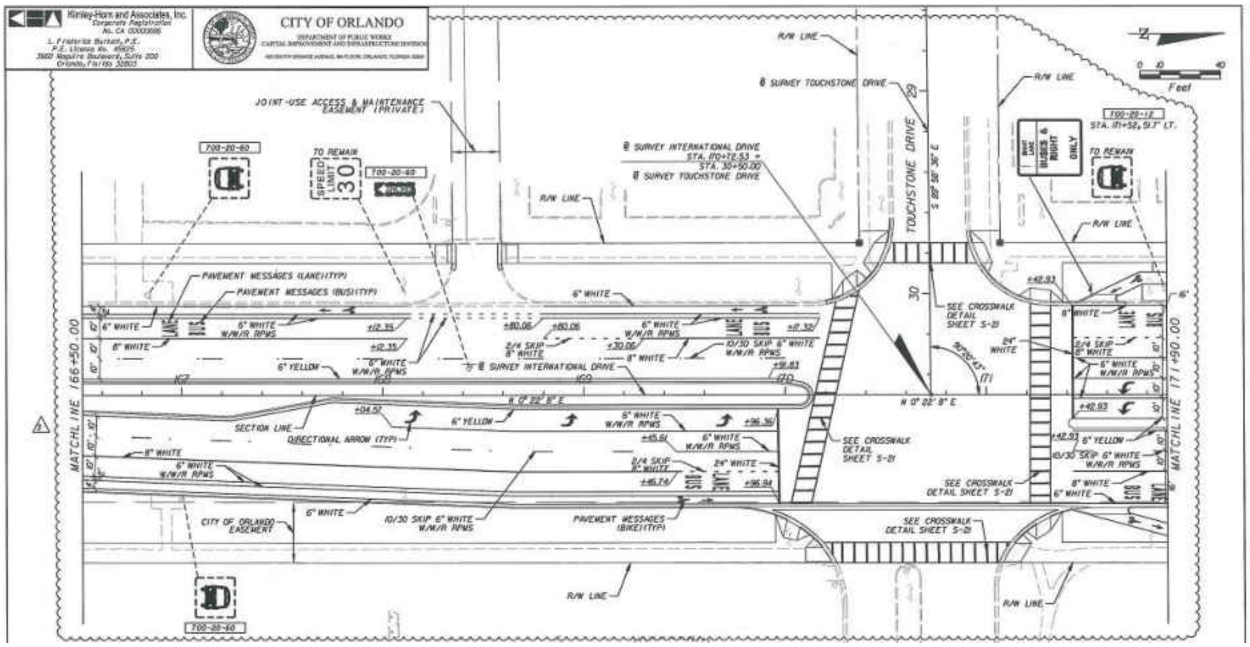

Kimley-Horn and Associates, Inc.
CITY OF ORLANDO
MATCHLINE 139+70.00
MATCHLINE 145+20.00
TO REMAIN
RIGHT OF WAY EASEMENT
FLORIDA POWER EASEMENT
SANITARY SEWER EASEMENT
DRAINAGE EASEMENT

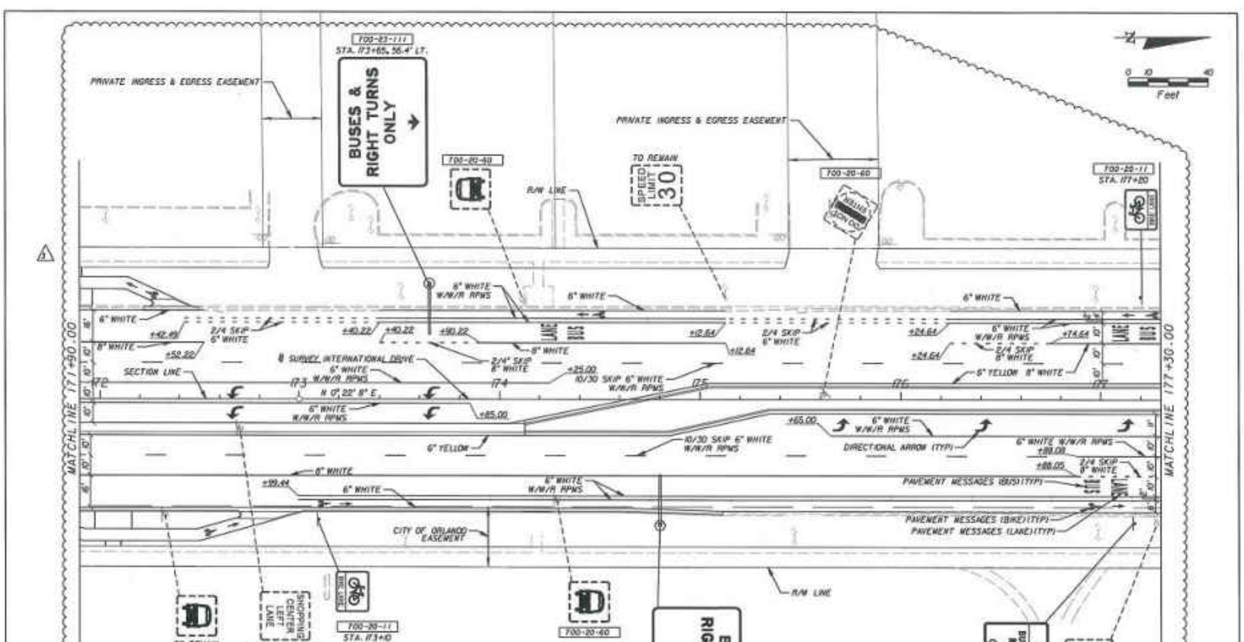

Kimley-Horn and Associates, Inc.
CITY OF ORLANDO
BUSES & RIGHT TURNS ONLY
DRAINAGE EASEMENT
SIDEWALK, DRAINAGE, UTILITY & SIGNAGE EASEMENT
MATCHLINE 145+20.00
MATCHLINE 150+70.00
FLORIDA POWER EASEMENT
UTILITY EASEMENT
R/W LINE
Feet


Kimley-Horn and Associates, Inc.
CITY OF ORLANDO
BUSES & RIGHT TURNS ONLY
PRIVATE INGRESS-EGRESS EASEMENT
MUNICIPAL DRIVE
MATCHLINE 155+90.00
SANITARY SEWER EASEMENT
R/W LINE
Feet


BUSES & RIGHT TURNS ONLY
700-23-111
STA. 156+93, 53.5' LT.
@ SURVEY DEL VERDE WAY
DEL VERDE WAY
R/W LINE
PRIVATE INGRESS-EGRESS EASEMENT
@ SURVEY INTERNATIONAL DRIVE
@ SURVEY DEL VERDE WAY
SEE CROSSWALK DETAIL SHEET S-21
MATCHLINE 155+90.00
MATCHLINE 161+10.00
6" WHITE
8" WHITE
6" YELLOW
24" WHITE
DIRECTIONAL ARROW (TYP)
SANITARY SEWER EASEMENT
PAVEMENT MESSAGES (BIKE)(TYP)
PAVEMENT MESSAGES (LANE)(TYP)
PAVEMENT MESSAGES (BUS)(TYP)
@ SURVEY INTERNATIONAL DRIVE
Kimley-Horn and Associates, Inc.
CITY OF ORLANDO
Feet


Kimley-Horn and Associates, Inc.
CITY OF ORLANDO
SECTION LINE
CITY OF ORLANDO UTILITY EASEMENT
DRIVEWAY EASEMENT
DRAINAGE EASEMENT
PAVEMENT MESSAGES (BUS)(TYP)
PAVEMENT MESSAGES (LANE)(TYP)
R/W LINE
6" WHITE
8" WHITE
6" YELLOW
DIRECTIONAL ARROW (TYP)
@ SURVEY INTERNATIONAL DRIVE
MATCHLINE 161+10.00
MATCHLINE 166+50.00
BUSES & RIGHT TURNS ONLY
700-23-111
STA. 166+01, 56.8' LT.
STA. 166+00, 56.4' RT.
SPEED LIMIT 30
700-20-11
STA. 162+10, 57.25' RT.
PAVEMENT MESSAGES (BIKE)(TYP)
ORLANDO UTILITIES COMMISSION UTILITY EASEMENT
CITY OF ORLANDO EASEMENT
Feet


Kimley-Horn and Associates, Inc.
CITY OF ORLANDO
TOUCHSTONE DRIVE
SEE CROSSWALK DETAIL SHEET S-21
MATCHLINE 166+50.00
MATCHLINE 171+90.00
SPEED LIMIT 30
TO REMAIN


BUSES & RIGHT TURNS ONLY
PRIVATE INGRESS & EGRESS EASEMENT
MATCHLINE 171+90.00
MATCHLINE 177+30.00
SPEED LIMIT 30
TO REMAIN
Kimley-Horn and Associates, Inc.
CITY OF ORLANDO

APPENDIX D: TRAFFIC SIGNALS CONTROL DATA

Intersection (T1)

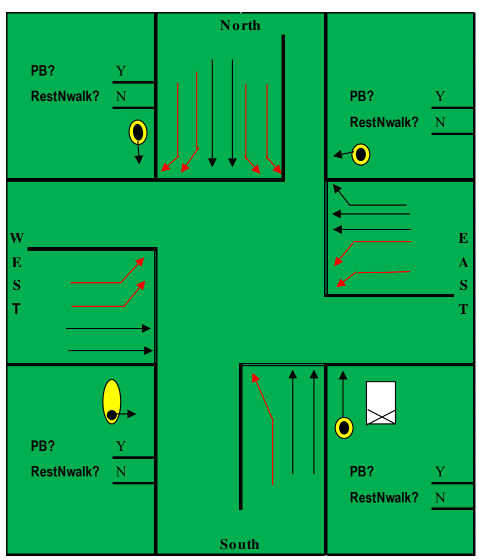
		Ring - 1				Ring - 2			
Name	376 - Universal Bv	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	10/16/2012	EBL	WB	SBL	NB	WBL	EB	NBL	SB
# of Cycles	53	36.0	58.0	23.0	52.5	17.3	76.6	16.6	59.5
Average of Cycles	170	Protected	Balls	Protected	Balls	Protected	Balls	Protected	Balls

		Ring - 1				Ring - 2			
Name	376 - Universal Bv	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	10/17/2012	EBL	WB	SBL	NB	WBL	EB	NBL	SB
# of Cycles	53	35.9	58.3	23.9	51.9	18.4	75.8	16.4	59.4
Average of Cycles	170	Protected	Balls	Protected	Balls	Protected	Balls	Protected	Balls

		Ring - 1				Ring - 2			
Name	376 - Universal Bv	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	3/6/2013	EBL	WB	SBL	NB	WBL	EB	NBL	SB
# of Cycles	87	31.0	59.0	24.0	52.0	19.0	71.0	15.0	61.0
Average of Cycles	166	Protected	Balls	Protected	Balls	Protected	Balls	Protected	Balls

	EB	WB	NB	SB
MIN GREEN	5	5	5	5
NUMBER OF FIXED INTERVALS	3	3	3	3
DWELL INTERVAL	1	2	1	1
Yellow	1	5	7	3
RED	1	5	7	3

CONTROLLER TIMING								
	RING 1				RING 2			
APPROACH	EBL	WB	SBL	NB	WBL	EB	NBL	SB
PHASE #	1	2	3	4	5	6	7	8
INITIAL	4	10	4	6	4	10	4	6
PASSAGE	2	3	2	2	2	3	2	2
YELLOW	4	4	4	4	4	4	4	4
RED CLEAR	2.5	2.8	3	3	2.8	2.5	3	3
MAX 1	24	45	19	45	19	45	12	45
MAX 2	10	25	10	25	10	25	10	25
WALK		10		10		20		7
PED CLEAR		32		32		23		34
MIN RECALL		Yes				Yes		
MAX RECALL								
PED RECALL								
NON -LOCK	N/L	Lock	N/L	N/L	N/L	Lock	N/L	N/L
REST IN WALK								
DISPLAY	Protected	Balls	Protected	Balls	Protected	Balls	Protected	Balls
U.C.F.	R	Y	R	R	R	Y	R	R
MAIN ST.		Yes				Yes		
L/S POSITION	1	2	3	4	5	6	7	8

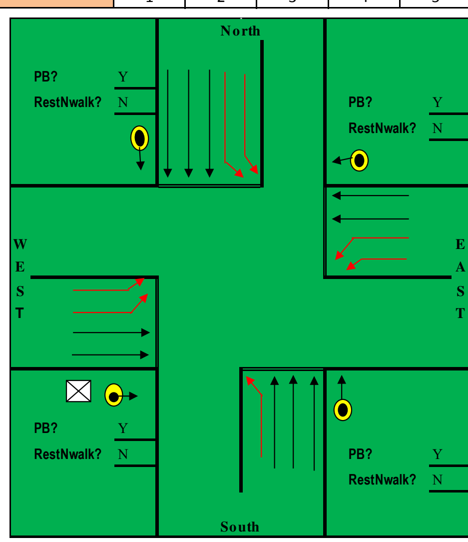


Intersection (T2)

		Ring - 1				Ring - 2			
Name	380 - Kirkman	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	10/16/2012	NBL	SB	EBL	WB	SBL	NB	WBL	EB
# of Cycles	53	23.1	69.2	17.7	60.1	33.3	59.0	17.7	60.1
Average of Cycles	170	Protected	Balls	Protected	Balls	Protected	Balls	Protected	Balls
		Ring - 1				Ring - 2			
Name	380 - Kirkman	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	10/17/2012	NBL	SB	EBL	WB	SBL	NB	WBL	EB
# of Cycles	53	25.8	66.8	18.0	59.3	33.7	59.0	18.0	59.3
Average of Cycles	170	Protected	Balls	Protected	Balls	Protected	Balls	Protected	Balls
		Ring - 1				Ring - 2			
Name	380 - Kirkman	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	3/6/2013	NBL	SB	EBL	WB	SBL	NB	WBL	EB
# of Cycles	87	22.7	65.3	17.3	59.5	34.2	53.9	17.0	59.8
Average of Cycles	164.8	Protected	Balls	Protected	Balls	Protected	Balls	Protected	Balls

	EB	WB	NB	SB
MIN GREEN	5	5	5	5
NUMBER OF FIXED INTERVALS	3	3	3	3
DWELL INTERVAL	1	1	1	1
Yellow	3	7	1	5
RED	3	7	1	5

CONTROLLER TIMING								
	RING 1				RING 2			
APPROACH	NBL	SB	EBL	WB	SBL	NB	WBL	EB
PHASE #	1	2	3	4	5	6	7	8
INITIAL	7	10	7	10	7	10	7	10
PASSAGE	3	6	2	2.5	2.5	6	2	2.5
YELLOW	4.5	4.5	4	4	4.5	4.5	4	4
RED CLEAR	2.5	2.5	3	3	2.5	2.5	3	3
MAX 1	35	60	25	35	25	60	15	35
MAX 2	10	45	10	30	10	45	10	30
WALK		7		7		7		7
PED CLEAR		29		42		29		43
MIN RECALL		Yes				Yes		
MAX RECALL								
PED RECALL								
NON -LOCK	N/L	Lock	N/L	N/L	N/L	Lock	N/L	N/L
REST IN WALK								
DISPLAY	Protected	Balls	Protected	Balls	Protected	Balls	Protected	Balls
U.C.F.	R	Y	R	R	R	Y	R	R
MAIN ST.		Yes				Yes		
L/S POSITION	1	2	3	4	5	6	7	8

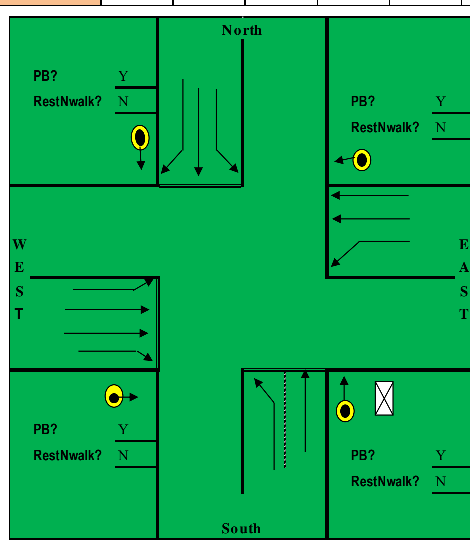


Intersection (T3)

		Ring - 1				Ring - 2			
Name	370-Grand-National	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	10/16/2012	EBL	WB	SBL	NB	WBL	EB	NBL	SB
# of Cycles	54	22.0	82.6	5.8	57.2	6.2	98.3	15.9	47.1
Average of Cycles	167.6	5-sect	Balls	5-sect	Balls	5-sect	Balls	5-sect	Balls
		Ring - 1				Ring - 2			
Name	370-Grand-National	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	10/17/2012	EBL	WB	SBL	NB	WBL	EB	NBL	SB
# of Cycles	53	21.4	83.8	5.2	57.3	7.2	98.0	15.4	47.1
Average of Cycles	167.7	5-sect	Balls	5-sect	Balls	5-sect	Balls	5-sect	Balls
		Ring - 1				Ring - 2			
Name	370-Grand-National	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	3/6/2013	EBL	WB	SBL	NB	WBL	EB	NBL	SB
# of Cycles	90	23.6	80.5	7.2	52.9	7.0	97.1	16.0	44.1
Average of Cycles	164.2	5-sect	Balls	5-sect	Balls	5-sect	Balls	5-sect	Balls

	EB	WB	NB	SB
MIN GREEN	5	5	5	5
NUMBER OF FIXED INTERVALS	3	3	3	3
DWELL INTERVAL	1	1	1	1
Yellow	1	5	1	1
RED	1	5	1	1

CONTROLLER TIMING								
	RING 1				RING 2			
APPROACH	EBL	WB	SBL	NB	WBL	EB	NBL	SB
PHASE #	1	2	3	4	5	6	7	8
INITIAL	5	8	5	5	5	8	5	5
PASSAGE	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
YELLOW	4	4	4	4	4	4	4	4
RED CLEAR	2	2	2.1	2.5	2.2	1.7	2.5	2.5
MAX 1	30	60	15	60	30	60	30	60
MAX 2	10	45	10	28	10	45	10	28
WALK		7		7		7		7
PED CLEAR		22		35		22		33
MIN RECALL		Yes				Yes		
MAX RECALL								
PED RECALL								
NON -LOCK	N/L	Lock	N/L	N/L	N/L	Lock	N/L	N/L
REST IN WALK								
DISPLAY	5-sect	Balls	5-sect	Balls	5-sect	Balls	5-sect	Balls
U.C.F.		Y		R		Y		R
MAIN ST.		Yes				Yes		
L/S POSITION	1	2	3	4	5	6	7	8

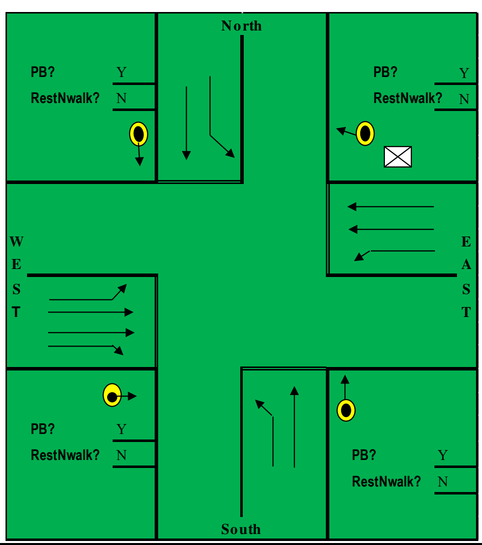


Intersection (T4)

		Ring - 1				Ring - 2			
Name	679 - Municipal Dr	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	10/16/2012	EBL	WB	-	NB	WBL	EB	-	SB
# of Cycles	60	2.2	114.7	-	33.1	7.3	109.6	-	33.1
Average of Cycles	150	5-Sect	Balls	-	Balls	5-Sect	Balls	-	Balls
		Ring - 1				Ring - 2			
Name	679 - Municipal Dr	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	10/17/2012	EBL	WB	-	NB	WBL	EB	-	SB
# of Cycles	60	1.7	120.4	-	27.6	8.4	113.7	-	27.6
Average of Cycles	149.7	5-Sect	Balls	-	Balls	5-Sect	Balls	-	Balls
		Ring - 1				Ring - 2			
Name	679 - Municipal Dr	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	3/6/2013	EBL	WB	-	NB	WBL	EB	-	SB
# of Cycles	95	1.5	121.1	-	28.0	7.3	115.4	-	28.0
Average of Cycles	150.7	5-Sect	Balls	-	Balls	5-Sect	Balls	-	Balls

	EB	WB	NB	SB
MIN GREEN	5	5	5	5
NUMBER OF FIXED INTERVALS	3	3	3	3
DWELL INTERVAL	1	1	1	1
Yellow	1	5	1	1
RED	1	5	1	1

CONTROLLER TIMING								
	RING 1				RING 2			
APPROACH	EBL	WB		NB	WBL	EB		SB
PHASE #	1	2	3	4	5	6	7	8
INITIAL	4	15	-	10	4	15	-	10
PASSAGE	3	3	-	4.5	3	3	-	3
YELLOW	4	4	-	4	4	4	-	4
RED CLEAR	2.5	1.5	-	2.5	2.5	1.5	-	2.9
MAX 1	20	60	-	35	30	60	-	35
MAX 2	10	45	-	33	10	45	-	42
WALK		7		7		7		7
PED CLEAR		16		33		16		29
MIN RECALL		Yes				Yes		
MAX RECALL								
PED RECALL								
NON -LOCK	N/L	Lock	-	N/L	N/L	Lock	-	N/L
REST IN WALK								
DISPLAY	5-Sect	Balls	-	Balls	5-Sect	Balls	-	Balls
U.C.F.		Y		R		Y		R
MAIN ST.		Yes				Yes		
L/S POSITION	1	2	3	4	5	6	7	8

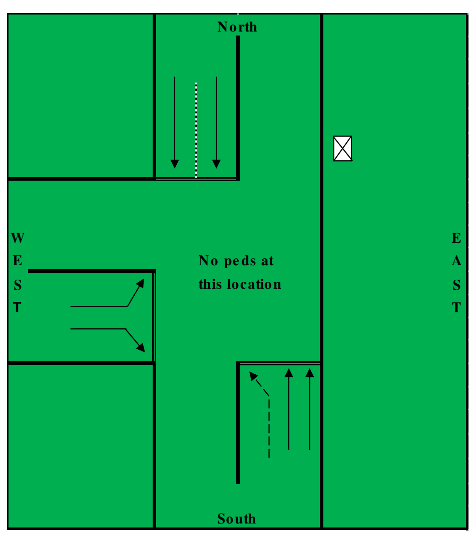


Intersection (T5)

		Ring - 1				Ring - 2			
Name	369 - Del Verde	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	10/16/2012	-	N/S	-	EB	-	-	-	-
# of Cycles	194	-	70	-	5	-	-	-	-
Average of Cycles	75	-	Balls	-	Balls	-	-	-	-
		Ring - 1				Ring - 2			
Name	369 - Del Verde	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	10/17/2012	-	N/S	-	EB	-	-	-	-
# of Cycles	120	-	70	-	5	-	-	-	-
Average of Cycles	75	-	Balls	-	Balls	-	-	-	-
		Ring - 1				Ring - 2			
Name	369 - Del Verde	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	3/6/2013	-	N/S	-	EB	-	-	-	-
# of Cycles	121	-	70	-	5	-	-	-	-
Average of Cycles	75	-	Balls	-	Balls	-	-	-	-

	EB	WB	NB	SB
MIN GREEN	5	5	5	5
NUMBER OF FIXED INTERVALS	3	3	3	3
DWELL INTERVAL	1	1	1	1
Yellow	1	1	1	1
RED	1	1	1	1

CONTROLLER TIMING								
	RING 1				RING 2			
APPROACH		N/S		EB				
PHASE #	1	2	3	4	5	6	7	8
INITIAL		15		5				
PASSAGE		4		2				
YELLOW		4		4				
RED CLEAR		1.7		2.1				
MAX 1		45		15				
MAX 2		25		10				
WALK								
PED CLEAR								
MIN RECALL		Yes						
MAX RECALL								
PED RECALL								
NON -LOCK		Lock		N/L				
REST IN WALK		Yes						
DISPLAY		Balls		Balls				
U.C.F.		Y		R				
MAIN ST.		Yes						
L/S POSITION		2		4				

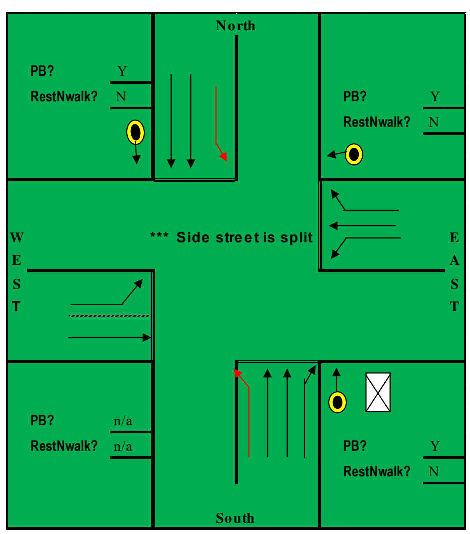


Intersection (T6)

		Ring - 1				Ring - 2			
Name	378-Fun-Spot	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	10/16/2012	NBL	SB	EB	WB	SBL	NB	-	-
# of Cycles	59	18.7	99.0	21.4	13.1	7.6	109.6	-	-
Average of Cycles	148.2	Protected	Balls	Both	Balls	Protected	Both	-	-
		Ring - 1				Ring - 2			
Name	378-Fun-Spot	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	10/17/2012	NBL	SB	EB	WB	SBL	NB	-	-
# of Cycles	60	20.6	100.3	20.2	8.9	7.5	113.3	-	-
Average of Cycles	150	Protected	Balls	Both	Balls	Protected	Both	-	-
		Ring - 1				Ring - 2			
Name	378-Fun-Spot	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
Date/Time	3/6/2013	NBL	SB	EB	WB	SBL	NB	-	-
# of Cycles	96	19.7	95.4	24.7	11.2	6.1	108.9	-	-
Average of Cycles	150.9	Protected	Balls	Both	Balls	Protected	Both	-	-

	EB	WB	NB	SB
MIN GREEN	5	5	5	5
NUMBER OF FIXED INTERVALS	3	3	3	3
DWELL INTERVAL	1	1	1	1
Yellow	1	1	1	1
RED	1	1	1	1

CONTROLLER TIMING								
	RING 1				RING 2			
APPROACH	NBL	SB	EB	WB	SBL	NB		
PHASE #	1	2	3	4	5	6	7	8
INITIAL	5	14	5	5	5	14	-	-
PASSAGE	2.5	3.5	2.5	2.5	2.5	3.5	-	-
YELLOW	4	4	4	4	4	4	-	-
RED CLEAR	2.2	1.5	3	3	2.5	1.7	-	-
MAX 1	20	45	20	45	20	45	-	-
MAX 2	10	45	10	43	10	45	-	-
WALK		7		7		7		
PED CLEAR		18		38		25		
MIN RECALL		Yes				Yes		
MAX RECALL								
PED RECALL								
NON -LOCK	N/L	Lock	N/L	N/L	N/L	Lock		
REST IN WALK								
DISPLAY	Protected	Balls	Both	Balls	Protected	Both		
U.C.F.	R	Y	R	R	R	Y		
MAIN ST.		Yes				Yes		
L/S POSITION	1	2	3	4	5	6		



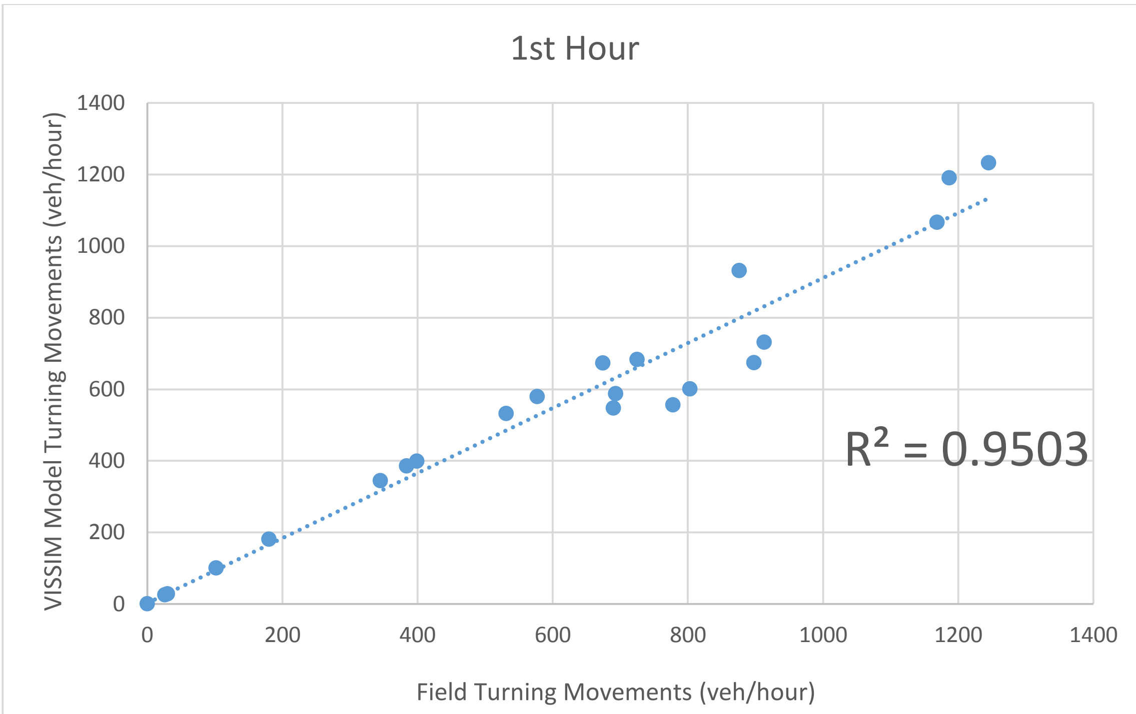
APPENDIX E: CALIBRATION & VALIDATION EXTRAS

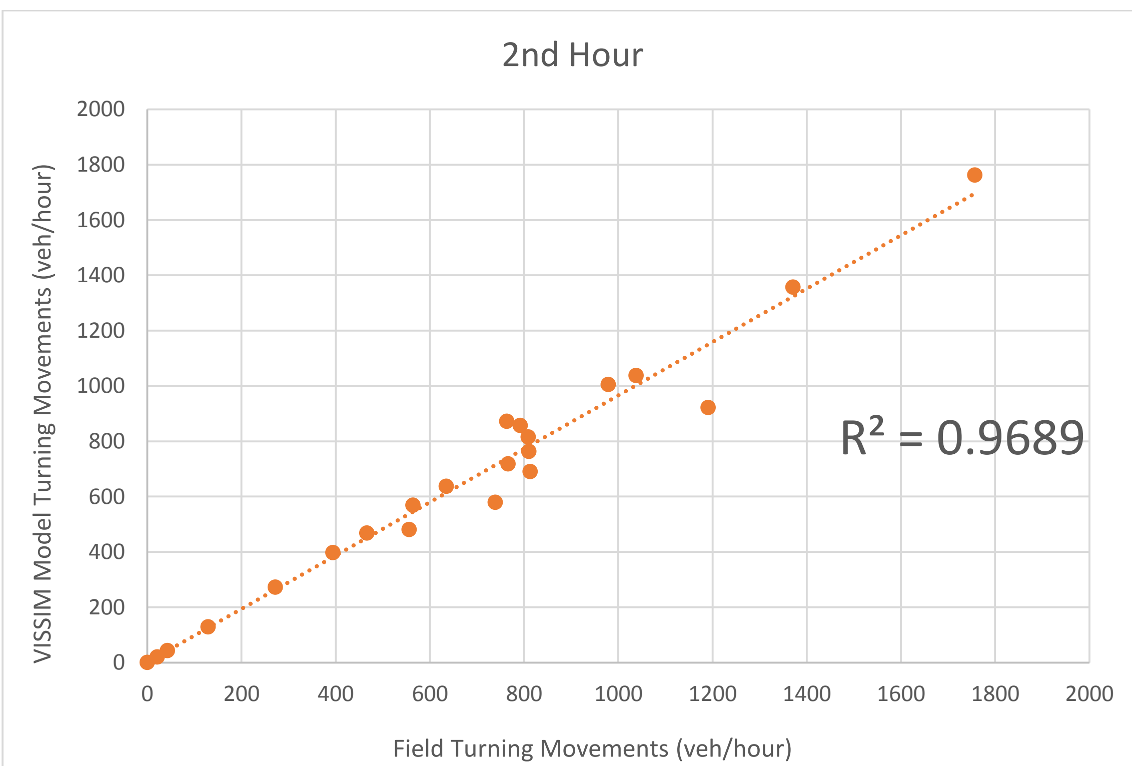
GEH for Individual Traffic Flows

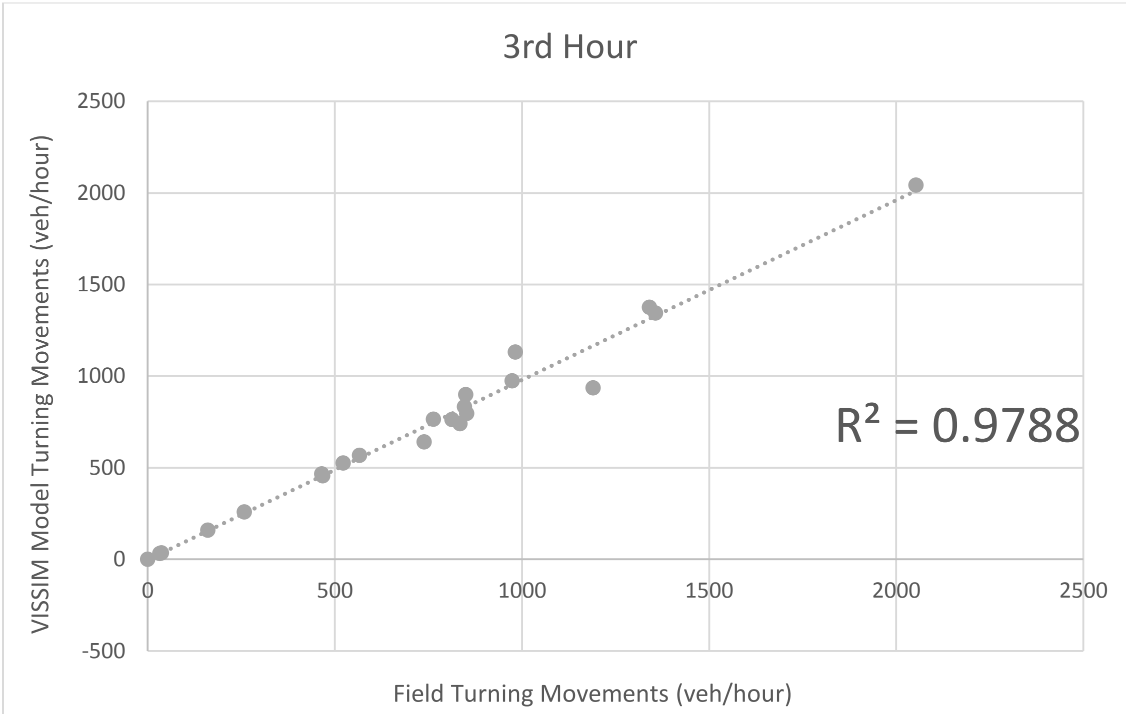
			m	c	
	From (sec)	To (sec)	Number Veh all veh. types	Field	GEH
1st Hour	0	3600	580	577	0.12473
	0	3600	399	399	0.020196
	0	3600	386	384	0.119785
	0	3600	684	725	1.558781
	0	3600	675	898	7.951618
	0	3600	1191	1187	0.116003
	0	3600	1233	1245	0.340915
	0	3600	1067	1169	3.048411
	0	3600	932	876	1.854489
	0	3600	345	345	0.003778
	0	3600	533	531	0.07151
	0	3600	557	778	8.562772
	0	3600	548	690	5.727597
	0	3600	181	180	0.082255
	0	3600	588	693	4.150312
	0	3600	601	803	7.623289
	0	3600	29	30	0.177602
	0	3600	732	913	6.311181
	0	3600	674	674	0.018249
	0	3600	101	102	0.064375
	0	3600	26	26	0.041204
2nd Hour	3600	7200	570	564	0.232132
	3600	7200	398	394	0.180777
	3600	7200	468	466	0.105522
	3600	7200	718	766	1.753628
	3600	7200	764	810	1.653684
	3600	7200	1763	1757	0.143019
	3600	7200	1358	1371	0.35193
	3600	7200	872	763	3.812261
	3600	7200	1005	979	0.831034
	3600	7200	481	556	3.29452
	3600	7200	637	635	0.091816
	3600	7200	816	809	0.229606
	3600	7200	580	739	6.211697
	3600	7200	273	272	0.065887
	3600	7200	858	792	2.284655
	3600	7200	691	813	4.448882
	3600	7200	21	21	0.03452
	3600	7200	922	1191	8.275944

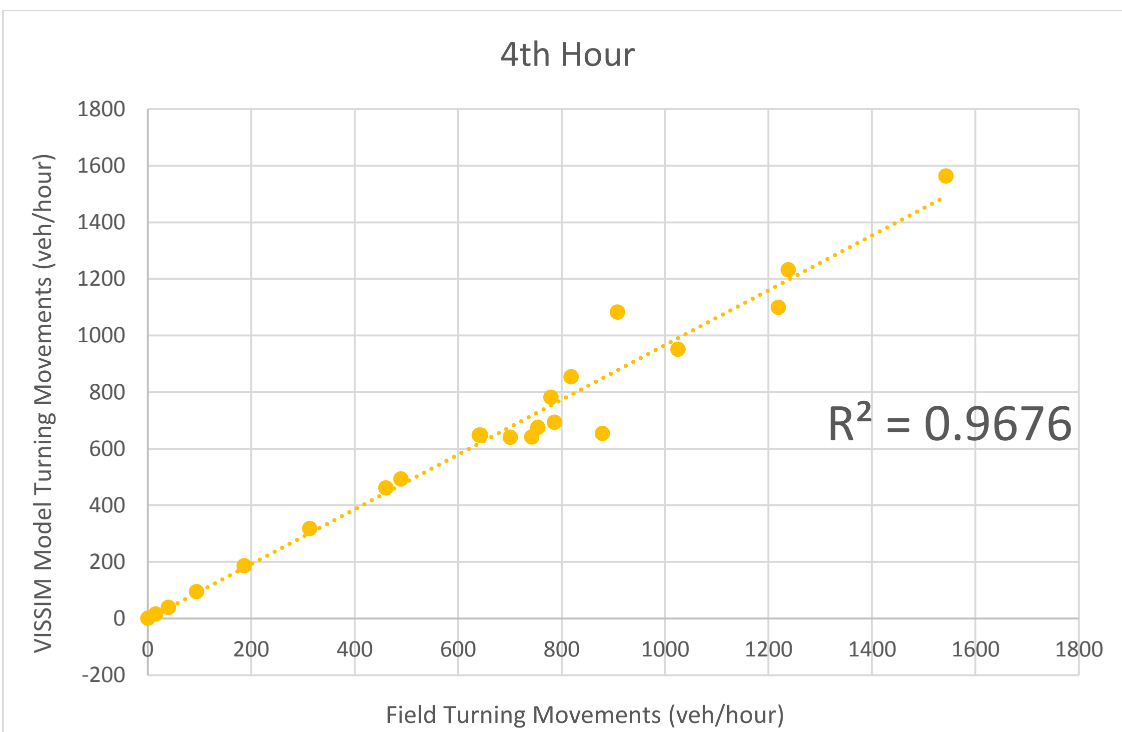
	3600	7200	1038	1038	0.012526
	3600	7200	129	129	0.026274
	3600	7200	43	43	0.050735
3rd Hour	7200	10800	765	763	0.066648
	7200	10800	467	465	0.096707
	7200	10800	526	522	0.160205
	7200	10800	899	850	1.650541
	7200	10800	763	813	1.78943
	7200	10800	2043	2053	0.220971
	7200	10800	1345	1357	0.326478
	7200	10800	1377	1340	0.991092
	7200	10800	1132	982	4.622074
	7200	10800	456	467	0.492331
	7200	10800	567	566	0.052328
	7200	10800	796	852	1.942151
	7200	10800	642	738	3.654658
	7200	10800	259	258	0.086171
	7200	10800	833	846	0.454755
	7200	10800	740	834	3.334639
	7200	10800	936	1190	7.790531
	7200	10800	974	974	0.010118
	7200	10800	160	160	0.006936
	7200	10800	36	36	0.017531
4th Hour	10800	14400	649	643	0.224358
	10800	14400	648	641	0.270218
	10800	14400	493	489	0.172615
	10800	14400	854	818	1.25949
	10800	14400	654	879	8.142575
	10800	14400	1564	1543	0.532799
	10800	14400	1232	1238	0.170733
	10800	14400	1100	1219	3.499998
	10800	14400	1083	908	5.5401
	10800	14400	317	313	0.252953
	10800	14400	462	460	0.080088
	10800	14400	640	701	2.343978
	10800	14400	642	742	3.804885
	10800	14400	187	186	0.065527
	10800	14400	675	754	2.950071
	10800	14400	693	786	3.415911
	10800	14400	40	40	0.005549
	10800	14400	952	1025	2.321852
	10800	14400	781	779	0.087303
	10800	14400	95	94	0.077653
	10800	14400	15	15	0.11689

Turning Movement Counts (VISSIM versus Field)

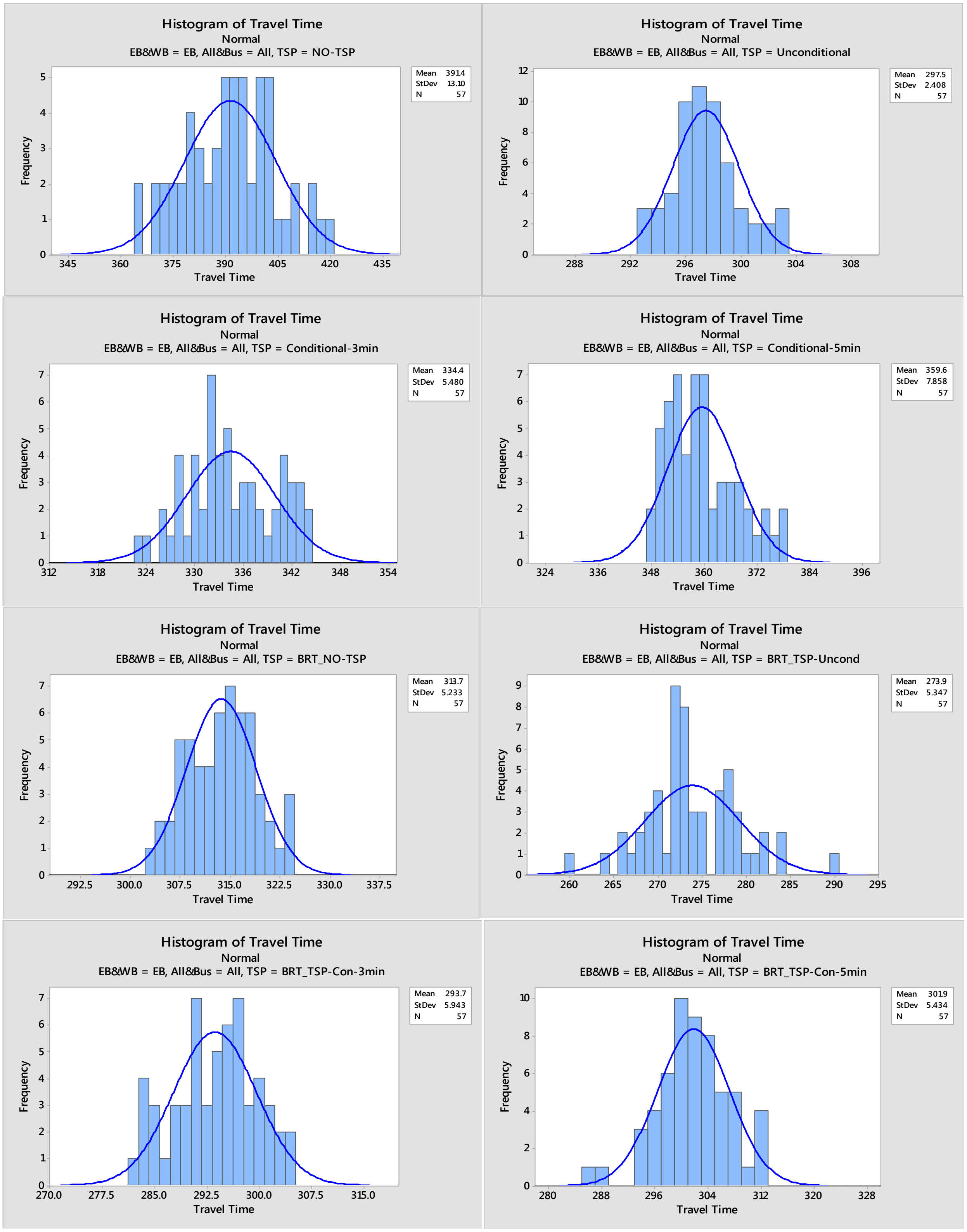




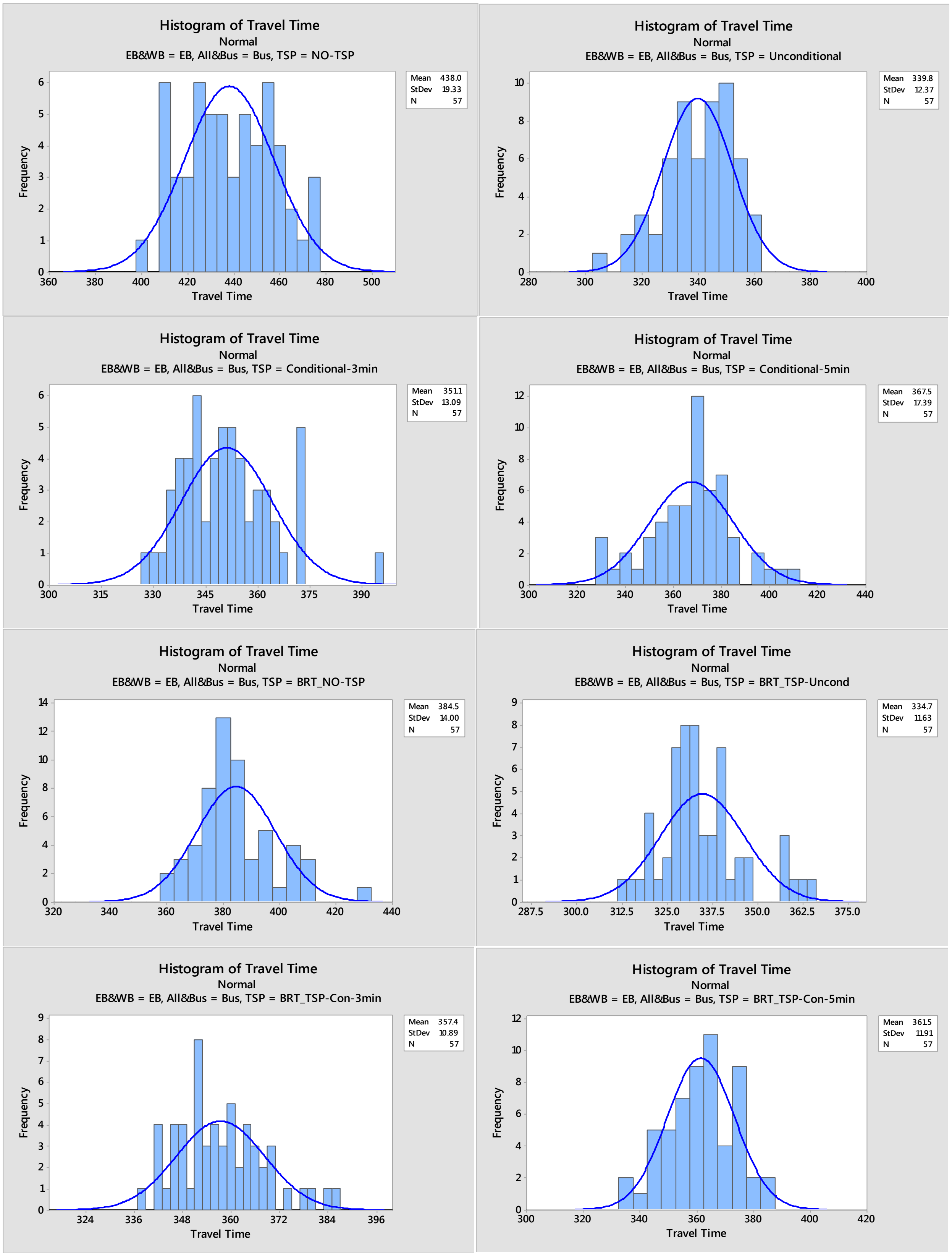

3rd Hour
VISSIM Model Turning Movements (veh/hour)
Field Turning Movements (veh/hour)
R² = 0.9788
2500
2000
1500
1000
500
0
-500


4th Hour
VISSIM Model Turning Movements (veh/hour)
Field Turning Movements (veh/hour)
R² = 0.9676
1800
1600
1400
1200
1000
800
600
400
200
0
-200

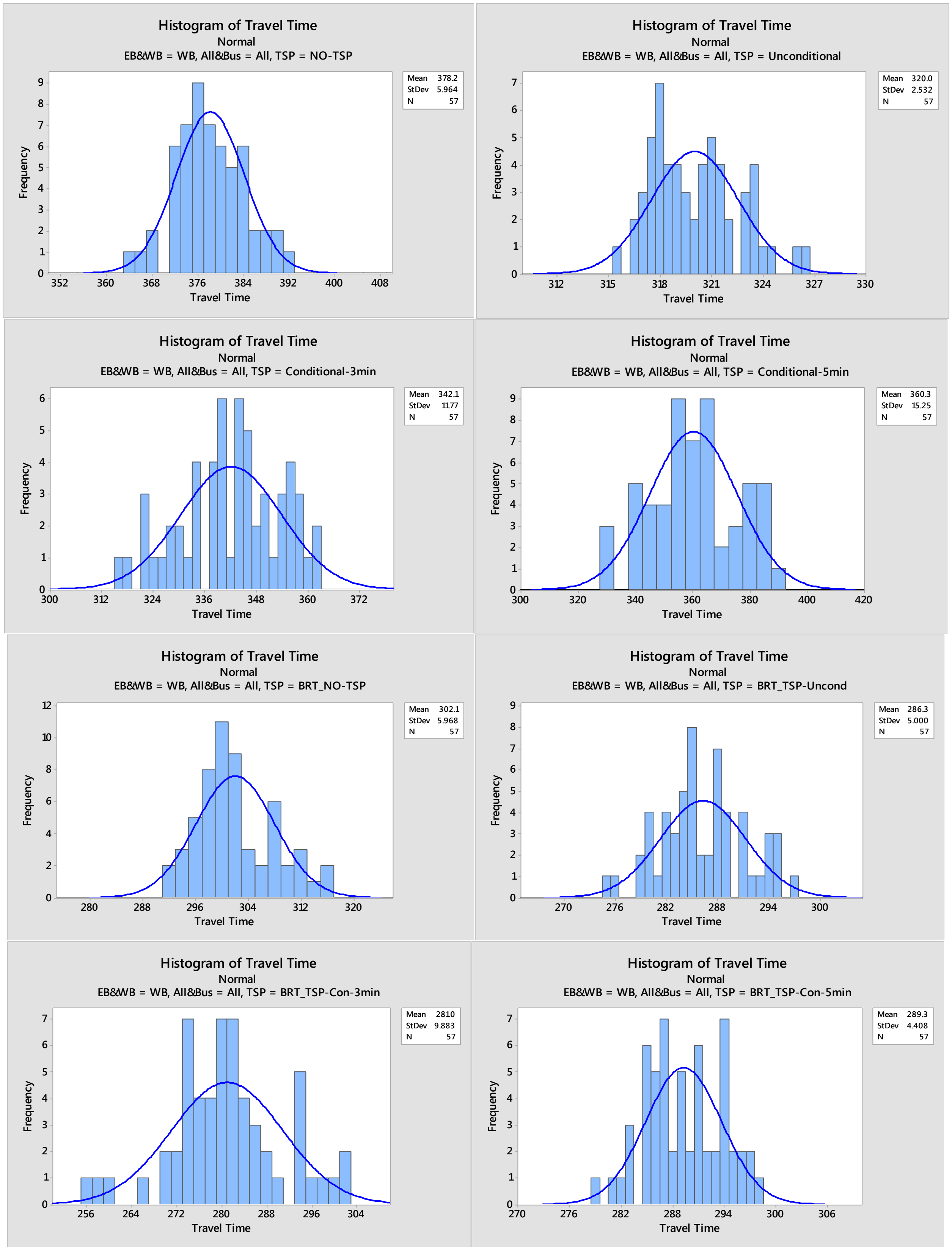
APPENDIX F: VISSIM (MOEs) OUTPUT DISTRIBUTIONS



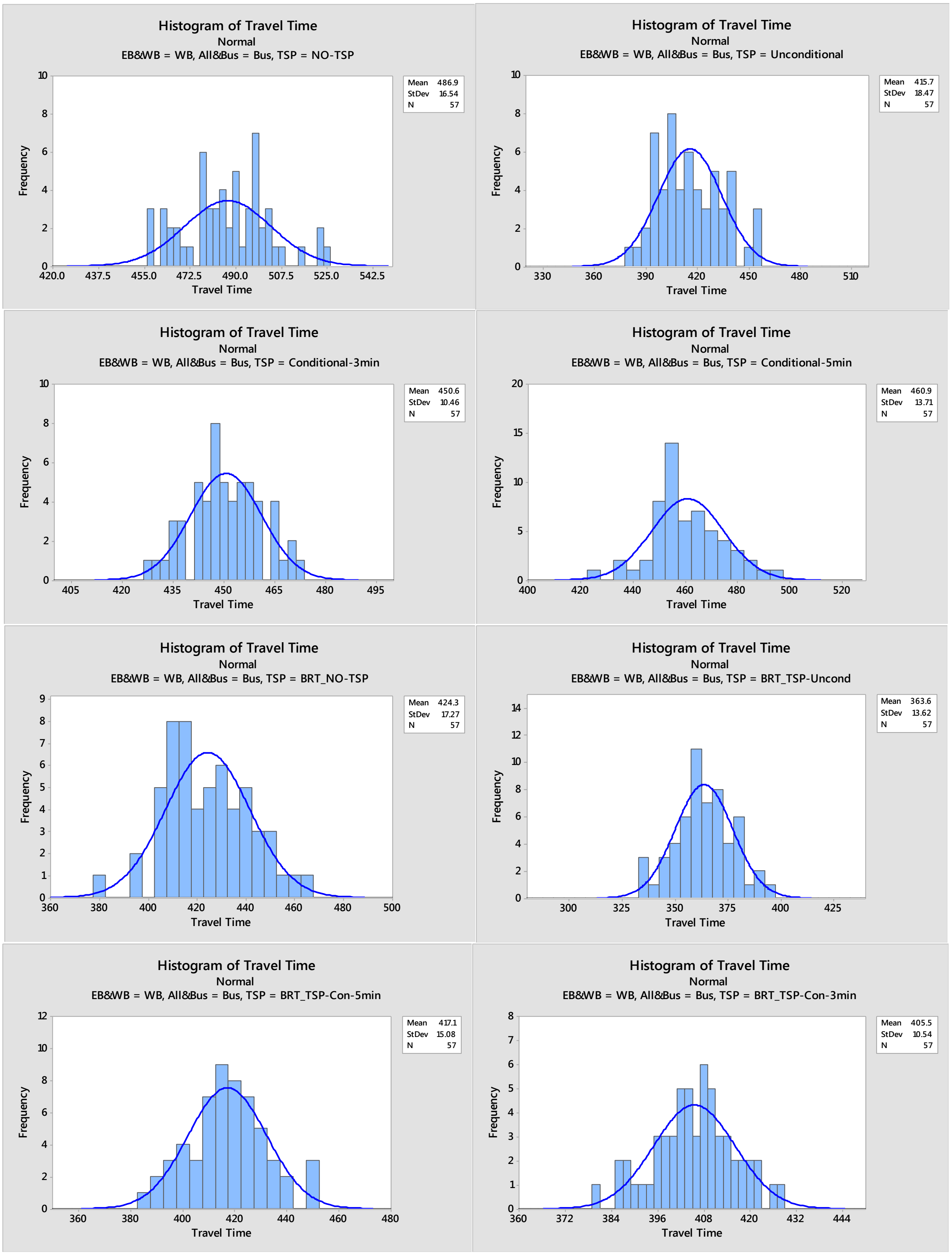
Histogram of Travel Time (Seconds) – All Vehicles – EB Direction



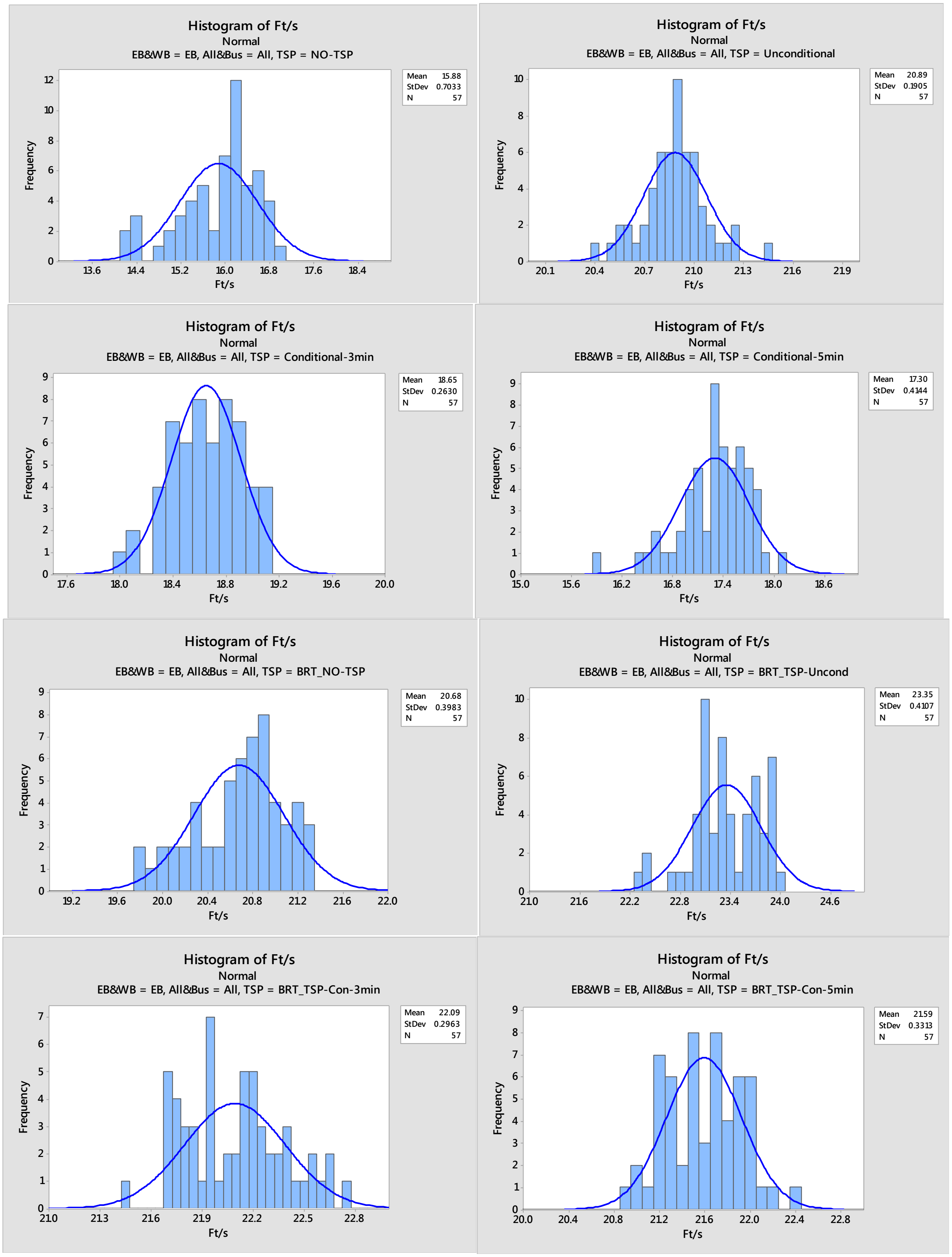
Histogram of Travel Time (Seconds) – Buses Only – EB Direction



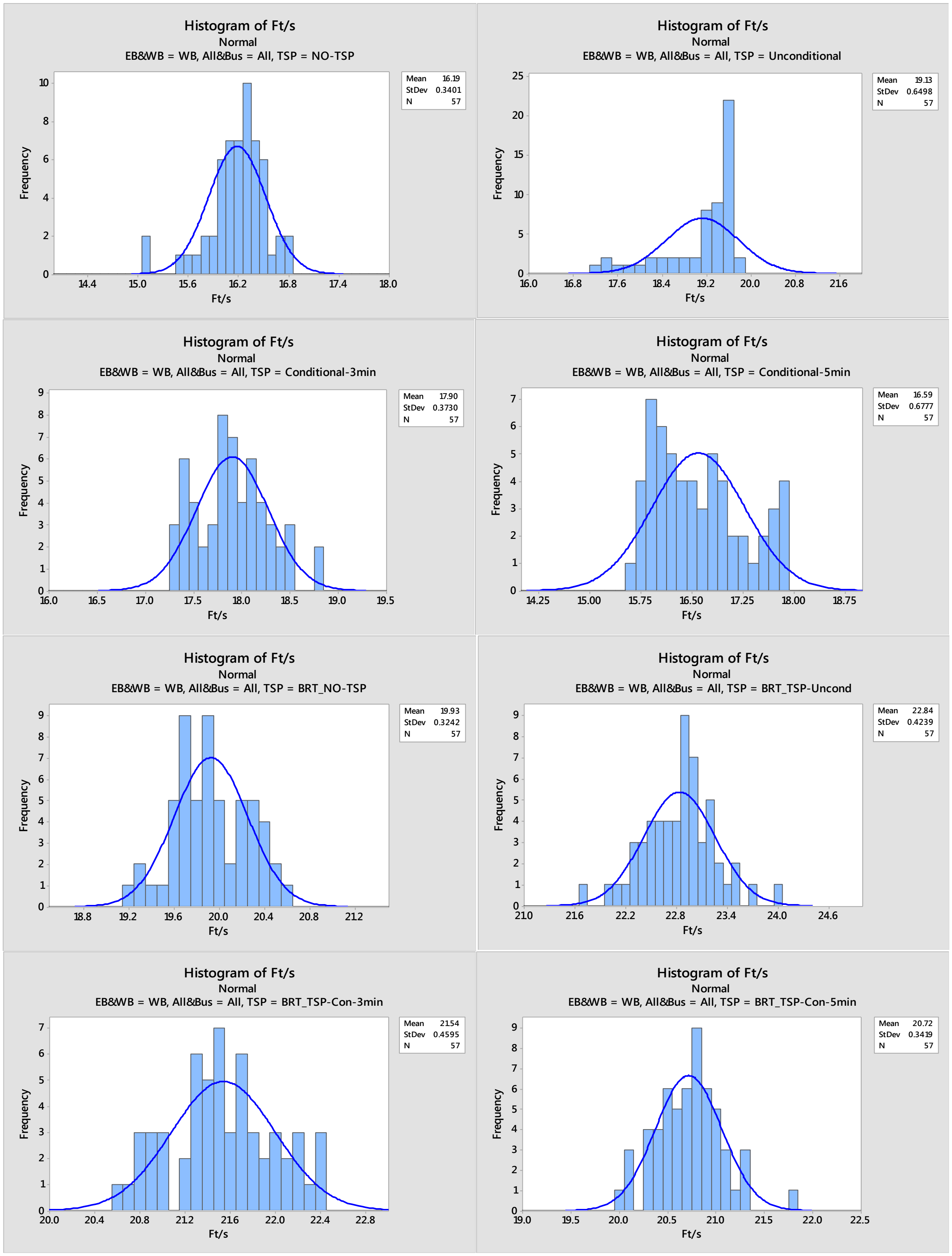
Histogram of Travel Time (Seconds) – All Vehicles – WB Direction



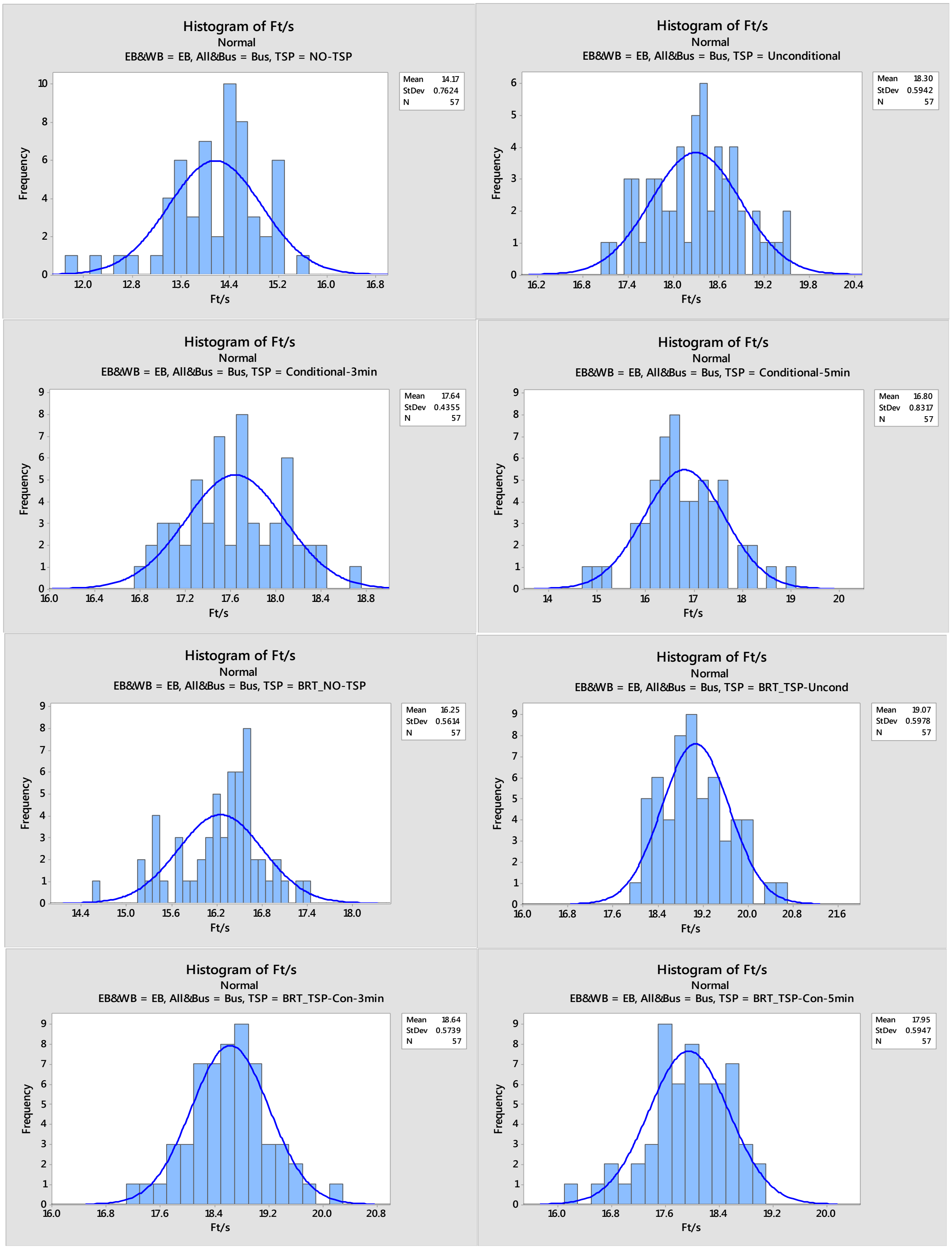
Histogram of Travel Time (Seconds) – Buses Only – WB Direction



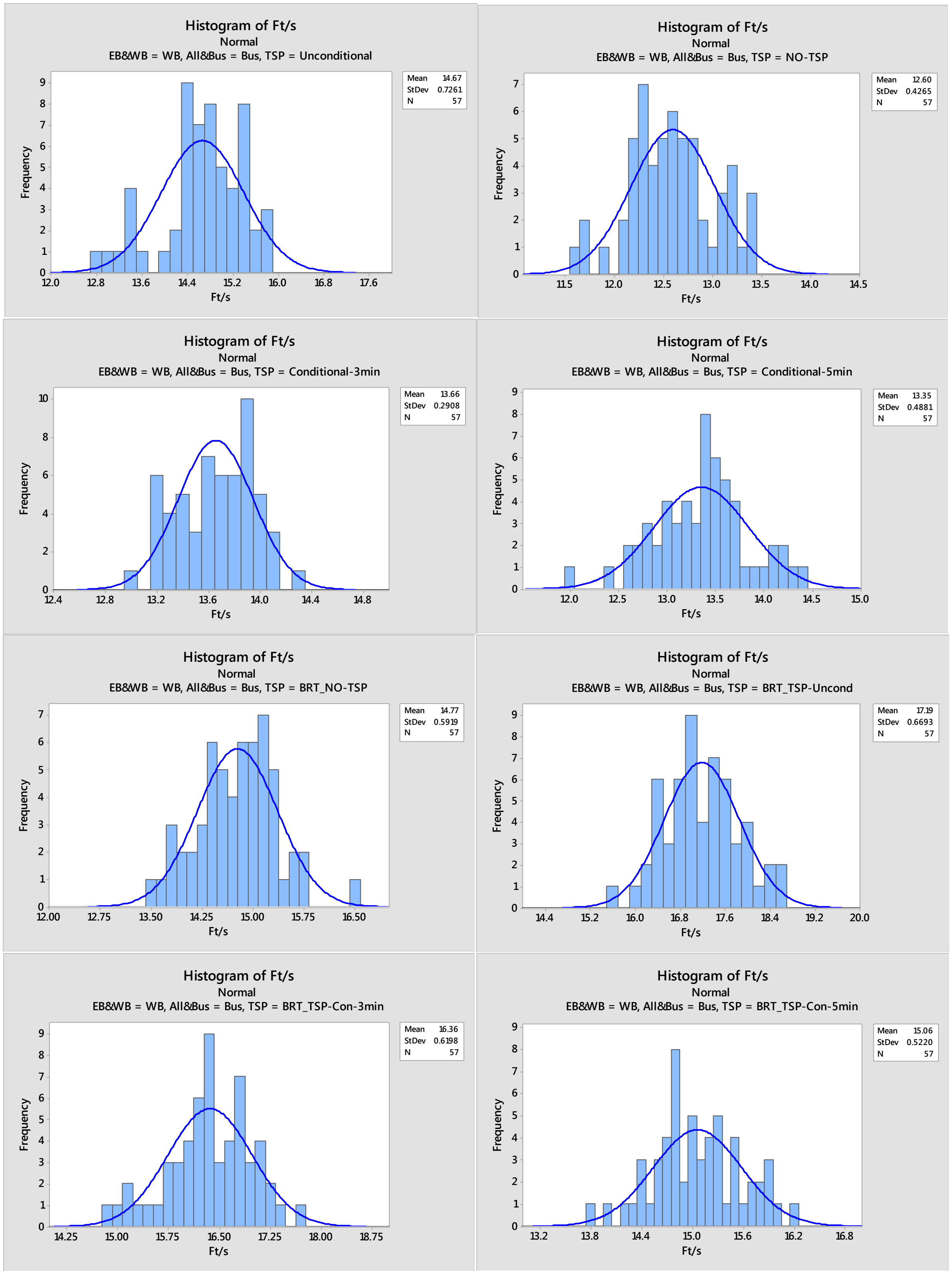
Histogram of Speed (ft. /sec) – All Vehicles – EB Direction



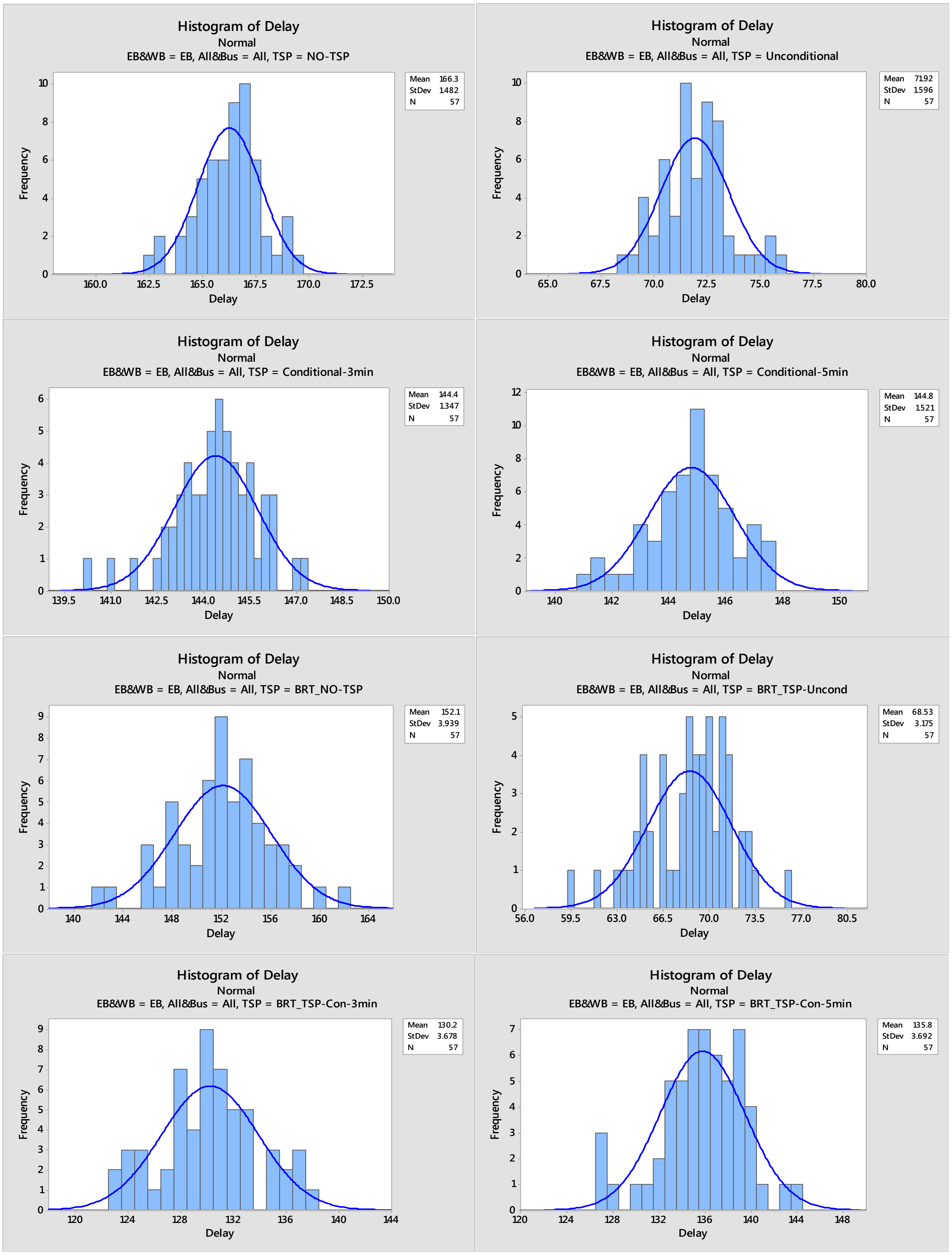
Histogram of Speed (ft. /sec) – All Vehicles – WB Direction



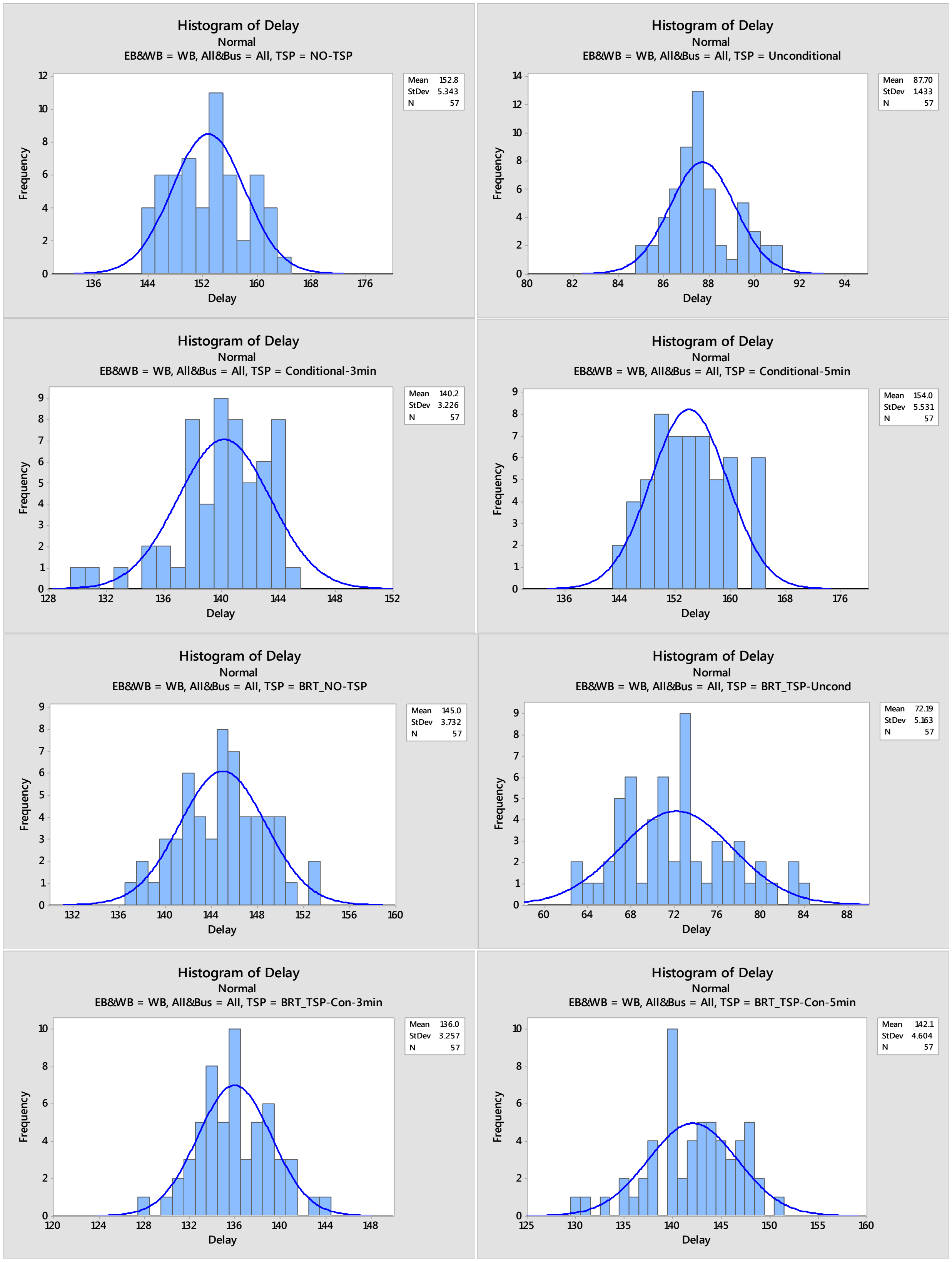
Histogram of Speed (ft. /sec) – Buses Only – EB Direction



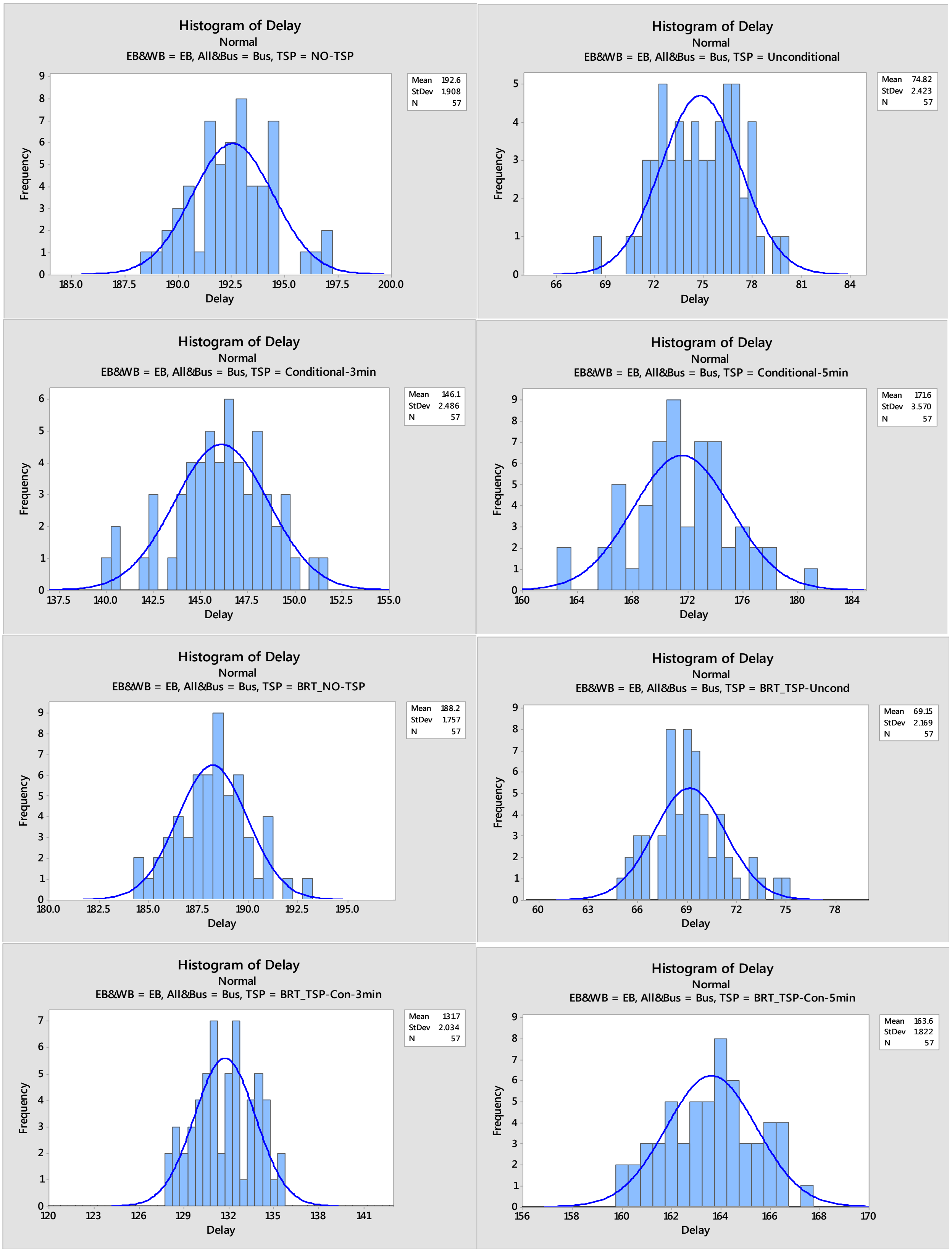
Histogram of Speed (ft. /sec) – Buses Only – WB Direction



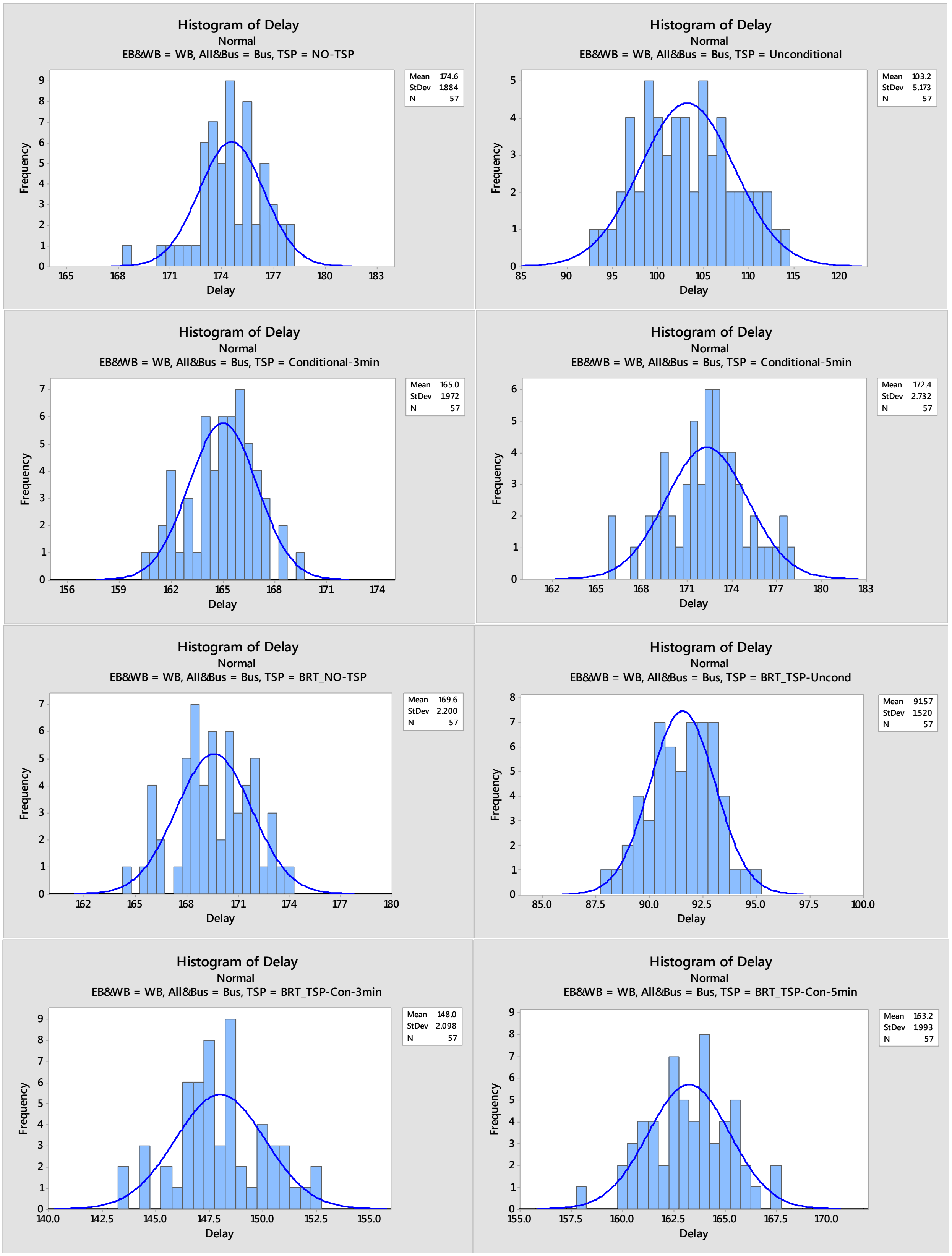
Histogram of Average Total Delay per Vehicle (seconds) – All Vehicles – EB Direction



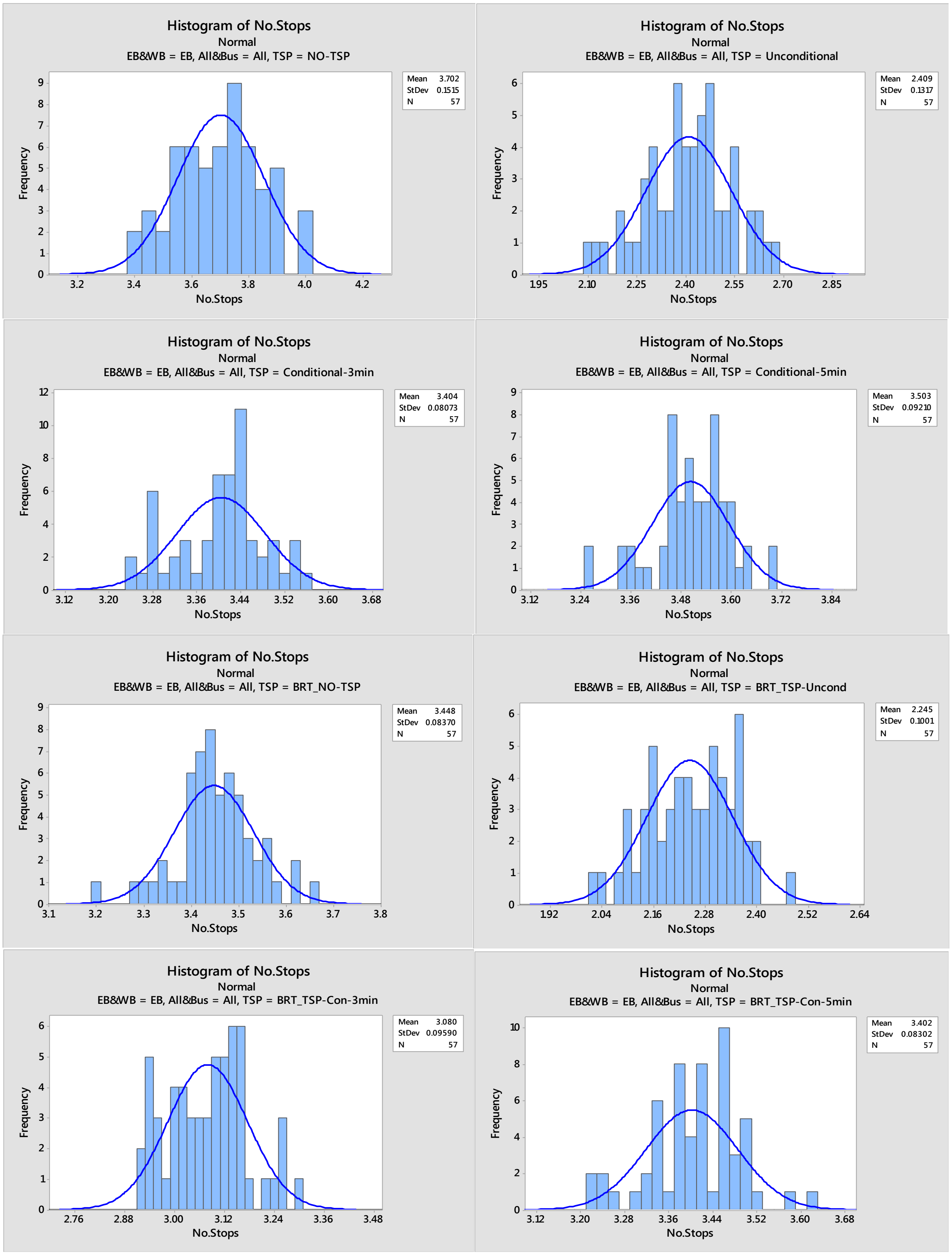
Histogram of Average Total Delay per Vehicle (seconds) – All Vehicles – WB Direction



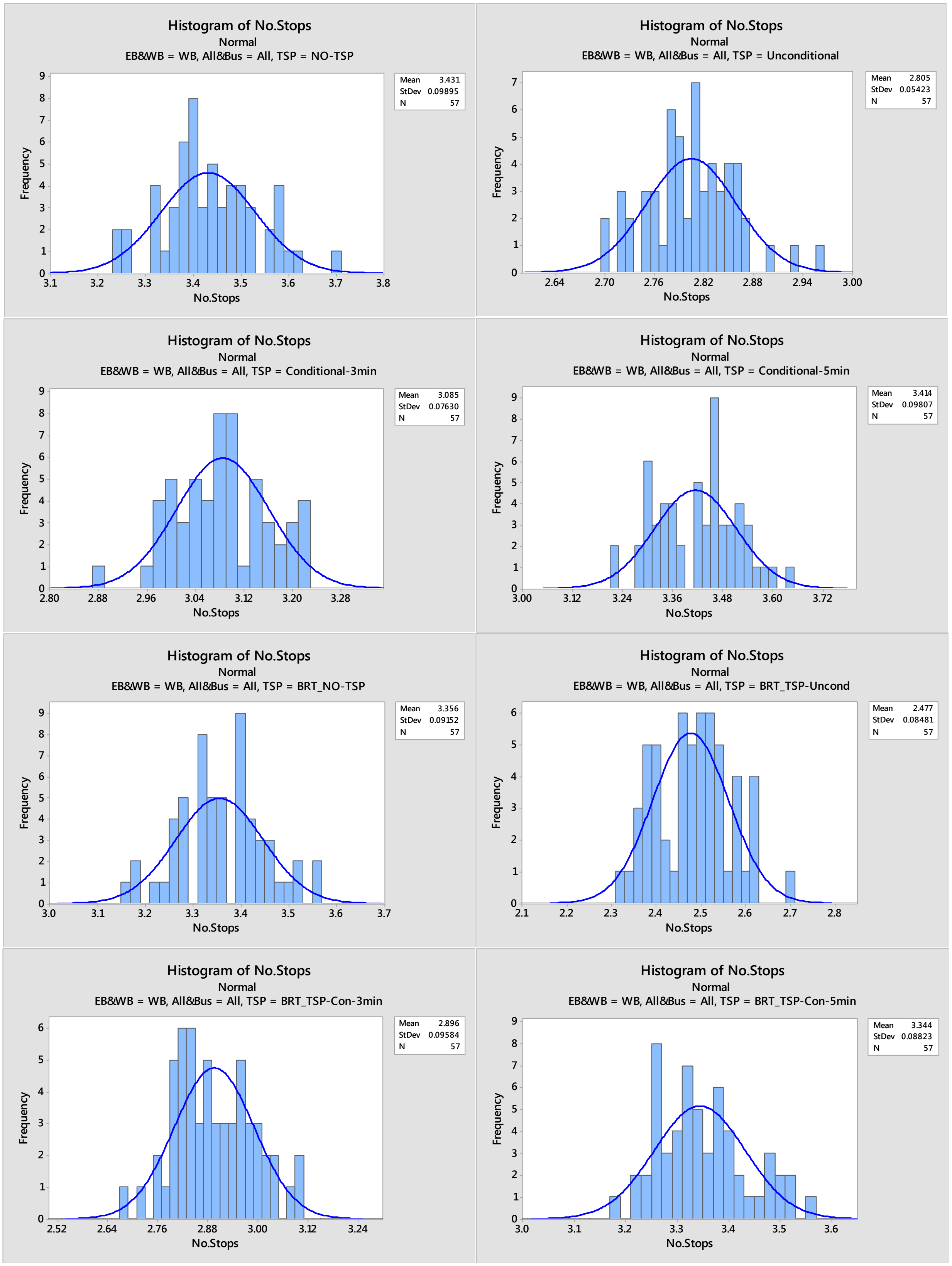
Histogram of Average Total Delay per Vehicle (seconds) – Buses Only – EB Direction



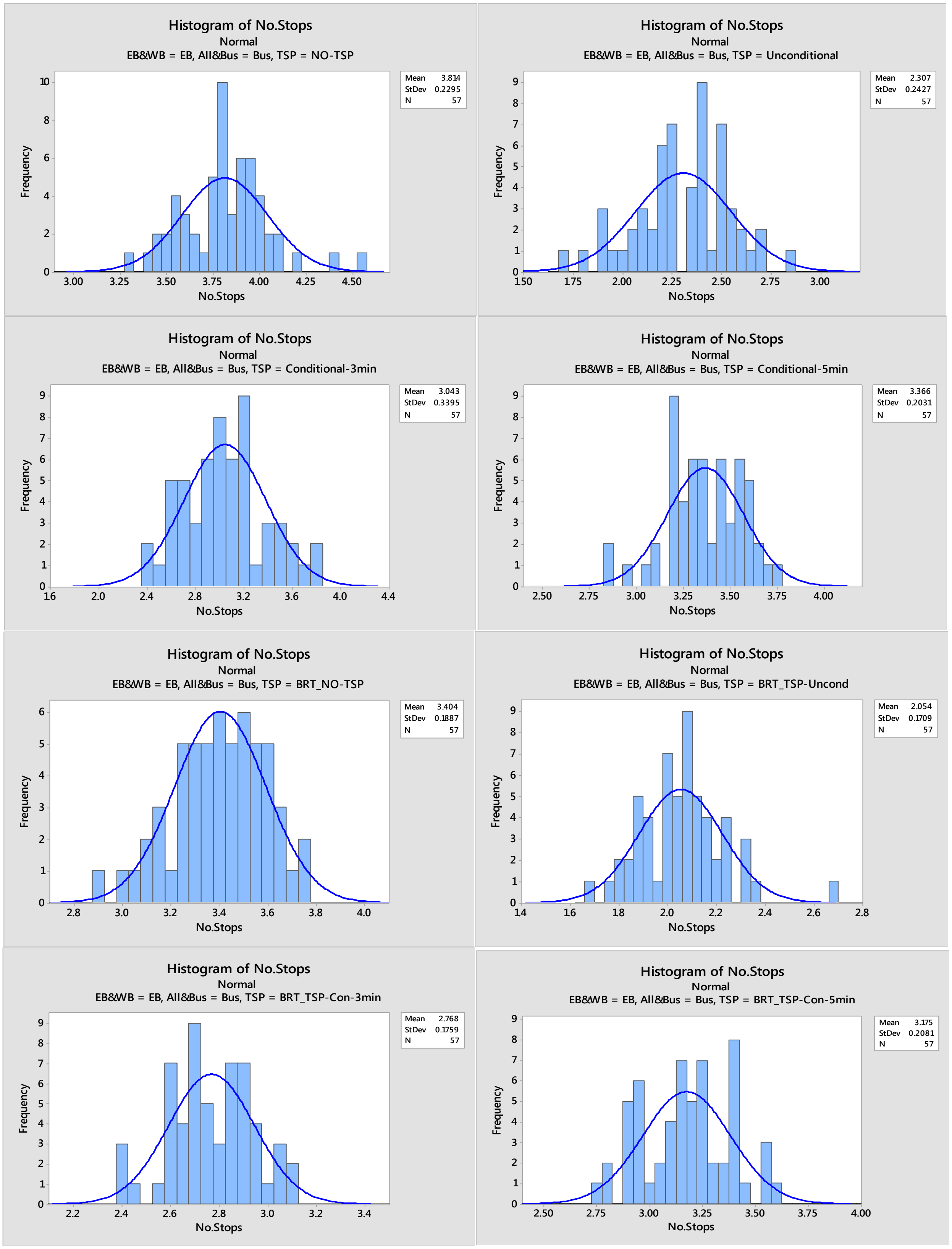
Histogram of Average Total Delay per Vehicle (seconds) – Buses Only – WB Direction



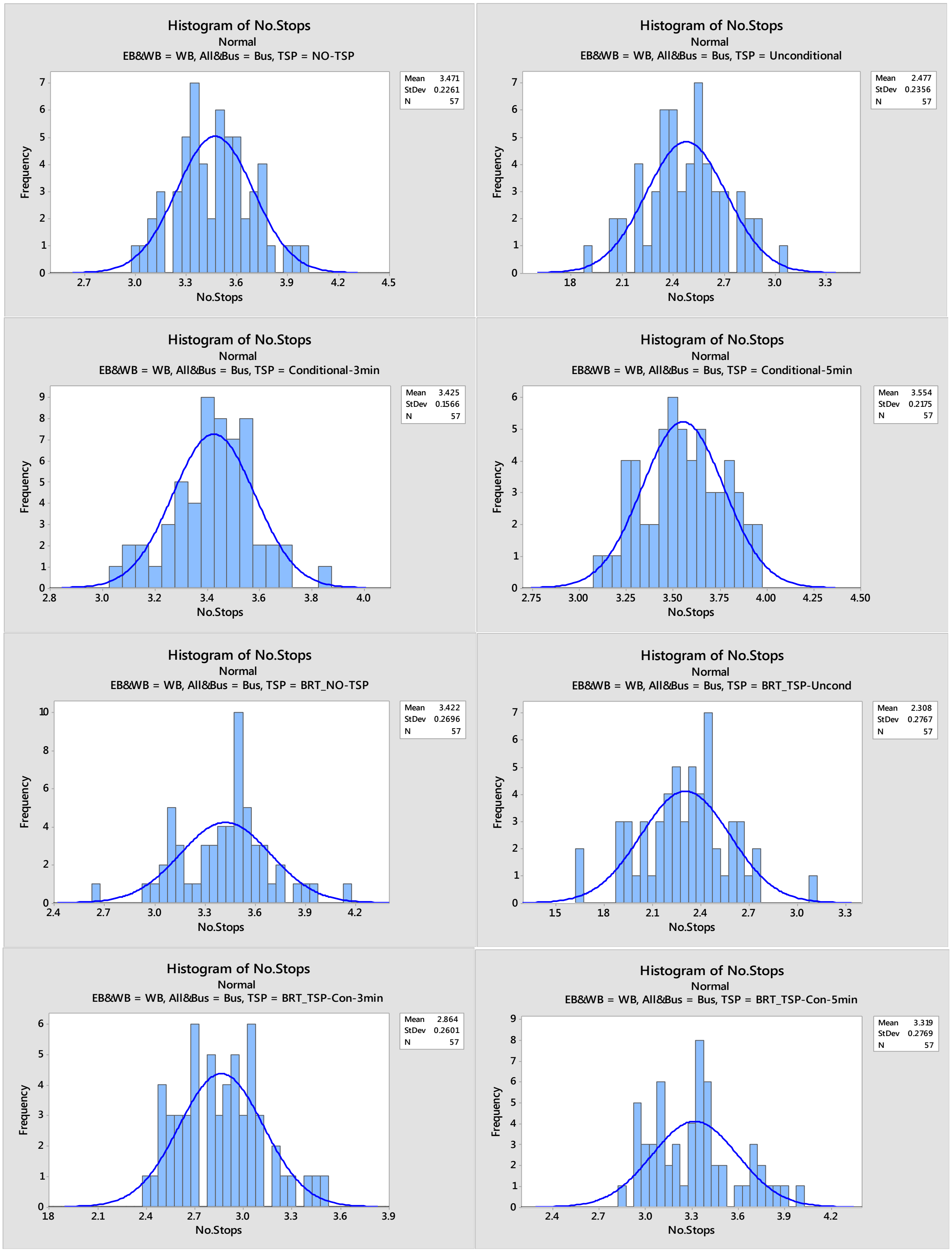
Histogram of Average Number of Stops per Vehicle – All Vehicles – EB Direction



Histogram of Average Number of Stops per Vehicle – All Vehicles – WB Direction



Histogram of Average Number of Stops per Vehicle – Buses Only – EB Direction



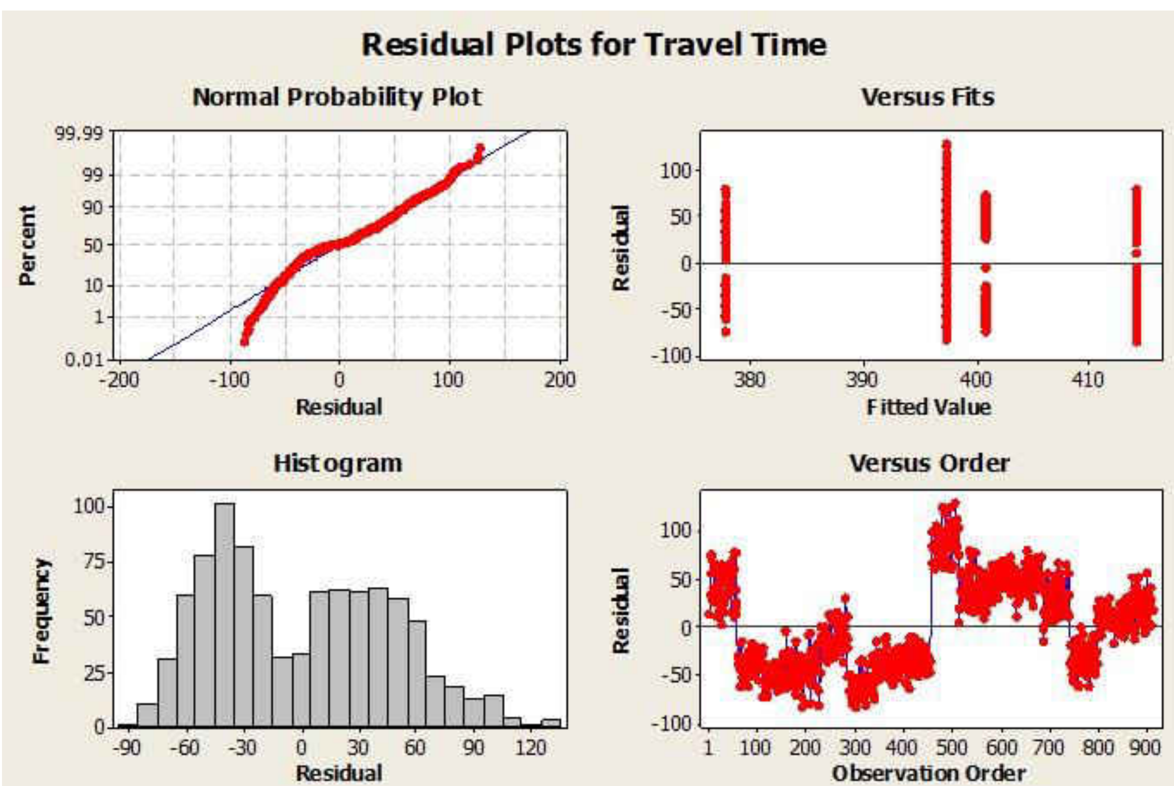
Histogram of Average Number of Stops per Vehicle – Buses Only – WB Direction

APPENDIX G: BUSES ONLY REGRESSION MODELS

1. THE BASE AND TSP SCENARIOS MODEL

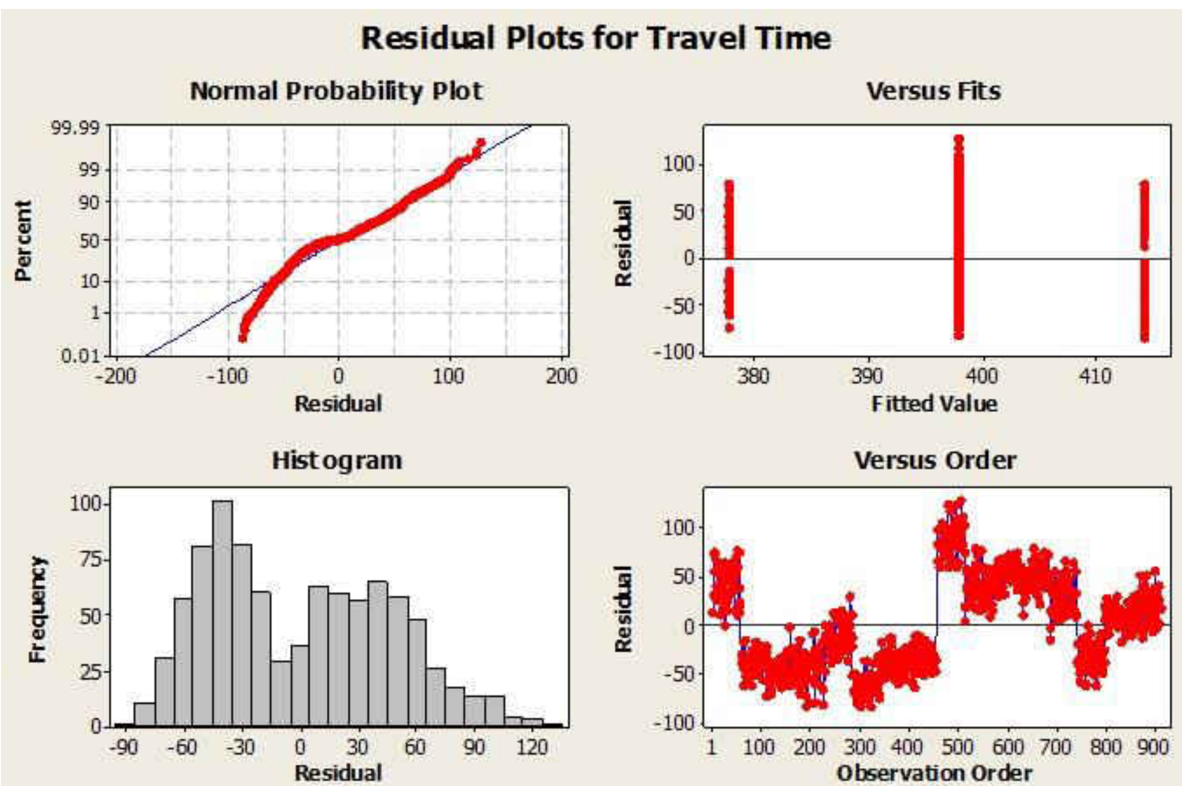
a) Travel Time

```
-   Analysis of Variance
-   Source               DF    Adj SS    Adj MS   F-Value   P-Value
-   Regression            3     77337     25779     11.92     0.000
-     Unconditional       1     36358     36358     16.82     0.000
-     Conditional-3min    1      1148      1148      0.53     0.466
-     Conditional-5min    1     26949     26949     12.47     0.000
-   Error               908   1963063      2162
-   Total               911   2040400
-
-   Model Summary
-         S    R-sq  R-sq(adj)  R-sq(pred)
-   46.4969   3.79%      3.47%       2.92%
-
-   Coefficients
-   Term                 Coef  SE Coef  T-Value  P-Value    VIF
-   Constant           397.36     1.95   204.03    0.000
-   Unconditional      -19.56     4.77    -4.10    0.000   1.05
-   Conditional-3min     3.48     4.77     0.73    0.466   1.05
-   Conditional-5min    16.84     4.77     3.53    0.000   1.05
-
-   Regression Equation
-
-   Travel Time = 397.36 - 19.56 Unconditional + 3.48 Conditional-3min
                  + 16.84 Conditional-5min
```



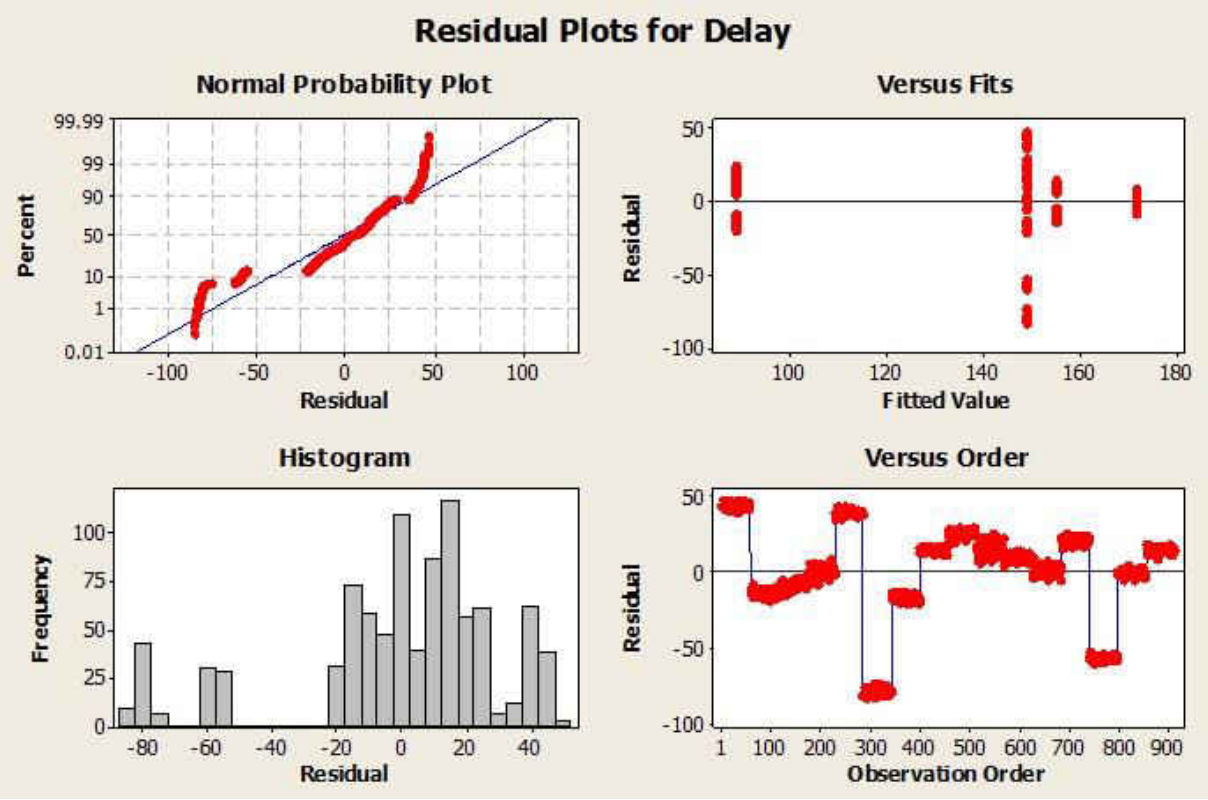
A new model developed in Minitab without the predictor variables (Conditional 3 Minutes).

```
-   Analysis of Variance
-   Source                DF    Seq SS    Adj SS    Adj MS         F          P
-   Regression             2     76190     76190   38094.9   17.6296  0.0000000
-     Unconditional        1     50344     39644   39643.8   18.3464  0.0000204
-     Conditional-5min     1     25846     25846   25845.5   11.9608  0.0005685
-   Error                909   1964210   1964210    2160.8
-   Total                911   2040400
-
-   Summary of Model
-   S = 46.4849      R-Sq = 3.73%         R-Sq(adj) = 3.52%
-   PRESS = 1976920  R-Sq(pred) = 3.11%
-
-   Coefficients
-   Term                  Coef   SE Coef        T       P
-   Constant           397.941   1.77740  223.890   0.000
-   Unconditional      -20.142   4.70255   -4.283   0.000
-   Conditional-5min    16.263   4.70255    3.458   0.001
-
-   Regression Equation
-
-   Travel Time  =  397.941 - 20.1423 Unconditional + 16.2635 Conditional-5min
```



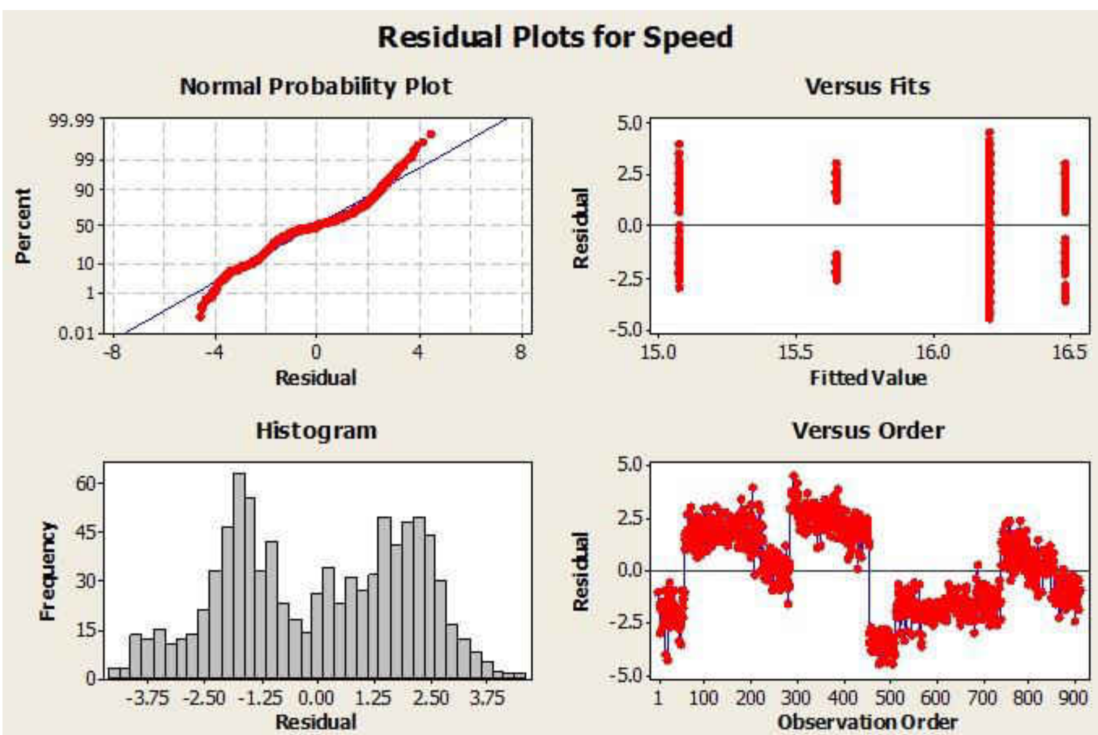
b) Delay

```
-     Analysis of Variance
-     Source                DF    Adj SS   Adj MS   F-Value   P-Value
-     Regression             3    463013   154338    157.73     0.000
-       Unconditional        1    344390   344390    351.96     0.000
-       Conditional-3min     1      3798     3798      3.88     0.049
-       Conditional-5min     1     49168    49168     50.25     0.000
-     Error                908    888474      978
-     Total                911   1351487
-
-     Model Summary
-           S     R-sq  R-sq(adj)  R-sq(pred)
-     31.2809  34.26%     34.04%      33.99%
-
-     Coefficients
-     Term                 Coef  SE Coef  T-Value  P-Value   VIF
-     Constant           149.23     1.31   113.90    0.000
-     Unconditional      -60.21     3.21   -18.76    0.000  1.05
-     Conditional-3min     6.32     3.21     1.97    0.049  1.05
-     Conditional-5min    22.75     3.21     7.09    0.000  1.05
-
-     Regression Equation
-
-     Delay = 149.23 - 60.21 Unconditional + 6.32 Conditional-3min
-             + 22.75 Conditional-5min
```



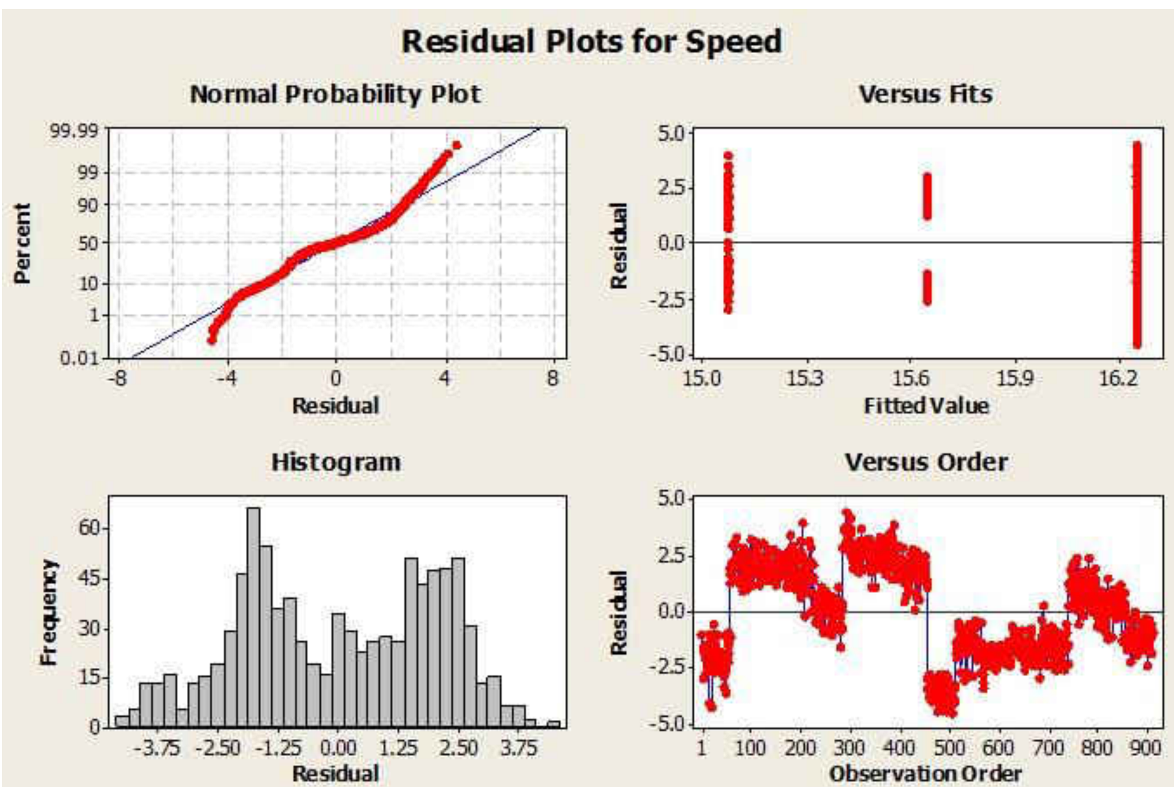
c) Speed

```
-    Analysis of Variance
-    Source               DF    Adj SS    Adj MS   F-Value   P-Value
-    Regression            3    161.07    53.689     13.21     0.000
-      Unconditional       1      7.34     7.345      1.81     0.179
-      Conditional-3min    1     29.50    29.496      7.26     0.007
-      Conditional-5min    1    120.90   120.900     29.75     0.000
-    Error               908   3690.04     4.064
-    Total               911   3851.11
-
-    Model Summary
-          S    R-sq  R-sq(adj)  R-sq(pred)
-    2.01592   4.18%      3.87%       3.37%
-
-    Coefficients
-    Term                  Coef   SE Coef  T-Value   P-Value    VIF
-    Constant           16.2054    0.0844   191.92     0.000
-    Unconditional        0.278     0.207     1.34     0.179   1.05
-    Conditional-3min    -0.557     0.207    -2.69     0.007   1.05
-    Conditional-5min    -1.128     0.207    -5.45     0.000   1.05
-
-    Regression Equation
-
-    Speed = 16.2054 + 0. 278 Unconditional - 0.557 Conditional-3min
             - 1.128 Conditional-5min
```



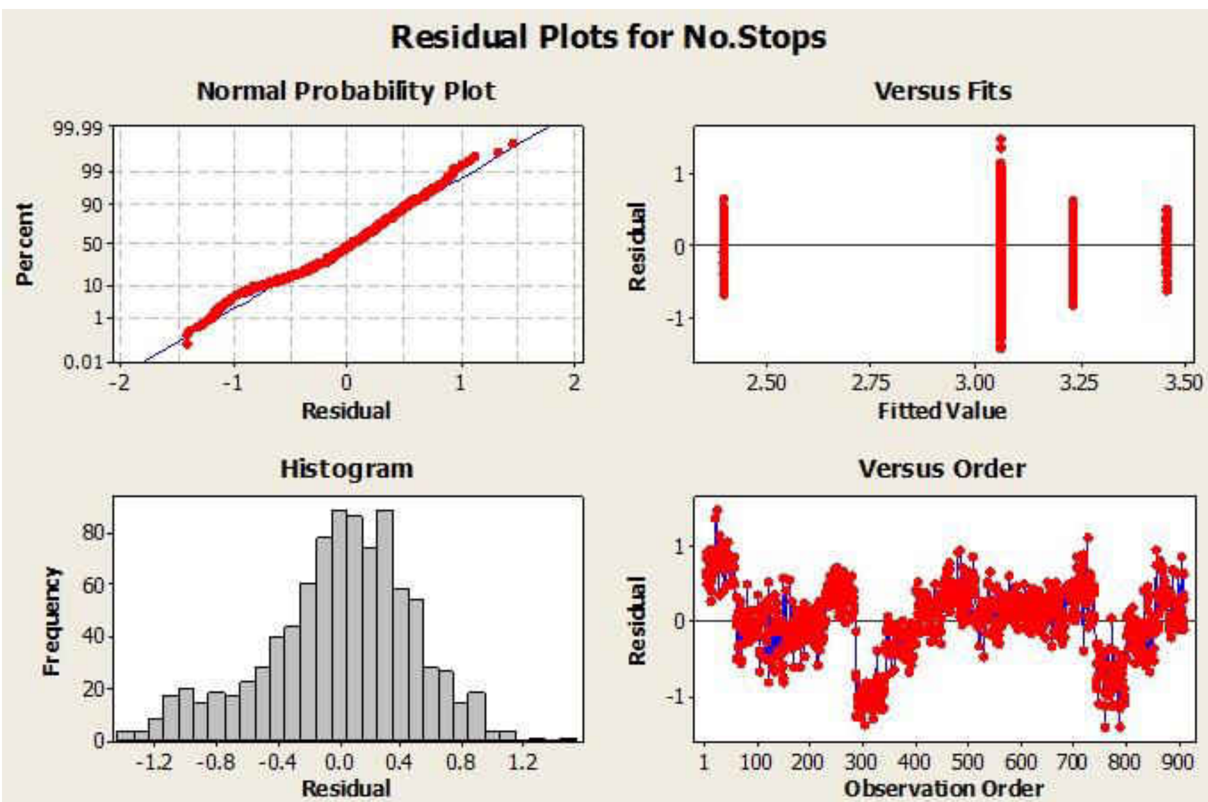
A new model developed in Minitab without the predictor variables (Unconditional).

```
-   Analysis of Variance
-   Source               DF    Seq SS    Adj SS    Adj MS         F          P
-   Regression            2    153.72    153.72    76.862   18.8964  0.0000000
-     Conditional-3min    1     18.94     35.59    35.595    8.7509  0.0031746
-     Conditional-5min    1    134.78    134.78   134.781   33.1358  0.0000000
-   Error               909   3697.39   3697.39     4.068
-   Total               911   3851.11
-
-   Summary of Model
-   S = 2.01681      R-Sq = 3.99%          R-Sq(adj) = 3.78%
-   PRESS = 3720.96  R-Sq(pred) = 3.38%
-
-   Coefficients
-   Term                  Coef   SE Coef        T      P
-   Constant           16.2518  0.077115  210.748  0.000
-   Conditional-3min   -0.6036  0.204027   -2.958  0.003
-   Conditional-5min   -1.1745  0.204027   -5.756  0.000
-
-   Regression Equation
-
-   Speed  =  16.2518 - 0.603551 Conditional-3min - 1.17445 Conditional-5min
```



d) Number of Stops

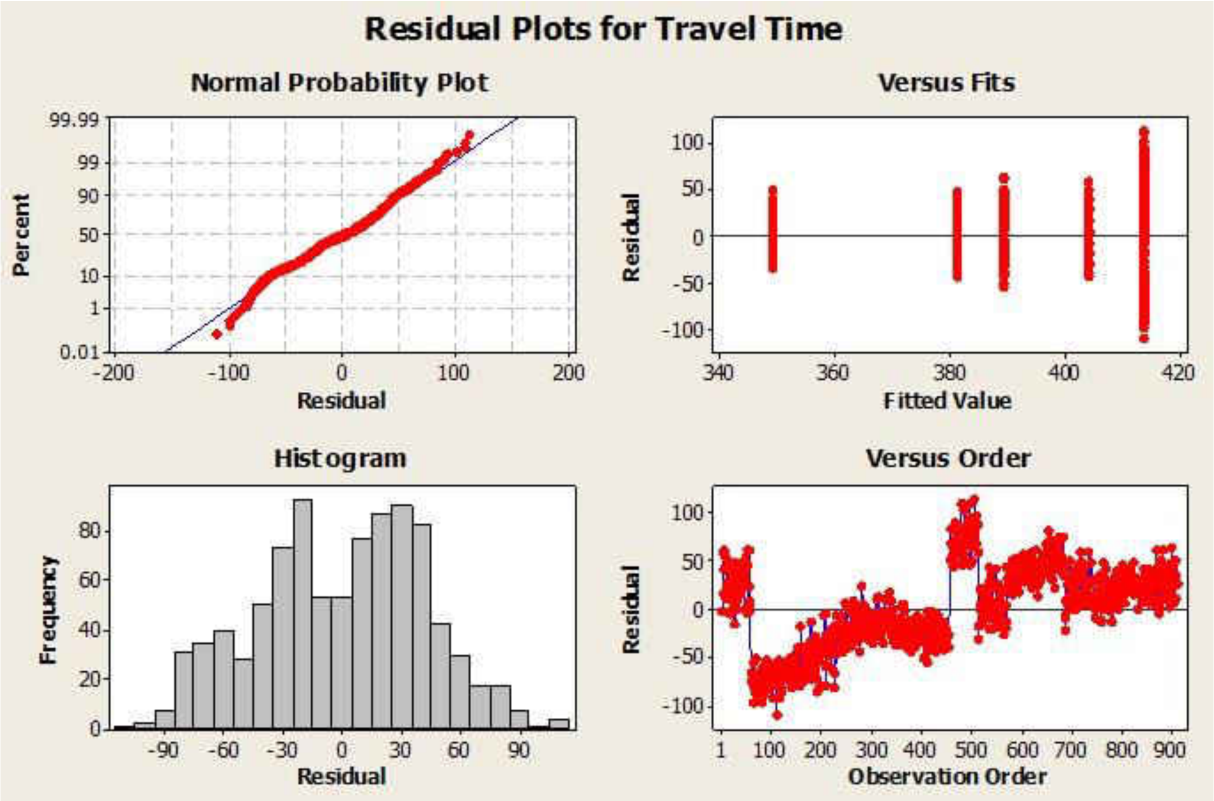
```
-   Analysis of Variance
-   Source                DF    Adj SS    Adj MS  F-Value  P-Value
-   Regression             3    72.401   24.1335   102.88    0.000
-     Unconditional        1    42.349   42.3490   180.54    0.000
-     Conditional-3min     1     2.880    2.8798    12.28    0.000
-     Conditional-5min     1    15.209   15.2088    64.84    0.000
-   Error                908   212.991    0.2346
-   Total                911   285.391
-
-   Model Summary
-          S     R-sq  R-sq(adj)  R-sq(pred)
-   0.484326  25.37%     25.12%      24.98%
-
-   Coefficients
-   Term                 Coef   SE Coef  T-Value  P-Value   VIF
-   Constant           3.0598    0.0203   150.83    0.000
-   Unconditional     -0.6677    0.0497   -13.44    0.000  1.05
-   Conditional-3min   0.1741    0.0497     3.50    0.000  1.05
-   Conditional-5min   0.4001    0.0497     8.05    0.000  1.05
-
-   Regression Equation
-
-   No.Stops = 3.0598 - 0.6677 Unconditional + 0.1741 Conditional-3min
               + 0.4001 Conditional-5min
```



2. THE BASE AND BRT SCENARIOS MODEL

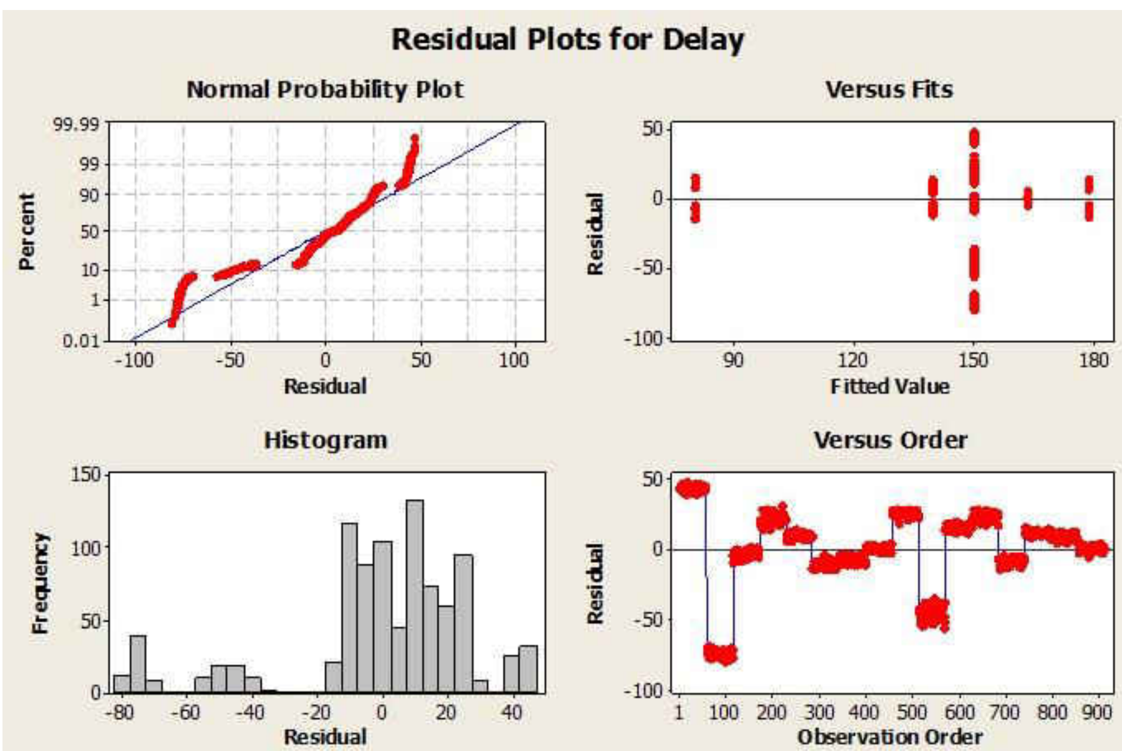
a) Travel Time

```
-    Analysis of Variance
-    Source                DF    Adj SS   Adj MS   F-Value   P-Value
-    Regression             4    430314   107579     60.60     0.000
-      BRT_NO-TSP           1      8050     8050      4.53     0.033
-      BRT_TSP-Uncond       1    381338   381338    214.82     0.000
-      BRT_TSP-Con-3min     1     95445    95445     53.77     0.000
-      BRT_TSP-Con-5min     1     54857    54857     30.90     0.000
-    Error                907   1610086     1775
-    Total                911   2040400
-
-    Model Summary
-          S     R-sq  R-sq(adj)  R-sq(pred)
-    42.1329  21.09%     20.74%      20.54%
-
-    Coefficients
-    Term                  Coef  SE Coef  T-Value  P-Value    VIF
-    Constant            413.82     1.97   209.74    0.000
-    BRT_NO-TSP           -9.39     4.41    -2.13    0.033   1.09
-    BRT_TSP-Uncond      -64.66     4.41   -14.66    0.000   1.09
-    BRT_TSP-Con-3min    -32.35     4.41    -7.33    0.000   1.09
-    BRT_TSP-Con-5min    -24.53     4.41    -5.56    0.000   1.09
-
-    Regression Equation
-    Travel Time = 413.82 - 9.39 BRT_NO-TSP - 64.66 BRT_TSP-Uncond
                  - 32.35 BRT_TSP-Con-3min - 24.53 BRT_TSP-Con-5min
```



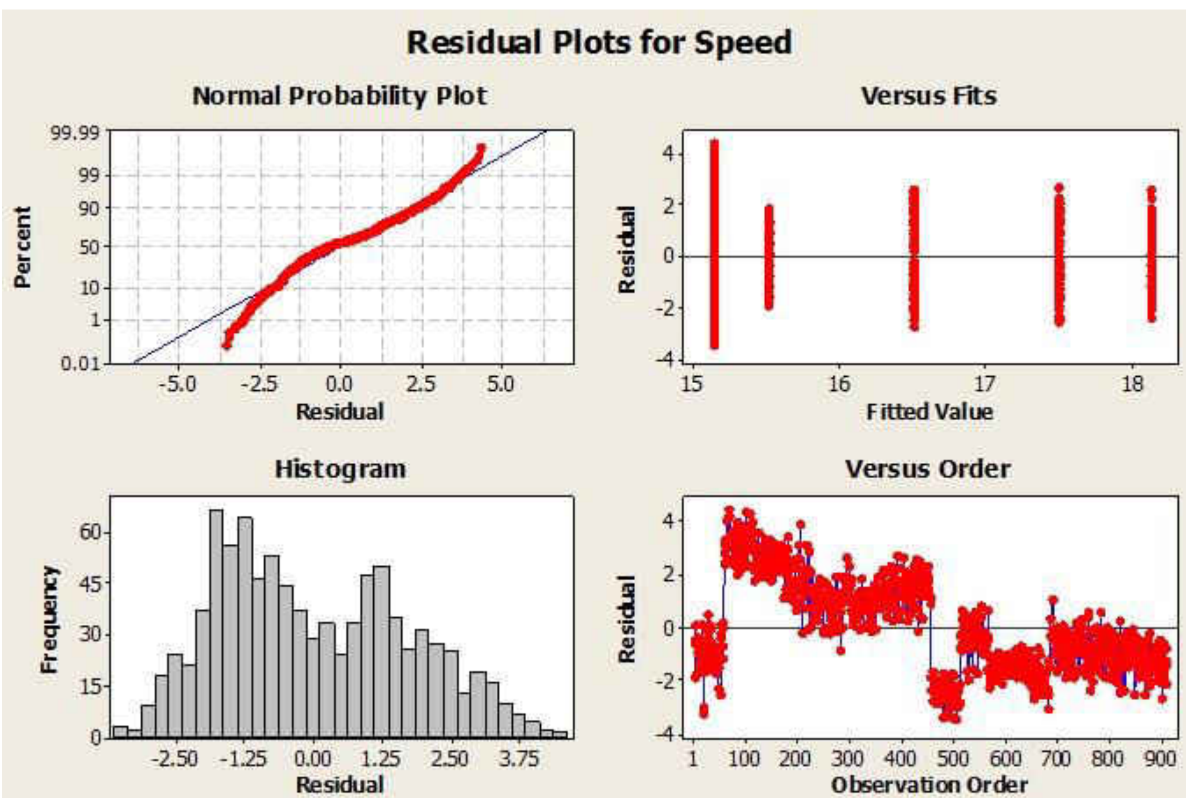
b) Delay

```
-   Analysis of Variance
-   Source               DF    Adj SS   Adj MS   F-Value   P-Value
-   Regression            4    660645   165161    216.84     0.000
-     BRT_NO-TSP          1     76040    76040     99.83     0.000
-     BRT_TSP-Uncond      1    442773   442773    581.31     0.000
-     BRT_TSP-Con-3min    1      9406     9406     12.35     0.000
-     BRT_TSP-Con-5min    1     16378    16378     21.50     0.000
-   Error               907    690842      762
-   Total               911   1351487
-
-   Model Summary
-         S     R-sq  R-sq(adj)  R-sq(pred)
-   27.5985  48.88%     48.66%      48.62%
-
-   Coefficients
-   Term                Coef  SE Coef  T-Value  P-Value   VIF
-   Constant          150.04     1.29   116.09    0.000
-   BRT_NO-TSP         28.88     2.89     9.99    0.000  1.09
-   BRT_TSP-Uncond    -69.68     2.89   -24.11    0.000  1.09
-   BRT_TSP-Con-3min  -10.16     2.89    -3.51    0.000  1.09
-   BRT_TSP-Con-5min   13.40     2.89     4.64    0.000  1.09
-
-   Regression Equation
-
-   Delay = 150.04 + 28.88 BRT_NO-TSP - 69.68 BRT_TSP-Uncond
            - 10.16 BRT_TSP-Con-3min + 13.40 BRT_TSP-Con-5min
```



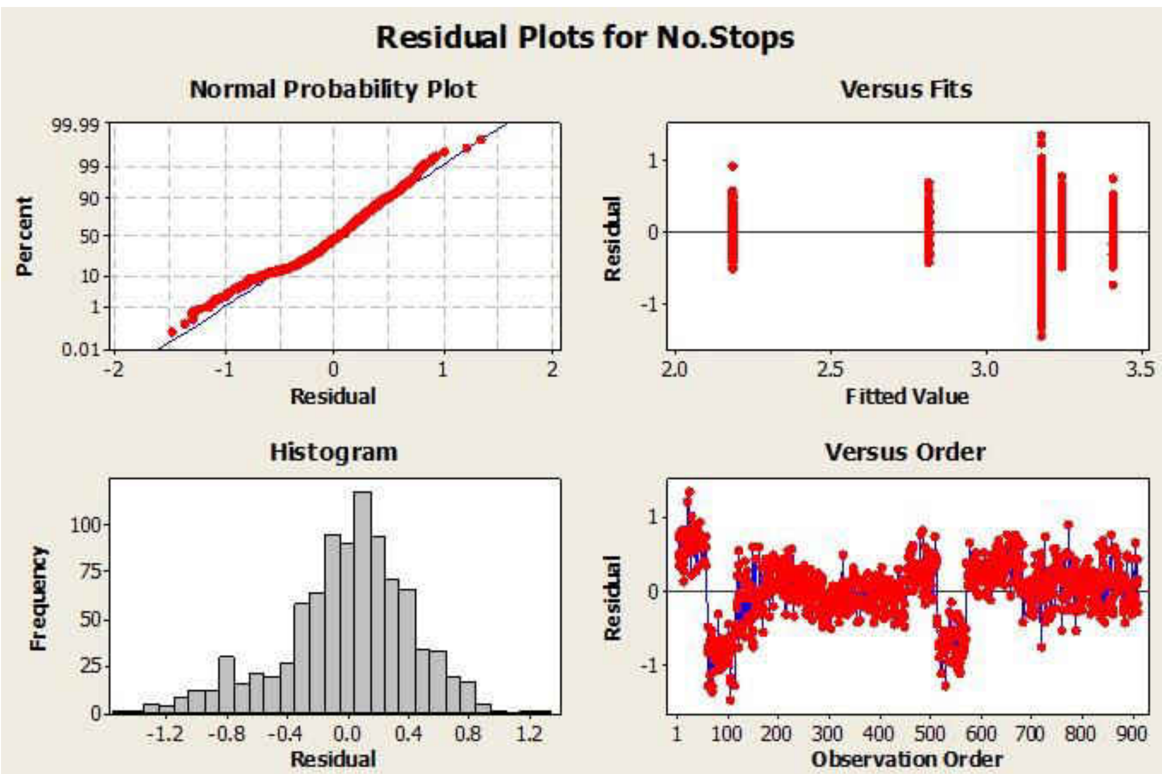
c) Speed

```
-   Analysis of Variance
-   Source                DF   Adj SS   Adj MS  F-Value  P-Value
-   Regression             4  1159.86  289.965    97.72    0.000
-     BRT_NO-TSP           1    12.03   12.028     4.05    0.044
-     BRT_TSP-Uncond       1   810.62  810.615   273.19    0.000
-     BRT_TSP-Con-3min     1   504.25  504.247   169.94    0.000
-     BRT_TSP-Con-5min     1   168.31  168.308    56.72    0.000
-   Error                907  2691.25    2.967
-   Total                911  3851.11
-
-   Model Summary
-         S    R-sq  R-sq(adj)  R-sq(pred)
-   1.72256  30.12%     29.81%      29.56%
-
-   Coefficients
-   Term                 Coef  SE Coef  T-Value  P-Value   VIF
-   Constant          15.1477   0.0807   187.78    0.000
-   BRT_NO-TSP          0.363    0.180     2.01    0.044  1.09
-   BRT_TSP-Uncond      2.981    0.180    16.53    0.000  1.09
-   BRT_TSP-Con-3min    2.351    0.180    13.04    0.000  1.09
-   BRT_TSP-Con-5min    1.358    0.180     7.53    0.000  1.09
-
-   Regression Equation
-
-   Speed = 15.1477 + 0.363 BRT_NO-TSP + 2.981 BRT_TSP-Uncond
            + 2.351 BRT_TSP-Con-3min + 1.358 BRT_TSP-Con-5min
```



d) Number of Stops

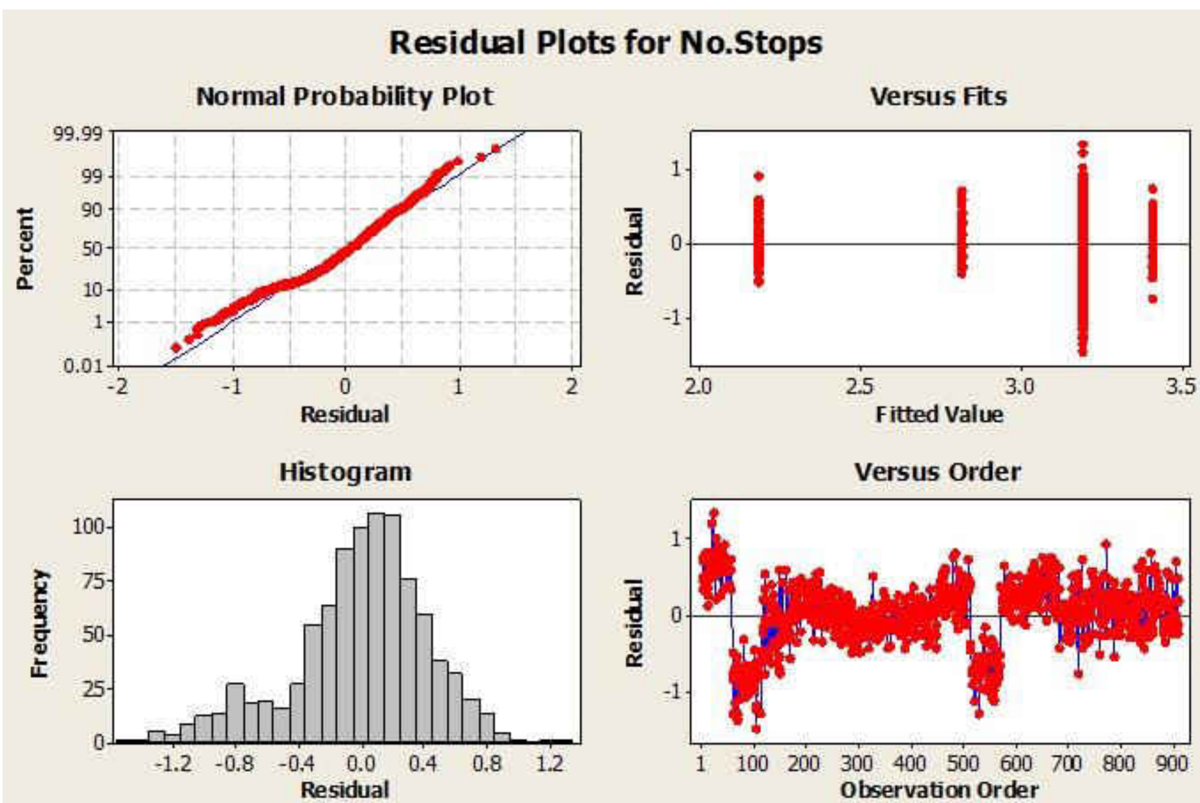
```
-   Analysis of Variance
-   Source               DF   Adj SS   Adj MS  F-Value  P-Value
-   Regression            4  119.758  29.9394   163.95    0.000
-     BRT_NO-TSP          1    4.852   4.8522    26.57    0.000
-     BRT_TSP-Uncond      1   91.448  91.4478   500.76    0.000
-     BRT_TSP-Con-3min    1   12.205  12.2048    66.83    0.000
-     BRT_TSP-Con-5min    1    0.387   0.3869     2.12    0.146
-   Error               907  165.634   0.1826
-   Total               911  285.391
-
-   Model Summary
-          S    R-sq  R-sq(adj)  R-sq(pred)
-   0.427337  41.96%     41.71%      41.58%
-
-   Coefficients
-   Term                 Coef  SE Coef  T-Value  P-Value   VIF
-   Constant           3.1821   0.0200   159.01    0.000
-   BRT_NO-TSP         0.2307   0.0447     5.15    0.000  1.09
-   BRT_TSP-Uncond    -1.0014   0.0447   -22.38    0.000  1.09
-   BRT_TSP-Con-3min  -0.3658   0.0447    -8.18    0.000  1.09
-   BRT_TSP-Con-5min   0.0651   0.0447     1.46    0.146  1.09
-
-   Regression Equation
-
-   No.Stops = 3.1821 + 0.2307 BRT_NO-TSP - 1.0014 BRT_TSP-Uncond
               - 0.3658 BRT_TSP-Con-3min + 0.0651 BRT_TSP-Con-5min
```



A new model developed in Minitab without the predictor variables (BRT TSP Cond. 5 Minutes).

```
-   Analysis of Variance
-   Source               DF   Seq SS   Adj SS   Adj MS        F          P
-   Regression            3  119.371  119.371  39.7902  217.620  0.0000000
-     BRT_NO-TSP          1   17.318    4.500   4.4996   24.609  0.0000008
-     BRT_TSP-Uncond      1   88.418   97.753  97.7527  534.628  0.0000000
-     BRT_TSP-Con-3min    1   13.635   13.635  13.6349   74.572  0.0000000
-   Error               908  166.021  166.021   0.1828
-   Total               911  285.391
-
-   Summary of Model
-   S = 0.427601     R-Sq = 41.83%         R-Sq(adj) = 41.63%
-   PRESS = 166.885  R-Sq(pred) = 41.52%
-
-   Coefficients
-   Term                   Coef    SE Coef        T      P
-   Constant            3.19509  0.0179102  178.395  0.000
-   BRT_NO-TSP          0.21763  0.0438709    4.961  0.000
-   BRT_TSP-Uncond     -1.01438  0.0438709  -23.122  0.000
-   BRT_TSP-Con-3min   -0.37885  0.0438709   -8.636  0.000
-
-   Regression Equation
```

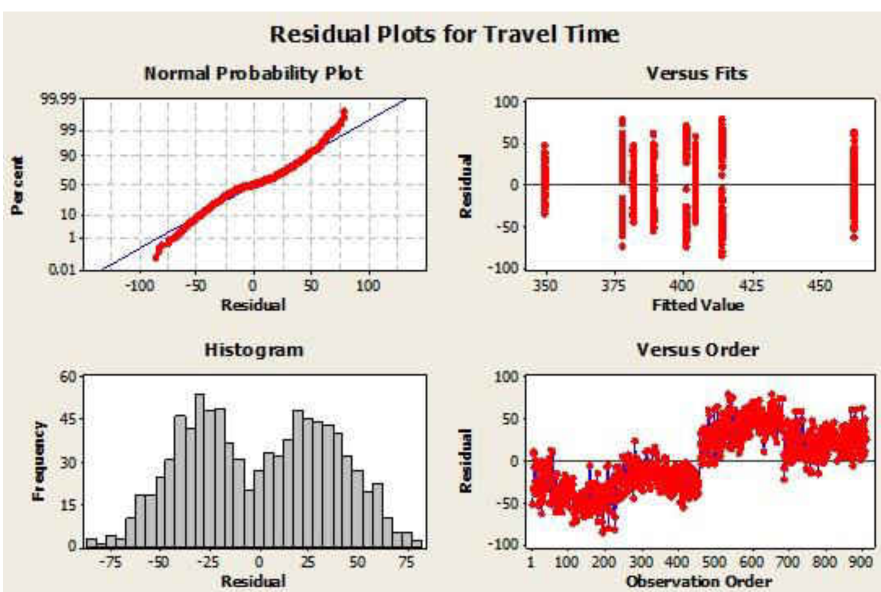
- **No.Stops = 3.19509 + 0.217633 BRT_NO-TSP - 1.01438 BRT_TSP-Uncond - 0.378847 BRT_TSP-Con-3min**



3. THE BASE, TSP, AND BRT SCENARIOS MODEL

a) Travel Time

```
-   Analysis of Variance
-   Source                DF   Adj SS   Adj MS  F-Value  P-Value
-   Regression             7   867071   123867    95.43    0.000
-     Unconditional        1   408463   408463   314.70    0.000
-     Conditional-3min     1   216386   216386   166.72    0.000
-     Conditional-5min     1   132681   132681   102.22    0.000
-     BRT_NO-TSP           1   191900   191900   147.85    0.000
-     BRT_TSP-Uncond       1   731591   731591   563.66    0.000
-     BRT_TSP-Con-3min     1   373779   373779   287.98    0.000
-     BRT_TSP-Con-5min     1   305033   305033   235.02    0.000
-   Error                904  1173329     1298
-   Total                911  2040400
-   Model Summary
-         S    R-sq  R-sq(adj)  R-sq(pred)
-   36.0268  42.50%     42.05%      41.47%
-   Coefficients
-   Term                 Coef  SE Coef  T-Value  P-Value   VIF
-   Constant           462.45     3.37   137.05    0.000
-   Unconditional      -84.65     4.77   -17.74    0.000  1.75
-   Conditional-3min   -61.61     4.77   -12.91    0.000  1.75
-   Conditional-5min   -48.25     4.77   -10.11    0.000  1.75
-   BRT_NO-TSP         -58.02     4.77   -12.16    0.000  1.75
-   BRT_TSP-Uncond    -113.29     4.77   -23.74    0.000  1.75
-   BRT_TSP-Con-3min   -80.98     4.77   -16.97    0.000  1.75
-   BRT_TSP-Con-5min   -73.15     4.77   -15.33    0.000  1.75
-
-   Regression Equation
-   Travel Time = 462.45 - 84.65 Unconditional - 61.61 Conditional-3min
                  - 48.25 Conditional-5min - 58.02 BRT_NO-TSP
                  - 113.29 BRT_TSP-Uncond - 80.98 BRT_TSP-Con-3min
                  - 73.15 BRT_TSP-Con-5min
```



b) Delay

- Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	7	1271663	181666	2057.37	0.000
Unconditional	1	509626	509626	5771.52	0.000
Conditional-3min	1	44763	44763	506.94	0.000
Conditional-5min	1	7666	7666	86.81	0.000
BRT_NO-TSP	1	1243	1243	14.07	0.000
BRT_TSP-Uncond	1	607317	607317	6877.86	0.000
BRT_TSP-Con-3min	1	108849	108849	1232.72	0.000
BRT_TSP-Con-5min	1	23128	23128	261.92	0.000
Error	904	79823	88		
Total	911	1351487			

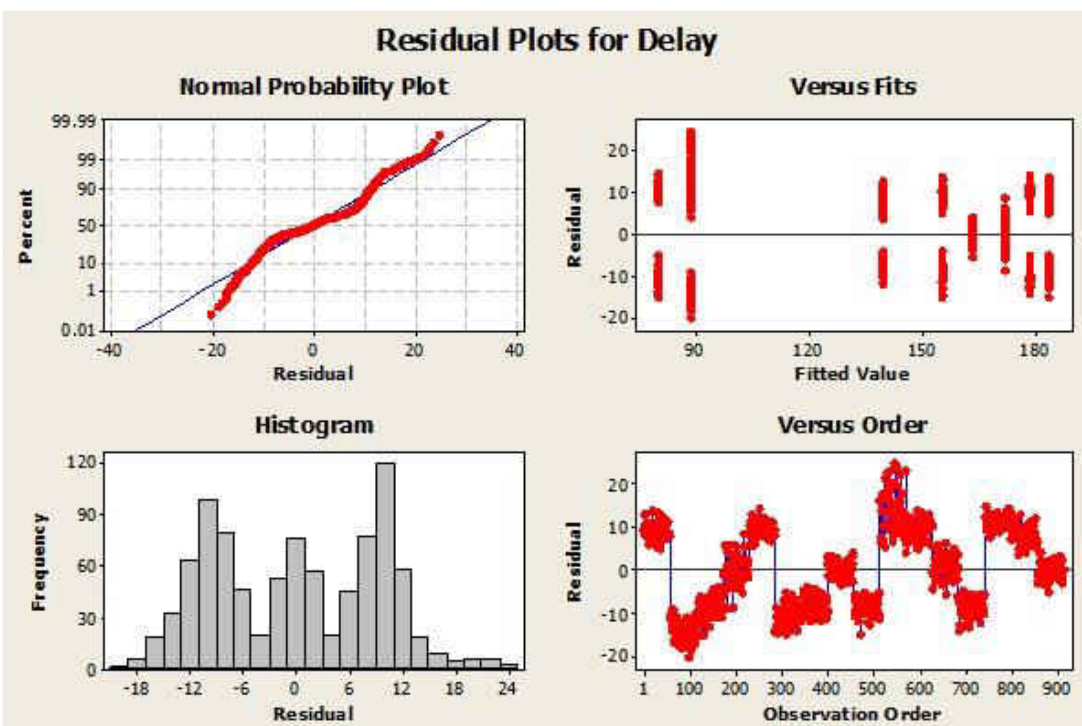
- Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
9.39682	94.09%	94.05%	93.99%

- Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	183.580	0.880	208.59	0.000	
Unconditional	-94.56	1.24	-75.97	0.000	1.75
Conditional-3min	-28.02	1.24	-22.52	0.000	1.75
Conditional-5min	-11.60	1.24	-9.32	0.000	1.75
BRT_NO-TSP	-4.67	1.24	-3.75	0.000	1.75
BRT_TSP-Uncond	-103.22	1.24	-82.93	0.000	1.75
BRT_TSP-Con-3min	-43.70	1.24	-35.11	0.000	1.75
BRT_TSP-Con-5min	-20.14	1.24	-16.18	0.000	1.75

- Regression Equation
- **Delay = 183.580 - 94.56 Unconditional - 28.02 Conditional-3min - 11.60 Conditional-5min - 4.67 BRT_NO-TSP - 103.22 BRT_TSP-Uncond - 43.70 BRT_TSP-Con-3min - 20.14 BRT_TSP-Con-5min**



c) Speed

- Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	7	1747.9	249.69	107.32	0.000
Unconditional	1	548.3	548.34	235.68	0.000
Conditional-3min	1	292.8	292.77	125.84	0.000
Conditional-5min	1	163.8	163.85	70.42	0.000
BRT_NO-TSP	1	258.4	258.36	111.05	0.000
BRT_TSP-Uncond	1	1284.5	1284.53	552.11	0.000
BRT_TSP-Con-3min	1	966.2	966.24	415.30	0.000
BRT_TSP-Con-5min	1	556.4	556.40	239.15	0.000
Error	904	2103.3	2.33		
Total	911	3851.1			

- Model Summary

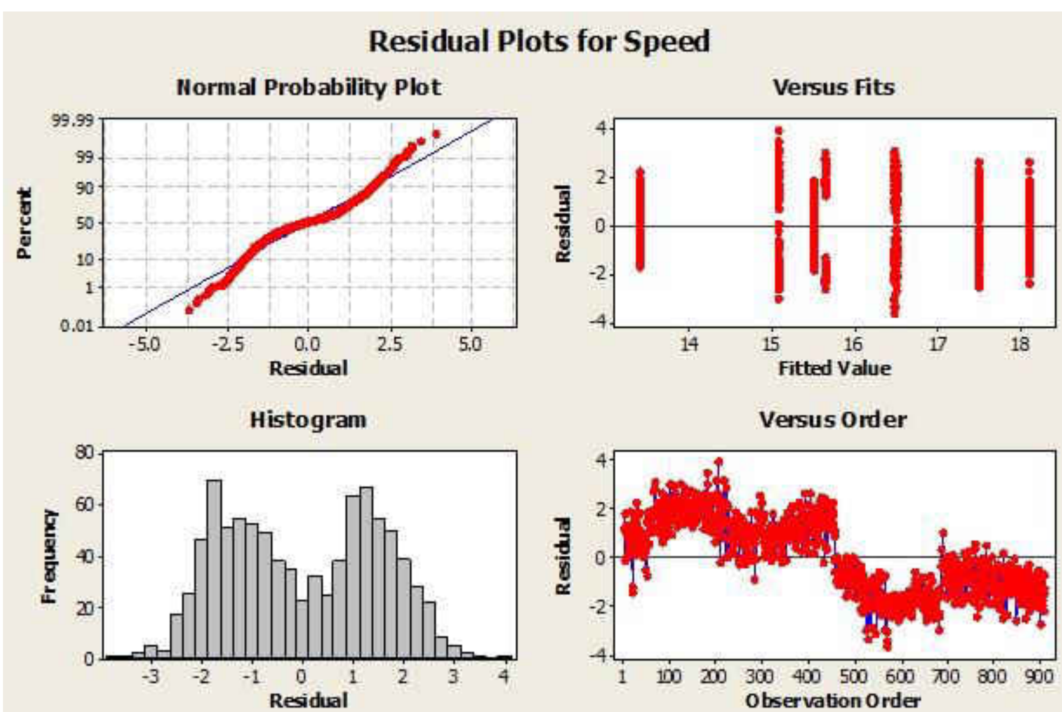
S	R-sq	R-sq(adj)	R-sq(pred)
1.52532	45.39%	44.96%	44.41%

- Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	13.382	0.143	93.67	0.000	
Unconditional	3.102	0.202	15.35	0.000	1.75
Conditional-3min	2.266	0.202	11.22	0.000	1.75
Conditional-5min	1.695	0.202	8.39	0.000	1.75
BRT_NO-TSP	2.129	0.202	10.54	0.000	1.75
BRT_TSP-Uncond	4.747	0.202	23.50	0.000	1.75
BRT_TSP-Con-3min	4.117	0.202	20.38	0.000	1.75
BRT_TSP-Con-5min	3.124	0.202	15.46	0.000	1.75

- Regression Equation

Speed = 13.382 + 3.102 Unconditional + 2.266 Conditional-3min
+ 1.695 Conditional-5min + 2.129 BRT_NO-TSP + 4.747 BRT_TSP-Uncond
+ 4.117 BRT_TSP-Con-3min + 3.124 BRT_TSP-Con-5min



d) Number of Stops

- Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	7	224.138	32.020	472.56	0.000
Unconditional	1	89.074	89.074	1314.58	0.000
Conditional-3min	1	9.503	9.503	140.24	0.000
Conditional-5min	1	1.894	1.894	27.96	0.000
BRT_NO-TSP	1	3.002	3.002	44.31	0.000
BRT_TSP-Uncond	1	121.756	121.756	1796.91	0.000
BRT_TSP-Con-3min	1	38.889	38.889	573.94	0.000
BRT_TSP-Con-5min	1	8.895	8.895	131.28	0.000
Error	904	61.253	0.068		
Total	911	285.391			

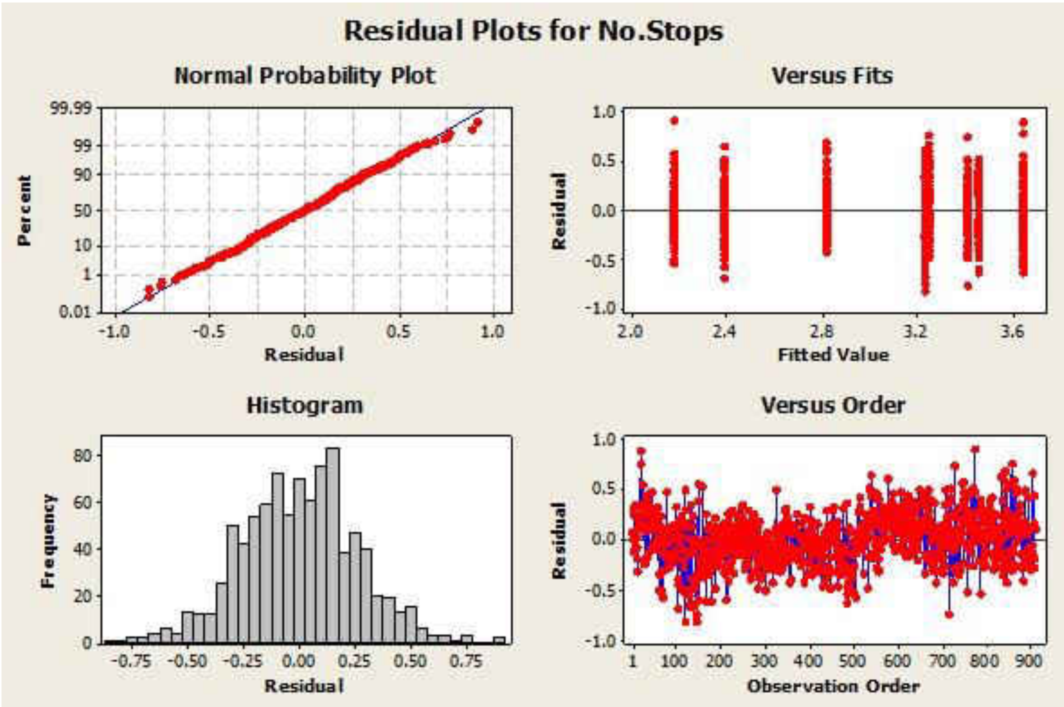
- Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.260304	78.54%	78.37%	78.16%

- Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	3.6422	0.0244	149.40	0.000	
Unconditional	-1.2501	0.0345	-36.26	0.000	1.75
Conditional-3min	-0.4083	0.0345	-11.84	0.000	1.75
Conditional-5min	-0.1823	0.0345	-5.29	0.000	1.75
BRT_NO-TSP	-0.2295	0.0345	-6.66	0.000	1.75
BRT_TSP-Uncond	-1.4615	0.0345	-42.39	0.000	1.75
BRT_TSP-Con-3min	-0.8260	0.0345	-23.96	0.000	1.75
BRT_TSP-Con-5min	-0.3950	0.0345	-11.46	0.000	1.75

- Regression Equation
- **No.Stops = 3.6422 - 1.2501 Unconditional - 0.4083 Conditional-3min - 0.1823 Conditional-5min - 0.2295 BRT_NO-TSP - 1.4615 BRT_TSP-Uncond - 0.8260 BRT_TSP-Con-3min - 0.3950 BRT_TSP-Con-5min**



APPENDIX H: DETAILED INTERSECTION TRAFFIC MOVEMENTS AFTER BRT

Turning Movement Counts on Intersection T1 after BRT

		International Dr						Universal Blvd						TOTAL
		EB			WB			NB			SB			
		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
4:00 - 4:15	PC	33	72	9	37	94	61	14	77	30	51	44	27	549
	HV	2	6	0	1	5	3	0	8	2	1	0	2	30
SUM		35	78	9	38	99	64	14	85	32	52	44	29	579
4:15 - 4:30	PC	45	86	3	21	71	53	12	82	34	71	31	21	530
	HV	1	3	0	4	2	6	0	5	0	2	2	0	25
SUM		46	89	3	25	73	59	12	87	34	73	33	21	555
4:30 - 4:45	PC	32	78	12	38	120	73	18	85	35	51	63	29	634
	HV	4	3	0	1	3	2	2	10	1	1	2	0	29
SUM		36	81	12	39	123	75	20	95	36	52	65	29	663
4:45 - 5:00	PC	32	86	11	44	118	56	19	92	37	55	63	42	655
	HV	4	1	0	3	3	3	0	10	1	1	5	1	32
SUM		36	87	11	47	121	59	19	102	38	56	68	43	687
1		Total PC		499	Total PC		786	Total PC		535	Total PC		548	2484
		Totl HV		24	Totl HV		36	Totl HV		39	Totl HV		17	
5:00 - 5:15	PC	45	90	13	35	123	99	17	155	29	38	58	43	745
	HV	1	4	0	1	4	4	1	6	3	8	3	2	37
SUM		46	94	13	36	127	103	18	161	32	46	61	45	782
5:15 - 5:30	PC	33	79	16	34	139	91	36	163	41	55	102	32	821
	HV	0	5	0	5	2	2	0	7	0	1	8	2	32
SUM		33	84	16	39	141	93	36	170	41	56	110	34	853
5:30 - 5:45	PC	58	80	17	54	158	83	21	129	41	62	120	64	887
	HV	1	4	1	1	7	3	0	2	2	4	6	1	32
SUM		59	84	18	55	165	86	21	131	43	66	126	65	919
5:45 - 6:00	PC	34	84	15	38	112	59	23	142	39	48	74	63	731
	HV	3	1	0	1	4	3	0	2	4	1	4	1	24
SUM		37	85	15	39	116	62	23	144	43	49	78	64	755
2		Total PC		564	Total PC		1025	Total PC		836	Total PC		759	3309
		Totl HV		20	Totl HV		37	Totl HV		27	Totl HV		41	
Total		328	682	97	318	965	601	163	975	299	450	585	330	5793
		1107			1884			1437			1365			
		2991						2802						

Turning Movement Counts on Intersection T2 after BRT

		International Dr						Kirkman Road						TOTAL
		EB			WB			NB			SB			
		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
4:00 - 4:15	PC	33	104	10	47	107	190	15	326	42	97	153	48	1172
	HV	2	4	1	0	2	4	1	12	1	5	14	5	51
SUM		35	108	11	47	109	194	16	338	43	102	167	53	1223
4:15 - 4:30	PC	30	156	11	58	144	214	10	326	50	87	183	36	1305
	HV	1	7	0	0	2	1	0	7	1	2	6	4	31
SUM		31	163	11	58	146	215	10	333	51	89	189	40	1336
4:30 - 4:45	PC	41	121	16	44	113	168	20	439	30	88	162	50	1292
	HV	1	3	2	0	6	1	2	4	0	3	8	3	33
SUM		42	124	18	44	119	169	22	443	30	91	170	53	1325
4:45 - 5:00	PC	33	95	14	61	117	170	9	501	40	93	145	46	1324
	HV	2	4	2	0	3	6	0	9	1	4	10	6	47
SUM		35	99	16	61	120	176	9	510	41	97	155	52	1371
1		Total PC		664	Total PC		1433	Total PC		1808	Total PC		1188	5255
		Totl HV		29	Totl HV		25	Totl HV		38	Totl HV		70	
5:00 - 5:15	PC	42	118	22	54	98	216	15	433	47	95	151	37	1328
	HV	1	4	2	1	6	0	0	5	2	4	4	5	34
SUM		43	122	24	55	104	216	15	438	49	99	155	42	1362
5:15 - 5:30	PC	33	128	27	61	129	184	24	404	50	106	177	51	1374
	HV	2	2	2	0	3	3	1	6	1	2	4	7	33
SUM		35	130	29	61	132	187	25	410	51	108	181	58	1407
5:30 - 5:45	PC	34	128	20	59	91	184	26	401	42	95	178	43	1301
	HV	1	4	1	0	4	1	0	5	2	4	2	6	30
SUM		35	132	21	59	95	185	26	406	44	99	180	49	1331
5:45 - 6:00	PC	40	96	11	55	122	151	15	415	47	103	170	49	1274
	HV	3	2	1	3	5	4	0	7	1	3	2	3	34
SUM		43	98	12	58	127	155	15	422	48	106	172	52	1308
2		Total PC		699	Total PC		1404	Total PC		1919	Total PC		1255	5408
		Totl HV		25	Totl HV		30	Totl HV		30	Totl HV		46	
Total		299	976	142	443	952	1497	138	3300	357	791	1369	399	10663
		1417			2892			3795			2559			
		4309						6354						

Turning Movement Counts on Intersection T3 after BRT

		International Dr						Grand National						TOTAL
		EB			WB			NB			SB			
		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
4:00 - 4:15	PC	77	161	14	12	184	4	39	40	11	4	33	101	680
	HV	0	4	0	0	4	1	0	1	0	1	1	1	13
SUM		77	165	14	12	188	5	39	41	11	5	34	102	693
4:15 - 4:30	PC	52	191	13	7	168	3	37	35	6	13	25	110	660
	HV	0	3	0	0	3	0	0	1	0	0	0	0	7
SUM		52	194	13	7	171	3	37	36	6	13	25	110	667
4:30 - 4:45	PC	43	166	13	9	179	1	37	54	10	4	27	115	658
	HV	0	3	0	0	3	1	0	1	0	0	0	3	11
SUM		43	169	13	9	182	2	37	55	10	4	27	118	669
4:45 - 5:00	PC	70	171	10	3	153	0	45	41	6	3	26	108	636
	HV	0	1	0	0	2	0	0	0	0	0	1	1	5
SUM		70	172	10	3	155	0	45	41	6	3	27	109	641
1		Total PC		981	Total PC		723	Total PC		361	Total PC		569	2670
		Totl HV		11	Totl HV		14	Totl HV		3	Totl HV		8	
5:00 - 5:15	PC	54	178	13	6	193	5	45	36	10	4	22	128	694
	HV	0	4	0	0	3	0	0	2	0	0	0	0	9
SUM		54	182	13	6	196	5	45	38	10	4	22	128	703
5:15 - 5:30	PC	51	200	14	2	189	4	62	56	13	7	24	90	712
	HV	0	5	0	0	4	0	0	0	1	1	2	0	13
SUM		51	205	14	2	193	4	62	56	14	8	26	90	725
5:30 - 5:45	PC	50	165	13	5	176	7	47	35	12	5	19	117	651
	HV	0	6	0	0	6	0	0	0	0	0	0	0	12
SUM		50	171	13	5	182	7	47	35	12	5	19	117	663
5:45 - 6:00	PC	61	176	11	9	195	10	38	37	4	7	29	95	672
	HV	0	1	0	0	2	0	0	1	0	0	0	1	5
SUM		61	177	11	9	197	10	38	38	4	7	29	96	677
2		Total PC		986	Total PC		801	Total PC		395	Total PC		547	2768
		Totl HV		16	Totl HV		15	Totl HV		4	Totl HV		4	
Total		458	1435	101	53	1464	36	350	340	73	49	209	870	5438
		1994			1553			763			1128			
		3547						1891						

Turning Movement Counts on Intersection T4 after BRT

		International Dr						Municipal						TOTAL
		EB			WB			NB			SB			
		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
4:00 - 4:15	PC	4	166	10	31	116	0	11	9	27	0	0	0	374
	HV	0	2	0	1	4	0	1	0	0	0	0	0	8
SUM		4	168	10	32	120	0	12	9	27	0	0	0	382
4:15 - 4:30	PC	9	150	15	37	147	0	12	2	48	0	0	0	420
	HV	0	5	1	0	5	0	0	0	0	0	0	0	11
SUM		9	155	16	37	152	0	12	2	48	0	0	0	431
4:30 - 4:45	PC	2	152	11	36	191	0	20	3	52	0	0	0	467
	HV	1	4	1	0	4	0	1	0	1	0	0	0	12
SUM		3	156	12	36	195	0	21	3	53	0	0	0	479
4:45 - 5:00	PC	1	179	26	23	181	0	24	3	61	0	0	0	498
	HV	0	2	2	0	3	0	0	0	0	0	0	0	7
SUM		1	181	28	23	184	0	24	3	61	0	0	0	505
1		Total PC		725	Total PC		762	Total PC		272	Total PC		0	1797
		Totl HV		18	Totl HV		17	Totl HV		3	Totl HV		0	
5:00 - 5:15	PC	6	176	30	34	144	0	28	2	53	0	0	0	473
	HV	0	2	0	1	3	0	2	0	0	0	0	0	8
SUM		6	178	30	35	147	0	30	2	53	0	0	0	481
5:15 - 5:30	PC	3	155	16	31	161	2	32	2	52	0	0	0	454
	HV	0	3	0	0	4	0	1	0	0	0	0	0	8
SUM		3	158	16	31	165	2	33	2	52	0	0	0	462
5:30 - 5:45	PC	5	163	15	30	148	0	31	3	58	0	0	0	453
	HV	2	4	0	0	4	0	1	0	0	0	0	0	11
SUM		7	167	15	30	152	0	32	3	58	0	0	0	464
5:45 - 6:00	PC	3	166	10	32	137	0	31	2	45	0	0	0	426
	HV	0	2	0	0	4	0	0	0	0	0	0	0	6
SUM		3	168	10	32	141	0	31	2	45	0	0	0	432
2		Total PC		748	Total PC		719	Total PC		339	Total PC		0	1839
		Totl HV		13	Totl HV		16	Totl HV		4	Totl HV		0	
Total		36	1331	137	256	1256	2	195	26	397	0	0	0	3636
		1504			1514			618			0			
		3018						618						

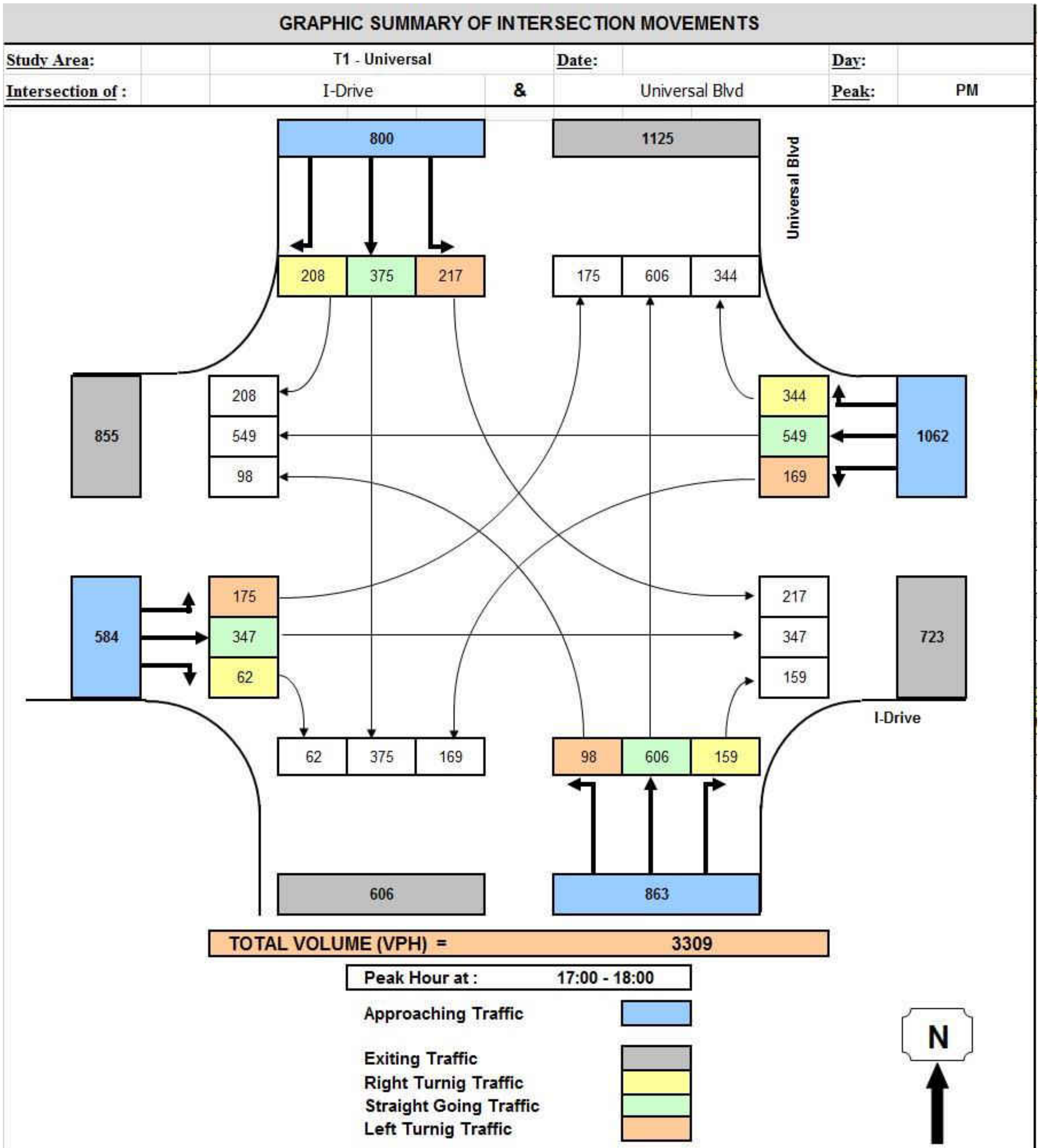
Turning Movement Counts on Intersection T5 after BRT

		Del Verde						International Dr						TOTAL
		EB			WB			NB			SB			
		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
4:00 - 4:15	PC	2	0	4	0	0	0	9	195	0	0	152	0	362
	HV	0	0	0	0	0	0	0	4	0	0	5	0	9
SUM		2	0	4	0	0	0	9	199	0	0	157	0	371
4:15 - 4:30	PC	5	0	1	0	0	0	10	237	0	0	203	5	461
	HV	0	0	0	0	0	0	0	2	0	0	3	0	5
SUM		5	0	1	0	0	0	10	239	0	0	206	5	466
4:30 - 4:45	PC	0	0	0	0	0	0	11	202	0	0	221	0	434
	HV	0	0	0	0	0	0	1	1	0	0	3	0	5
SUM		0	0	0	0	0	0	12	203	0	0	224	0	439
4:45 - 5:00	PC	8	0	3	0	0	0	10	231	0	0	160	0	412
	HV	0	0	0	0	0	0	0	6	0	0	5	3	14
SUM		8	0	3	0	0	0	10	237	0	0	165	3	426
1		Total PC		23	Total PC		0	Total PC		905	Total PC		741	1702
		Totl HV		0	Totl HV		0	Totl HV		14	Totl HV		19	
5:00 - 5:15	PC	3	0	4	0	0	0	4	223	0	0	175	0	409
	HV	0	0	0	0	0	0	0	2	0	0	5	1	8
SUM		3	0	4	0	0	0	4	225	0	0	180	1	417
5:15 - 5:30	PC	9	0	4	0	0	0	10	213	0	0	184	3	423
	HV	0	0	0	0	0	0	2	1	0	0	3	0	6
SUM		9	0	4	0	0	0	12	214	0	0	187	3	429
5:30 - 5:45	PC	1	0	3	0	0	0	5	241	0	0	185	0	435
	HV	0	0	0	0	0	0	0	5	0	0	3	0	8
SUM		1	0	3	0	0	0	5	246	0	0	188	0	443
5:45 - 6:00	PC	7	0	0	0	0	0	6	249	0	0	186	4	452
	HV	0	0	0	0	0	0	0	3	0	0	2	1	6
SUM		7	0	0	0	0	0	6	252	0	0	188	5	458
2		Total PC		31	Total PC		0	Total PC		951	Total PC		737	1747
		Totl HV		0	Totl HV		0	Totl HV		13	Totl HV		15	
Total		35	0	19	0	0	0	68	1815	0	0	1495	17	3449
			54			0			1883			1512		
		54						3395						

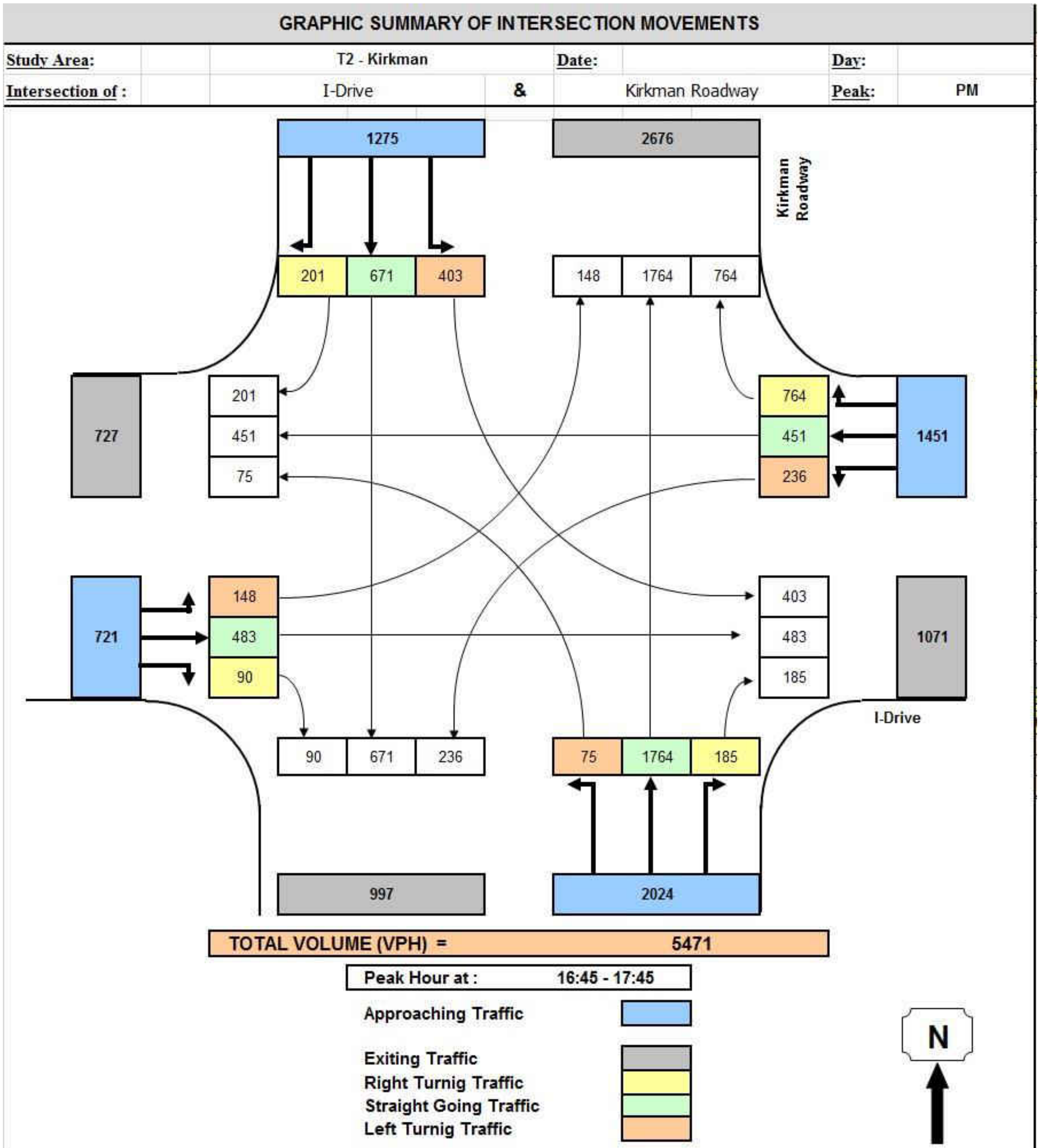
Turning Movement Counts on Intersection T6 after BRT

		Fun Spot						International Dr						TOTAL
		EB			WB			NB			SB			
		LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT	
4:00 - 4:15	PC	15	0	11	1	0	1	29	194	19	1	162	8	441
	HV	0	0	0	0	0	0	0	3	0	0	4	0	7
SUM		15	0	11	1	0	1	29	197	19	1	166	8	448
4:15 - 4:30	PC	12	0	14	4	1	2	28	169	12	3	173	2	420
	HV	0	0	0	0	0	0	0	1	0	0	2	0	3
SUM		12	0	14	4	1	2	28	170	12	3	175	2	423
4:30 - 4:45	PC	14	0	9	3	2	1	23	187	8	4	160	10	421
	HV	0	0	0	0	0	0	0	4	0	0	4	0	8
SUM		14	0	9	3	2	1	23	191	8	4	164	10	429
4:45 - 5:00	PC	9	2	16	3	1	1	25	195	16	4	182	11	465
	HV	0	0	0	0	0	0	0	0	0	0	2	0	2
SUM		9	2	16	3	1	1	25	195	16	4	184	11	467
1		Total PC		102	Total PC		20	Total PC		905	Total PC		720	1767
		Totl HV		0	Totl HV		0	Totl HV		8	Totl HV		12	
5:00 - 5:15	PC	8	2	13	4	0	0	26	206	15	2	164	9	449
	HV	0	0	0	0	0	0	0	4	0	0	3	0	7
SUM		8	2	13	4	0	0	26	210	15	2	167	9	456
5:15 - 5:30	PC	6	1	17	3	0	2	29	198	10	2	147	11	426
	HV	0	0	0	0	0	0	0	1	0	0	1	0	2
SUM		6	1	17	3	0	2	29	199	10	2	148	11	428
5:30 - 5:45	PC	17	0	15	4	2	0	19	199	11	3	159	6	435
	HV	0	0	0	0	0	0	0	4	0	0	3	0	7
SUM		17	0	15	4	2	0	19	203	11	3	162	6	442
5:45 - 6:00	PC	12	2	15	7	1	1	30	170	6	2	157	13	416
	HV	0	0	0	0	0	0	0	2	0	0	1	0	3
SUM		12	2	15	7	1	1	30	172	6	2	158	13	419
2		Total PC		108	Total PC		24	Total PC		919	Total PC		675	1745
		Totl HV		0	Totl HV		0	Totl HV		11	Totl HV		8	
Total		93	7	110	29	7	8	209	1537	97	21	1324	70	3512
			210			44			1843			1415		
		254						3258						

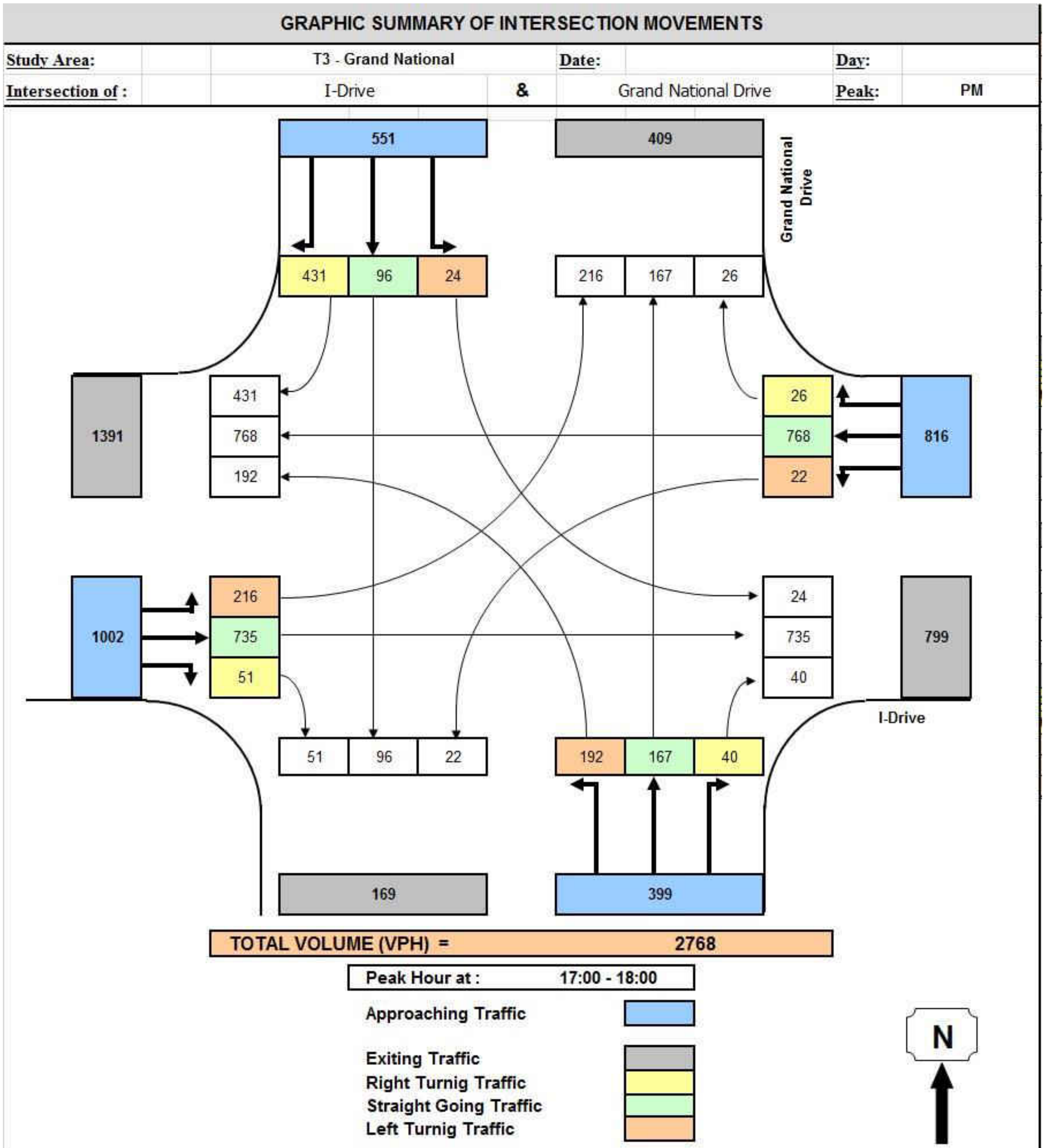
Graphic Summary of Intersection Peak Hour Movements - T1 after BRT



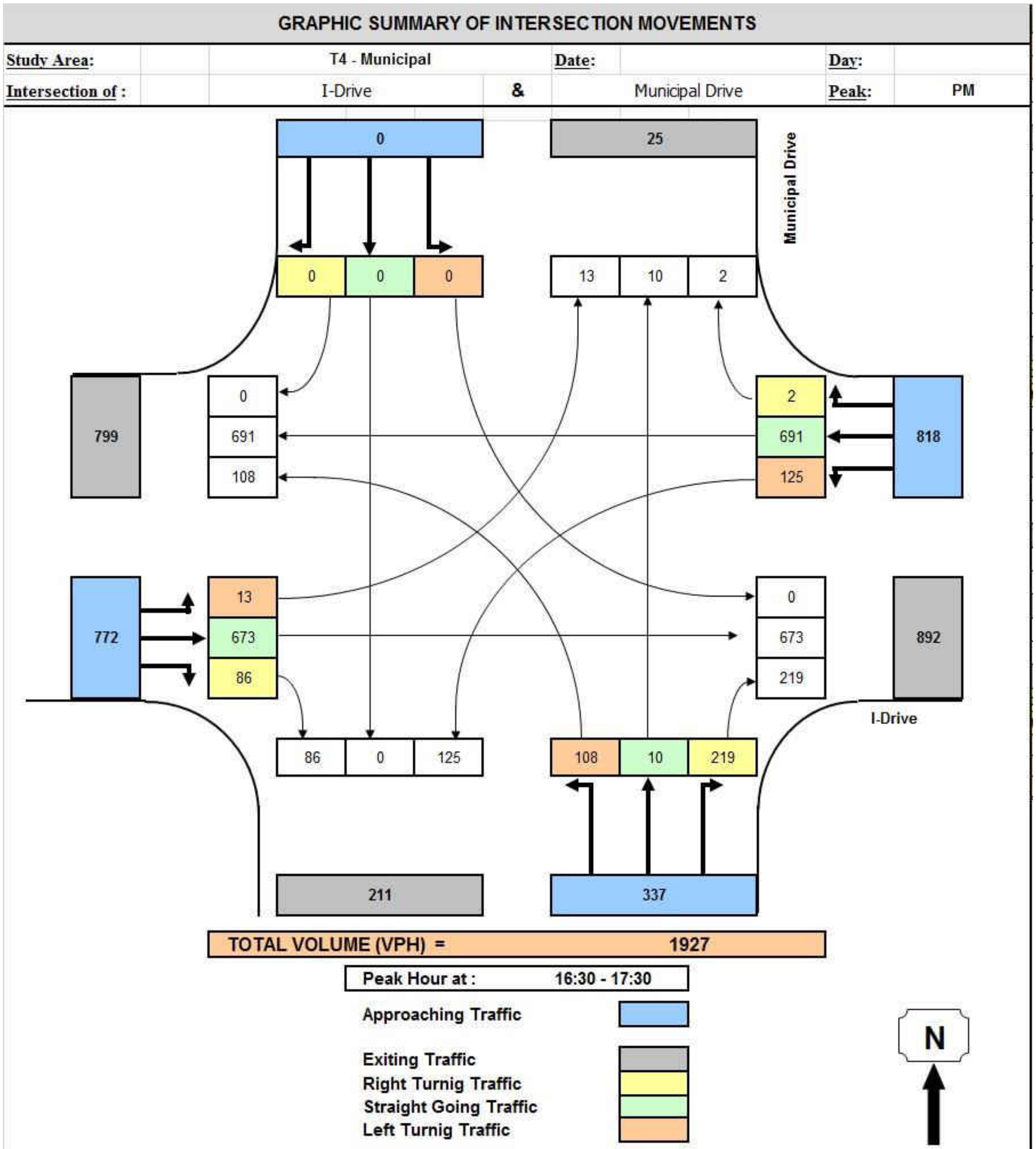
Graphic Summary of Intersection Peak Hour Movements – T2 after BRT



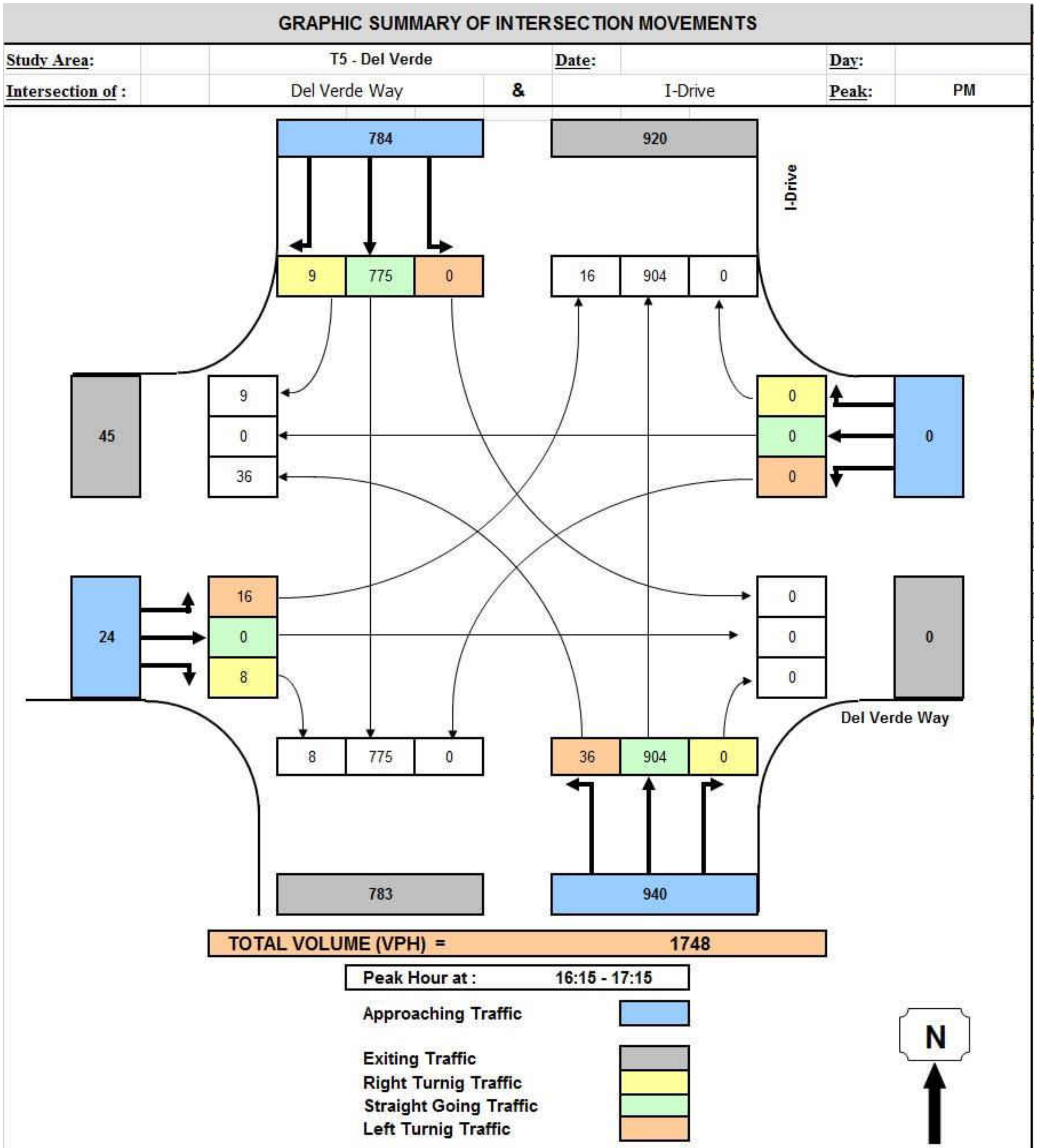
Graphic Summary of Intersection Peak Hour Movements – T3 after BRT



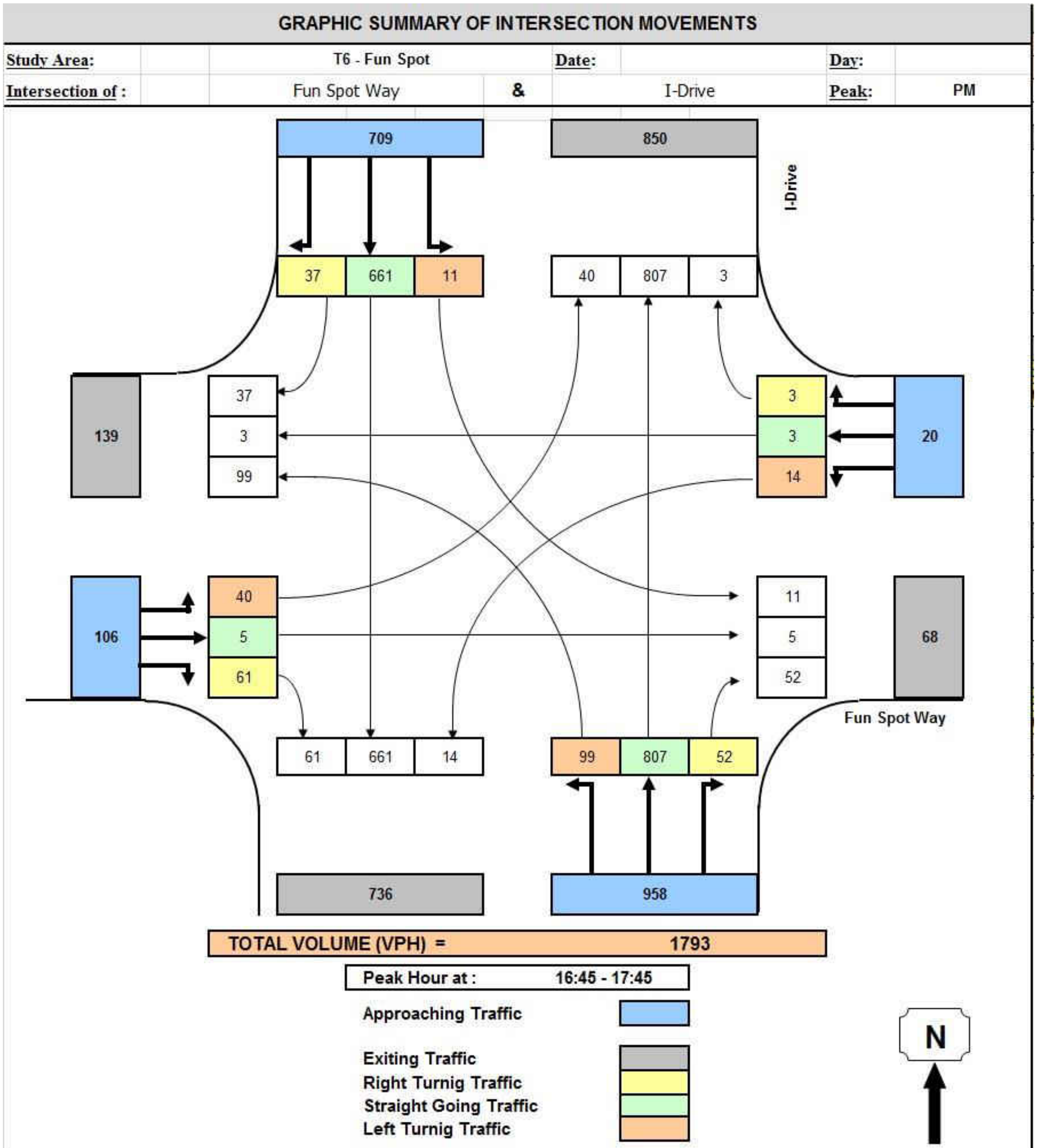
Graphic Summary of Intersection Peak Hour Movements – T4 after BRT



Graphic Summary of Intersection Peak Hour Movements – T5 after BRT



Graphic Summary of Intersection Peak Hour Movements – T6 after BRT



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