EVALUATION OF TRANSIT SIGNAL PRIORITY STRATEGIES FOR BUS RAPID TRANSIT PROJECT ON 3500 SOUTH STREET IN SALT LAKE COUNTY, UT

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Disclaimer

ABSTRACT

Bus Rapid Transit (BRT) is becoming one of the most popular transit services in the United States. BRT is a viable option for many cities and can offer commuters travel times comparable to those experienced in private cars. With about 100 miles of BRT service scheduled for deployment in future years, Utah Transit Authority (UTA) for the first time is facing questions related to BRT service. How will the service interact with private traffic? Will passengers accept unfamiliar features of the new service? We looked at the new BRT deployment in West Valley City, Salt Lake County, UT. Lacking BRT operational data from the field, but with a need to estimate operational challenges before the actual implementation, we used estimates generated from a microsimulation model. In addition, a series of surveys were conducted to gain feedback from the users of the BRT system. Results from the microsimulation runs show that the new BRT line leads to significant improvements of transit operations, with reductions of close to 20% in travel times and 40% in dwell times. An additional transit signal priority (TSP) feature is estimated to reduce travel times another 15%. The results showed that TSP has minor negative impact on side-street traffic and no impact or minor positive impact on main traffic. Results from the surveys show a high degree of acceptance of the new MAX buses among passengers and drivers. In short, the first BRT system in Utah can be qualified as another success story for the BRT systems in the United States.

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EXECUTIVE SUMMARY

Bus Rapid Transit (BRT) is a flexible, high performance rapid transit mode that uses buses or specialized rubber tire-based vehicles operating on pavement, and combines a variety of physical, operating, and system elements into a permanently integrated system (1). Because of its benefits and lower costs, Utah Transit Authority (UTA) has decided to begin with BRT implementations in Salt Lake County. The first BRT line is implemented along 3500 South Street.

BRT implementations usually go along with Transit Signal Priority (TSP), which is one of the transit strategies that provide priority for transit vehicles on signalized intersections along the main corridor. Many studies and implementations have proven its efficiency. On the other hand, providing priority along the main corridor has impacts on other vehicular traffic. For each TSP implementation, it is very important to find the optimum balance between the amounts of priority provided for transit vehicles weighed against the negative impacts on vehicular traffic.

This research evaluates BRT and TSP implementations along 3500 South Street in Salt Lake County through microsimulation. This is one of the major arterials and it has been chosen for the first BRT implementation in Utah. Field of study consists of a section with 13 signalized intersections along 3500 South, where traffic volumes are highest. Evaluations are based on a VISSIM simulation model, which was created for this sub-network, based on real traffic and transit data from the field.

BRT implementation consists of two phases, and this paper describes the first phase, where the BRT line will be located with respect to other traffic, without exclusive lanes and also along with the existing bus line, RT 35. In this phase, TSP will be provided on six intersections within the field of study.

The final results show that the implementation of BRT operations along the busiest segments of the 3500 S corridor provides a reduction in transit travel time by approximately 20% compared with the regular bus route, RT 35, while simultaneous implementation of BRT operations and TSP strategies can reduce transit travel time up to 30%, with no impact on vehicular traffic along the main corridor and negative impacts only on high traffic volume side streets. There are no negative impacts on low traffic volume side streets.

The report also provides recommendations for future evaluations.

1. INTRODUCTION

With overall traffic growth on city highways and streets, congestion is becoming a significant problem with various impacts on transit vehicles, especially those that do not use exclusive rights-of-way. These negative impacts often result in travel time increases, bad reliability and on-time performance, bus crowding, increase in passengers' bus stop waiting times, etc. In order to overcome these impacts, transit agencies introduce new, high capacity rapid transit modes, along with transit operational strategies.

In recent years, Bus Rapid Transit (BRT) has become one of the most commonly used rapid transit modes. BRT is a flexible, high performance rapid transit mode that uses buses or specialized rubber tire-based vehicles operating on pavement, and combines a variety of physical, operating, and system elements into a permanently integrated system (1). It is intended to provide the quality of rail transit at much lower construction and operational costs and combine it with the flexibility of buses.

BRT is an integrated system which consists of running ways (very often exclusive lanes), specially designed enhanced stations, high-capacity low-floor vehicles, services and Intelligent Transportation Systems (ITS). Transit Signal Priority (TSP) is an operational strategy often implemented on the most signalized intersections along a BRT line. TSP facilitates the movements of in-service transit vehicles through signalized intersections and makes transit faster, more reliable and more cost-effective (2). It is often used for regular bus lines, but is most beneficial when combined with BRT systems.
According to the Regional Transportation Plan: 2007–2030 (2030 RTP), adopted by the Wasatch Front Regional Council, 96 miles of BRT lines are planned for construction in Salt Lake, Davis, and Weber counties in Utah (3). The first BRT line, which will be implemented, is along 3500 South Street in Salt Lake County. BRT was chosen over other alternatives because of the costs and funding.

The goal of this study is to evaluate BRT operations and impacts of TSP implementation on BRT and vehicular traffic through microsimulation. The test-bed for the research is a part of the planned BRT line along the 3500 South. Currently, the deployment of the BRT line is in the first phase. This study uses a VISSIM simulation model to estimate BRT operations in this phase and the impacts that TSP implementation will have on BRT and vehicular traffic.

2. SUCCESSFUL BRT IMPLEMENTATIONS

The idea of using buses to provide rapid transit is not new. Studies and designs have been prepared since the 1930s (1). Some of the first studies and implementations were done in Chicago in 1937 (1,4), Washington D.C. from 1956 to 1959 (1,5), St. Louis in 1959 (1,6) and Milwaukee in 1970 (1,7).

However, truly efficient BRT systems have been implemented within the last 15 years. Some of these BRT implementations were very successful and exceeded the initial expectations (1,8).

A BRT line called TransMilenio in Bogota, Colombia, was introduced in 2000. So far, it has more than 50 miles of dedicated bus lanes and it carries more than one million passengers per day (9, 10). Travel time decreased by more than 30% compared with the previous system.

Metro Orange Line in Los Angeles County, California, was opened in 2005. It consists of a 14-mile dedicated busway. During the first seven months of operating, it achieved 2020 ridership predictions, with constant increase in ridership and lower travel times than any other travel mode along the corridor (8).

The implementation of a BRT line in Vancouver and Richmond, Canada, led to a 20% travel time decrease compared with the previous bus line, an increase in ridership of about 1.2 million passengers per year and a 23% mode shift of the car users from private cars to BRT, and an annualized benefit that has exceeded annual cost (11).

TSP is a set of operational strategies implemented at signalized intersections that provide a certain priority for transit vehicles, such as additional green times, earlier return to the green time, special transit phases, and similar strategies. The first attempts to implement TSP for transit vehicles in the United States appeared in the 1970s. However, these systems were based on preemption rather than transit priority. The difference is that preemption interrupts the normal operations to provide right of way for special events (i.e., for high priority vehicles, such as trains, emergency vehicles, fire trucks), while priority only modifies signal operations to better accommodate transit vehicles. The first TSP studies in the United States were conducted by Ludwick in 1975 in Washington D.C. (12). With the development of new technologies in recent years, such as Automatic Vehicle Location (AVL), Automatic Vehicle Identification (AVI), Global Positioning Systems (GPS), and systems for communication between buses and controllers, TSP systems became more efficient and their use is constantly increasing. The 2006 survey found that 38 metropolitan areas in the United States were using TSP technology (13).

3. PROJECT DESCRIPTION

3.1 Project Corridor

The first BRT line in Utah is implemented along 3500 South in Salt Lake County, which is one of the major arterials that connects the fast growing western part of the county with major north–south highway and transit routes, such as I-15, I-215, Bangerter Highway, and light rail transit system (TRAX). This arterial carries a significant amount of traffic, with average annual daily traffic (AADT) between 33,000 and 51,000 vehicles per day along the busiest corridors, as reported by UDOT for the year 2006 (14).

3.2 Bus Line RT 35

Currently, a city bus line, RT 35, operates along this corridor. It connects Magna and 3300 South Millcreek TRAX station. The length of the line is 10.1 miles (without the Magna loop) with 56 eastbound and 77 westbound bus stops (15). The line is in service daily for 19 hours from Monday to Friday, and buses depart every 15 minutes from 6 AM to 9 PM, and 30 to 60 minutes after 9 PM. Headways are reduced during weekends to 30 minutes on Saturdays and 60 minutes on Sundays. Time schedule is coordinated with the TRAX line.

Fare is collected onboard. Passengers pay their fares at the fare box on the bus. If they use a bus pass, transfer ticket, or all-day ticket, they must show it to the driver. This kind of fare payment affects bus operations at bus stops, because only the front bus door can be used for boarding and alighting, which increases dwell times.

Most of the bus stops along the line are on-street stops. Each bus stop is marked with a sign that provides information about the lines that use that bus stop. A few bus stops are sheltered or located in a bus bay and buses stop on-demand at all locations. Currently, the total daily ridership on this line is approximately 3,600 passengers.

3.3 BRT Implementation

Wasatch Region's transit agency, Utah Transit Authority (UTA), has started a project called "MAX," which refers to BRT implementations in the county (16). These implementations are planned according to the 2030 RTP (3), and there will be seven BRT implementations in the future.

The 3500 South corridor has been chosen for the first BRT implementation, because it is one of UTA's busiest routes (RT 35). The 3500 South BRT line will run from Magna to 3300 South TRAX station, covering 10.1 miles and containing 23 BRT related stops. This line will provide fast and reliable connection from Magna and West Valley to the TRAX line.

Deployment of the 3500 South BRT line is split into two phases. The first phase deploys a type-one BRT, which includes the following:

- Buses travel in mixed traffic
- Buses operate on a headway-based schedule, with 15-minute headways or less between 4:30 AM – 12:00 AM, Monday through Saturday
- Bus stops have increased spacing, one-half to one-quarter miles apart
- Passenger shelters on bus stops will be upgraded
- TSP will be provided on most intersections

This phase is currently in deployment. It was launched in July 2008.

In the second phase, center-running BRT lanes will be constructed from 2700 West to Bangerter Highway, and then from 3300 South TRAX station to 2700 West, and Bangerter Highway to 7200 West. This will separate BRT vehicles from other traffic, providing even better, faster, more reliable, and safer transit service. New BRT stops will be built and will include ticket vending machines and passenger information displays. Total costs of this BRT implementation will be $7 million.

3.4 3500 South BRT Operations

The 3500 South BRT line will operate six days a week, with no service on Sundays. During weekdays and Saturdays it will provide all-day service, from 5:30 AM to 12:30 AM with 15-minute headways. Schedules are coordinated with the TRAX line to facilitate transfers. The old RT 35 will continue to operate along with the BRT line, but less frequently (30- to 60-minute headways). On Sundays, only RT 35 will be in service.

UTA has purchased 10 new buses from Belgian manufacturer, Van Hool, which will be assigned to the BRT line. Each bus seats 60 passengers, and boarding and alighting will be possible through any of the three doors. The buses are equipped with stainless steel frames and body panels, top mounted cooling systems, object detection systems, full low-floor boarding capabilities, center ADA boarding, wider aisles, and more windows. The buses will have a new and unique paint scheme, which will give identity to the new MAX system. The cost of each bus is $403,000.

The BRT line will use fewer bus stops than RT 35. There will be 23 BRT stops along the line. Each BRT stop will be sheltered and lit, so the passengers will be better accommodated and protected than in a standard bus stop. BRT stops will be equipped with passenger information displays, and the design will also affect MAX system identity.

In order to decrease bus stop dwell times and improve accessibility, UTA will install ticket vending machines on BRT bus stops (the same machines already used in TRAX stations). Passengers will be able to buy one-way tickets ($2) or all-day passes ($5). After buying a ticket, passengers can board through any of the three doors and they will not need to show the driver their fare. UTA transit police officers will be checking fares.

UTA expects that ridership will increase 18%-20% after the BRT line implementation. In order to improve accessibility, about 400 park-and-ride spaces will be provided along the BRT line.

Figure 3.1 shows the whole route of the RT 35 and the BRT line with BRT bus stop locations.

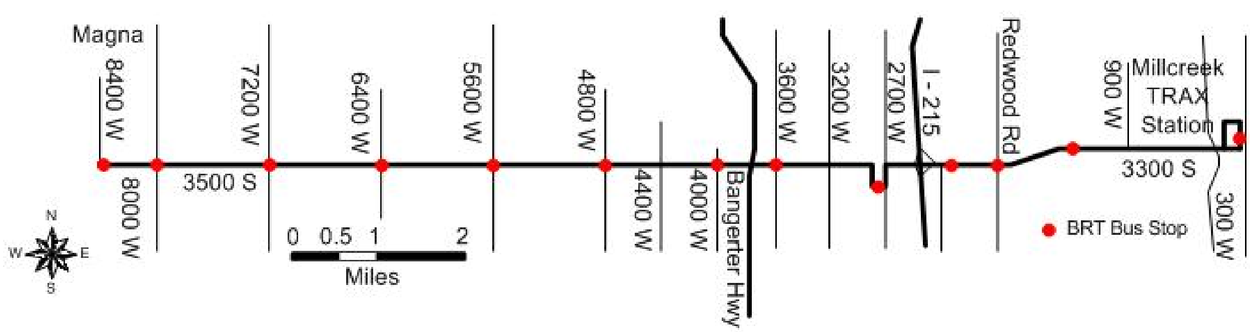


Figure 3.1 3500 South RT 35 and BRT Route with BRT Bus Stop Locations

4. MODELING METHODOLOGY

BRT operations and the impacts of TSP implementations in the first phase of BRT deployment were evaluated through a VISSIM microsimulation model. Modeling and evaluations were done for PM peak period, from 4 PM to 6 PM.

4.1 Simulation Network

The simulation network includes the busiest section of the new BRT corridor, from 2700 West to 5600 West Street, with a small digression from 2700 West to 2820 West, where the line makes a turn in order to service West Valley City's Valley Fair Mall. This section is four miles long with 13 signalized intersections along it (Figure 4.1).

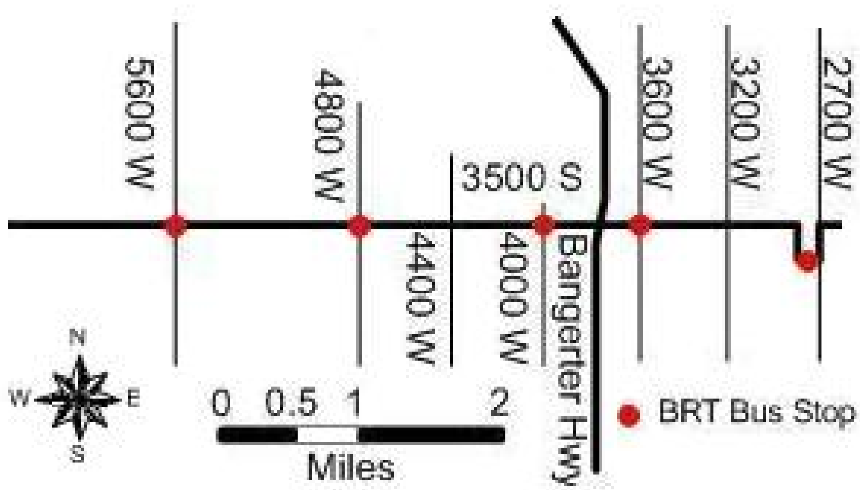


Figure 4.1 Study Area Along 3500 South

4.2 Modeling Process

For network modeling, VISSIM simulation software was used. VISSIM is a microscopic, time step, and behavior-based simulation model of urban traffic and public transit operations and is easily programmable. The modeling process was started in VISSIM Version 4.30, and continued in Version 5.00.

The existing network that reflects 2008 traffic conditions was modeled, calibrated and validated based on real data from the field, including network geometry, traffic and transit operations. For this project, VISSIM's features for transit operations modeling were very useful. It enabled the modeling of some basic parameters of transit, such as routes, transit stops, time scheduling, passenger movements (passenger arrivals at stops based on Poisson's distribution, passenger boarding for each stop, passenger alighting based on a user-defined alighting probability for each stop), and TSP.

The final output from this process was a validated and calibrated simulation model of the existing conditions for PM peak period (4 PM to 6 PM, with 15-minute build-up time). The same model was later used for modeling the BRT system and its evaluations. All VISSIM simulations for the three scenarios described below were run for 10 random seeds and all the results represent averaged values from 10 measurements.

4.3 Traffic Control

All signalized intersections along this section are part of a coordinated system (except the outlier intersection 3650 South and 2700 West, which is a free-running intersection). For PM peak period, cycle lengths on intersections around Bangerter Hwy (from 3450 West to 4000 West Street) are 150 seconds, on other intersections 120 seconds (except 4155 West, which is 75 seconds, and 5200 West, 60 seconds).

Traffic operations were modeled based on historical traffic data for the corridor (traffic counts collected in recent years). Based on the historical traffic counts, traffic was generated and distributed on the network using static assignment. Each signalized intersection was modeled based on actual signal timing data. These data were obtained from the Utah Department of Transportation (UDOT). Two of UDOT's data sources were used: SYNCHRO files for PM peak period for this corridor and I2 software, which enables direct on-line connection to traffic controllers and downloading signal control information.

4.4 Transit Operations

The model includes transit lines, RT 35 and the BRT line. Two scenarios were developed for the BRT line, one with TSP and the other one without TSP provided. RT 35 uses 39 bus stops within the field of study, 19 eastbound, and 20 westbound. As for the BRT line, there are 10 bus stops, five eastbound and five westbound. In this phase of BRT deployment, both lines operate in mixed traffic lanes, and they were simulated as that.

The research considered all transit operations, such as bus routes, locations of bus stops, time scheduling, bus ridership (existing and estimated), passenger loadings on each bus stop, and bus stop dwell times, for both transit lines.

The existing RT 35 was modeled according to its transit operations. The modeling included defining the route, bus stop locations (in both directions), time schedule, passenger loadings for each bus stop and passenger alighting (based on alighting probability for each bus stop). Passenger boarding and alighting were used for simulating dwell times at bus stops. There are two methods to define dwell times in VISSIM. The first is to define dwell time distributions, and the second is to calculate dwell times based on passenger boarding, alighting and clearance time for buses (17). Both methods were used in order to determine which provides more representative data of the actual conditions. Ultimately, the second method was chosen because it generates more correlated results for dwell times compared with the field results. This method is easier for defining purposes and allows VISSIM to track each passenger on a bus stop (waiting, boarding, and alighting), which cannot be done with dwell time distributions.

Boarding and alighting times depend on many factors, such as: bus stop design, the number of doors used for boarding or alighting, and their width, bus floor height, payment process, etc. After reviewing data from previous studies (18), during the modeling process it was determined that for the existing conditions, boarding time was 4.0 seconds per passenger, alighting time 2.6 seconds per passenger, and clearance time 10.0 seconds per bus stop.

Dwell time data collected from the field were for the three major bus stops (Valley Fair, 4000 West, and 5600 West, in both directions). These data were compared with dwell times gained from the VISSIM model, in order to create a model that would represent highly similar operations to the real ones. Table 4.1

shows bus stop dwell time comparison. Another advantage of this technique of dwell time defining is that it can be easily adjusted at any time using new data from the field.

Table 4.1 Bus Stops Dwell Times Modeling and Comparison

Eastbound	VISSIM Simulation		FIELD DATA	
Bus stop	Average Dwell Time (s)	Standard Deviation (s)	Average Dwell Time (s)	Standard Deviation (s)
Valley Fair	49.4	11.8	55	24
4000 West	29.9	7.4	29	11
5600 West	23.6	6.6	29	11

Westbound	VISSIM Simulation		FIELD DATA	
Bus stop	Average Dwell Time (s)	Standard Deviation (s)	Average Dwell Time (s)	Standard Deviation (s)
Valley Fair	40.9	11.6	37	12
4000 West	27.0	6.9	32	13
5600 West	31.9	11.2	32	13

The new BRT system was created using the same procedure. UTA has estimated bus ridership for the new BRT line, as well as for the modified RT 35, and these data were used in modeling.

Bus stop dwell times for the BRT line were changed. It came as a consequence of modified bus ridership (boarding and alighting passengers) for both BRT line and RT 35, and different boarding and alighting times for the BRT line. BRT will operate differently than RT 35. Vehicles will have three doors for boarding and alighting (regular RT 35 have only one) and fare payment will be off board. For these kinds of operations, it was determined that boarding time was 1.10 seconds per passenger and alighting time 1.20 seconds per passenger (18). This resulted in significant dwell time reductions.

4.5 Transit Signal Priority

Two TSP strategies were chosen for modeling and estimating: green extension and red truncation. These strategies are implemented on six signalized intersection within the field of study, from 4000 West to 5600 West. The maximum green extension and red truncation provided in the model is 10 seconds. In the BRT model, TSP is provided only for BRT vehicles, while RT 35 buses operate without TSP provided.

4.6 Calibration and Validation of the Model

The basic existing network model had to be calibrated and validated. Calibration and validation were based on the traffic data collected in the field. Model calibration was performed based on traffic movement counts for each signalized intersection in the network. Travel times between each pair of signalized intersections, which were collected using GPS, have been used to validate the model.

4.6.1 Calibration

Traffic movements for each signalized intersection were used to calibrate the model. Most of the traffic counts were collected in 2006, except for two intersections (3500 South and 3450 West in 2007, and 3650 South and 2700 West in 2008). VISSIM was programmed to collect the same data on all 13 signalized intersections. Calibration was performed by comparing data from the field counts to the data from the simulation. Figure 4.2 shows this comparison after the calibration was completed. The R Square value shows high correlation between the two data sets. In addition to this, a set of transit data, including passenger activity at stations, was used to calibrate the transit operations, as described in section 4.4.

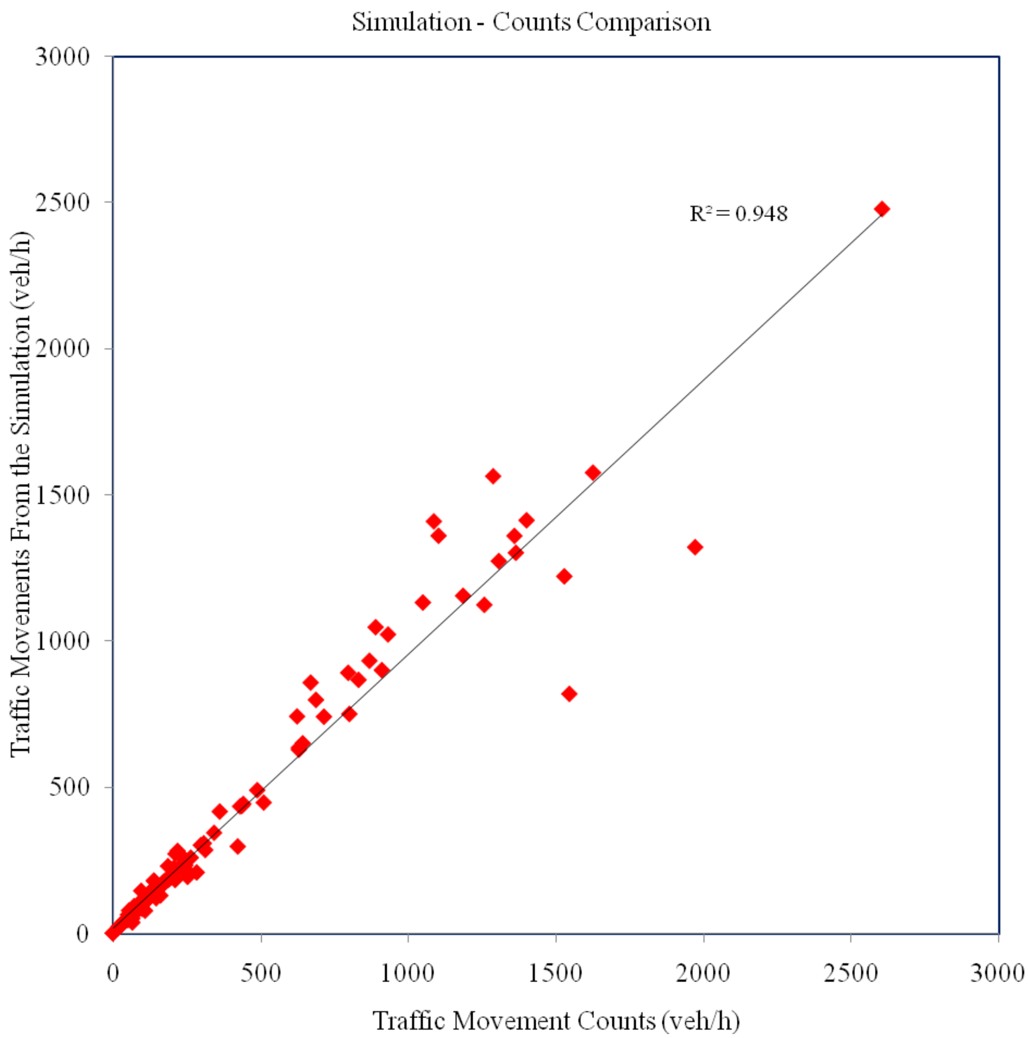
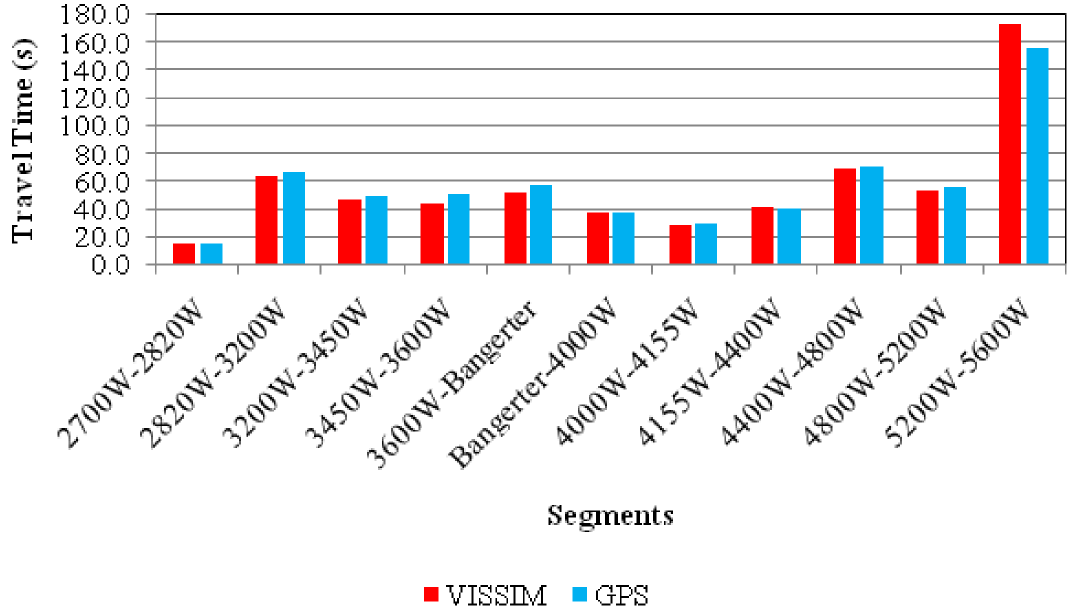


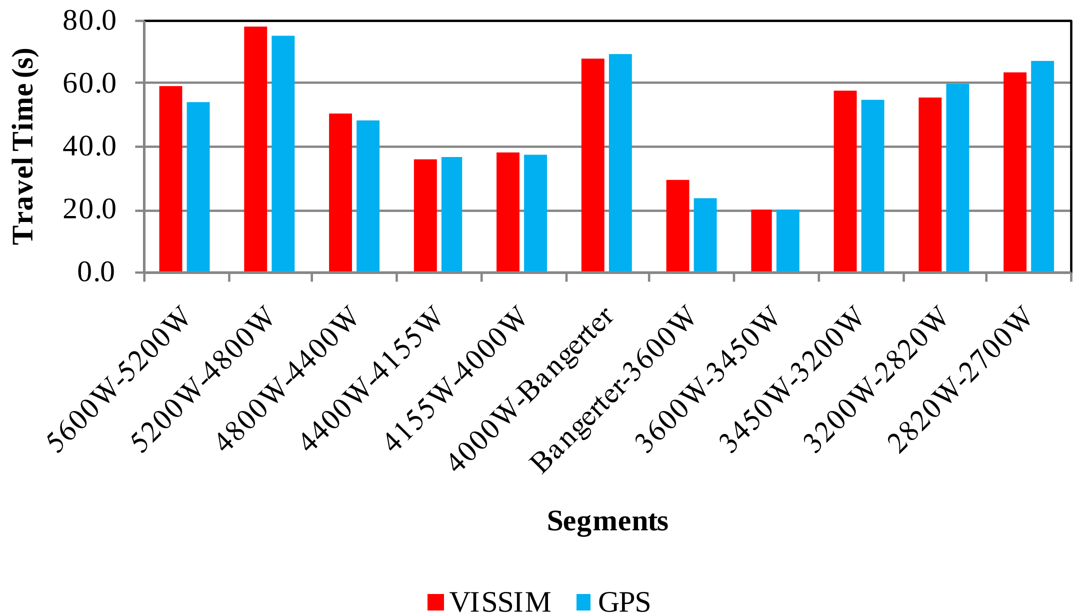
Figure 4.2 Model Calibration Results – Traffic Movement Comparison

4.6.2 Validation

The corridor along 3500 South, from 2700 West to 5600 West, was split into 22 segments (11 in eastbound and 11 in westbound direction). These segments are parts of the corridor between each pair of signalized intersections. Travel times for each segment were measured in the field using GPS in PM peaks. Travel time measuring points in VISSIM were set for the same segments. Travel times from the field were used to validate those from the model. Figure 4.3 shows comparison of travel times after the validation was completed. Depending on the random seed that is used in the simulation, R Square value for travel times varies between 96% and 99%.



a) Westbound Travel times



b) Eastbound Travel times

Figure 4.3 Model Validation – Travel Times Comparison

5. RESULTS AND DISCUSSION

The new BRT system was created as described in the previous chapter. In order to see the advantages that this system provides, it needs to be compared to the existing system in multiple ways. In order to analyze all impacts of the new systems, three scenarios were compared:

- Scenario RT 35, which introduces line RT 35 and its transit operations, before the BRT was implemented (noted as RT 35)
- Scenario BRT without TSP, which introduces the new BRT line and modified RT 35, but without TSP provided (noted as BRT No TSP)
- Scenario BRT, the new BRT line, modified RT 35 and TSP provided only for the BRT line (noted as BRT TSP)

In the initial phase of BRT implementation, TSP will be provided only on six intersections within the field of study, from 4000 West to 5600 West.

5.1 Transit Travel Times

The main goal of the project is to evaluate BRT operations and impacts of TSP implementation on BRT and vehicular traffic. The most visible parameter affected by these implementations is transit travel time. Table 5.1 and Figure 5.1 show comparisons of transit travel times for the three scenarios.

It can be seen that RT 35 has much higher travel times than the BRT line (with or without TSP). When BRT No TSP and BRT TSP scenarios are compared, it can be seen that there is no difference in travel times along the segments where TSP is not provided (from 2700 West to 4000 West, both westbound and eastbound). However, on segments west of 4000 West, where TSP is implemented, BRT TSP scenario does have lower travel times.

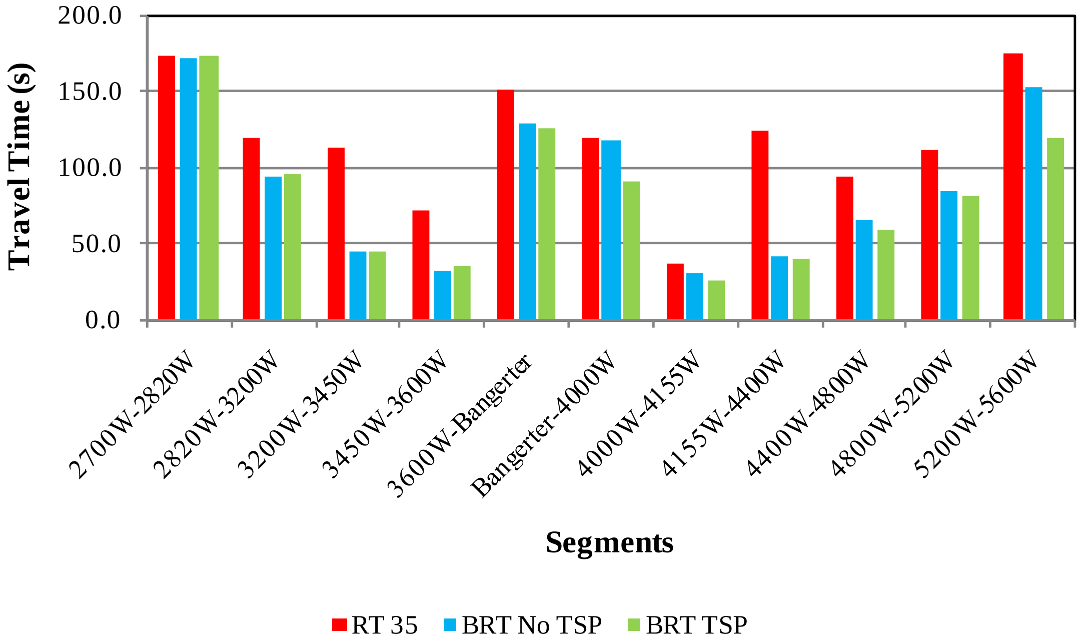
The analyses from the model show that implementing BRT operations (without TSP) can reduce transit travel times by approximately 20%, compared with RT 35. This reduction is a result of reduced dwell times on bus stops and reduced number of bus stops along the corridor. Implementing TSP can further reduce these times by approximately 31%. This is a reduction of five to six minutes for a 20-minute trip.

Parallel analysis of the BRT scenarios (with and without TSP) shows that TSP implementation can reduce BRT travel times by approximately 15% compared with the BRT No TSP scenario. There are two eastbound segments (4800 W – 4400 W and 3600 W – 3450 W) where the BRT travel times in both BRT scenarios are higher than RT 35 travel times. This is due to the two BRT stations at these locations where the BRT buses load more passengers than RT 35, creating higher station dwell times that impact BRT travel times.

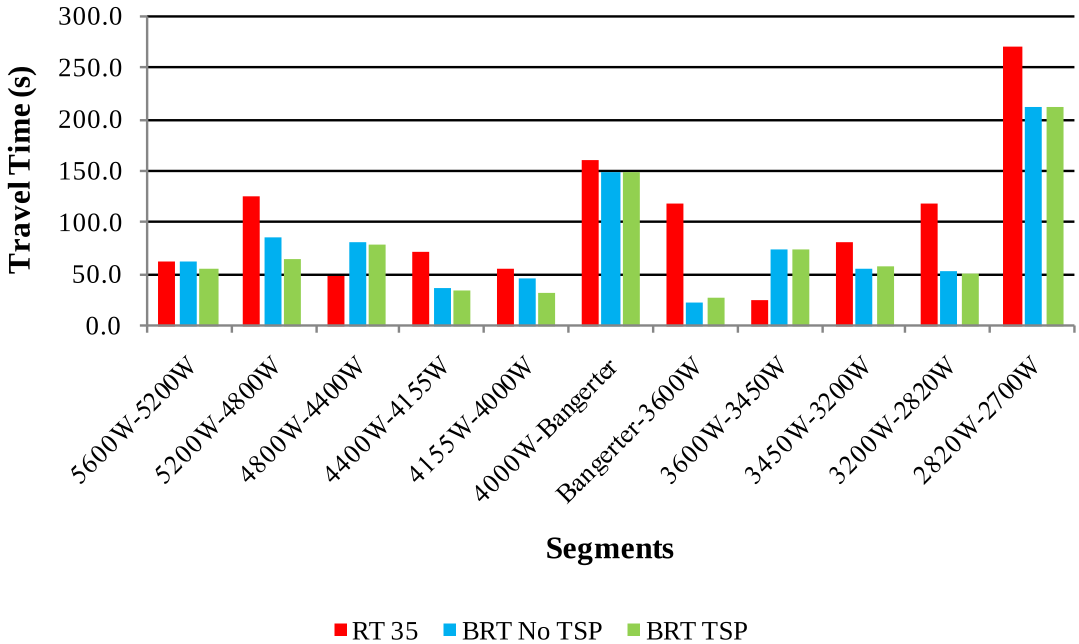
Table 5.1 Transit Travel Times Comparison

	Segments	RT 35	BRT No TSP	BRT TSP
Westbound Travel Times (s)	2700W-2820W	172.6	172.2	172.7
	2820W-3200W	118.5	94.3	94.5
	3200W-3450W	113.4	44.9	44.4
	3450W-3600W	71.3	31.7	34.3
	3600W-Bangerter	150.8	128.3	125.9
	Bangerter-4000W	118.7	117.0	91.0
	4000W-4155W	36.4	30.8	26.1
	4155W-4400W	124.4	41.2	39.9
	4400W-4800W	93.4	65.5	58.7
	4800W-5200W	111.2	84.6	81.5
	5200W-5600W	174.0	152.7	119.0
Eastbound Travel Times (s)	5600W-5200W	63.8	62.0	56.3
	5200W-4800W	126.3	87.1	64.2
	4800W-4400W	48.7	81.1	79.5
	4400W-4155W	72.6	36.5	33.9
	4155W-4000W	54.8	46.8	33.5
	4000W-Bangerter	159.5	148.3	149.0
	Bangerter-3600W	118.7	24.0	28.2
	3600W-3450W	25.5	74.9	74.7
	3450W-3200W	82.2	55.5	59.0
	3200W-2820W	118.7	53.4	50.4
	2820W-2700W	270.4	210.8	211.7
Total (s)	**2700W-5600W**	**1278.3**	**953.6**	**886.9**
	5600W-2700W	**1139.9**	**879.4**	**838.2**

The T-test with a level of confidence $\alpha = 0.05$ was used to test if the differences in transit travel times are statistically significant. The results show statistically significant differences between each pair of tested scenario, which means that only BRT implementation and BRT with TSP have significant impacts on transit travel times.



a) Westbound Travel times



b) Eastbound Travel times

Figure 5.1 Transit Travel Times Comparison

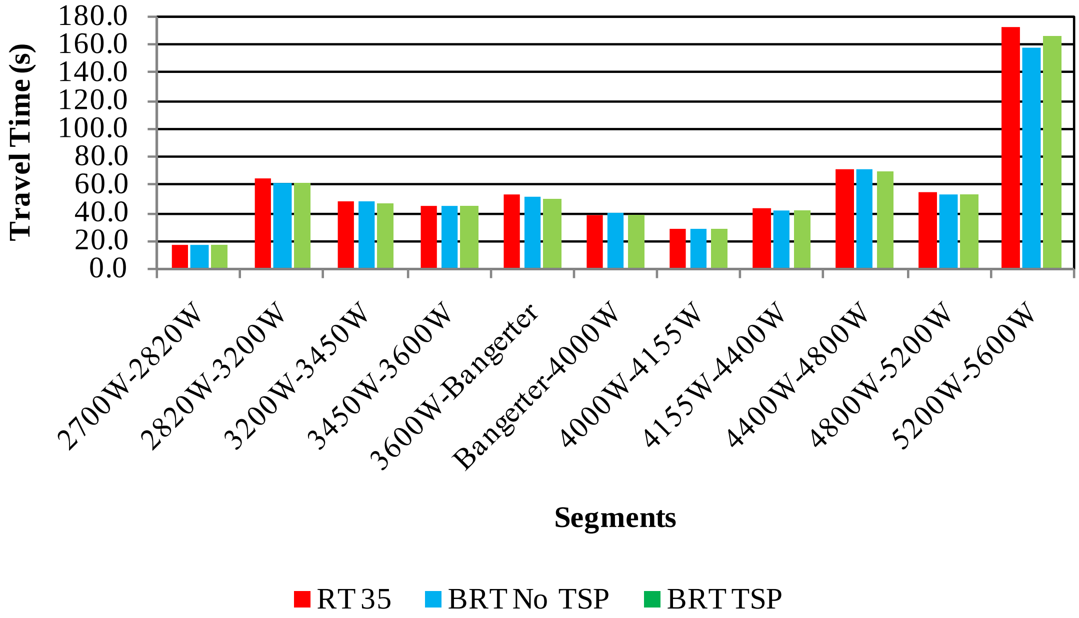
5.2 Vehicular Travel Times

In order to determine the impact of BRT and TSP implementations on vehicular travel times along 3500 South, a comparison between vehicular travel times for the three scenarios was made. Table 5.2 and Figure 5.2 show these comparisons for Eastbound and Westbound vehicular travel times.

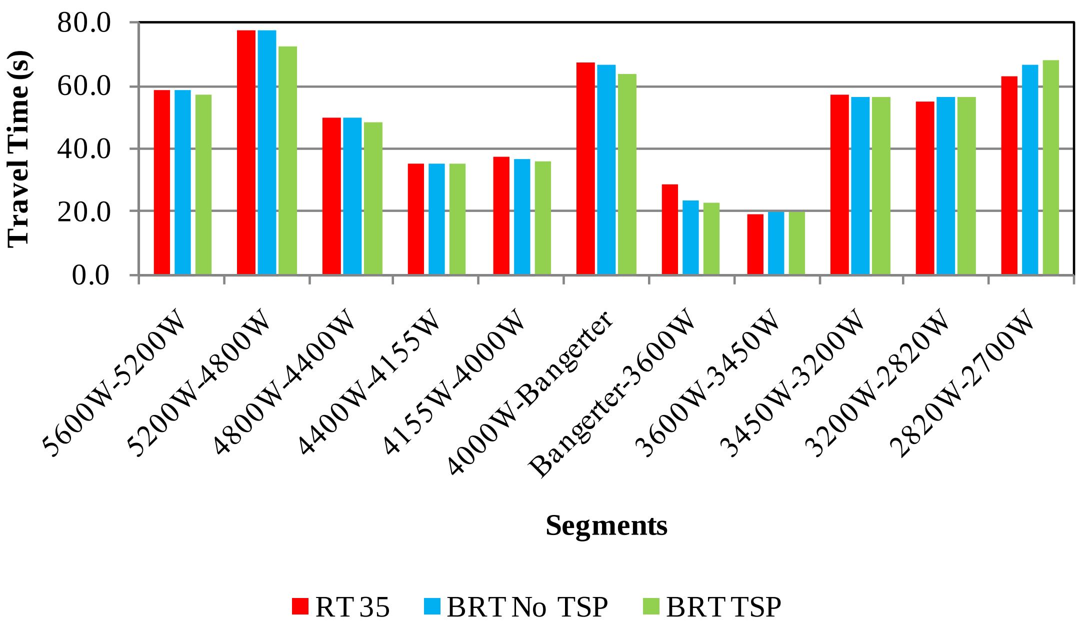
Table 5.2 Vehicular Travel Times Comparison

	Segments	RT 35	BRT No TSP	BRT TSP
Westbound Travel Times (s)	2700W-2820W	16.0	16.0	16.0
	2820W-3200W	63.9	61.1	61.0
	3200W-3450W	46.9	46.8	46.7
	3450W-3600W	44.5	43.8	44.0
	3600W-Bangerter	52.6	50.4	49.6
	Bangerter-4000W	37.3	39.8	38.3
	4000W-4155W	28.3	28.0	27.4
	4155W-4400W	42.3	41.2	40.7
	4400W-4800W	69.8	69.6	68.5
	4800W-5200W	53.3	53.1	53.0
	5200W-5600W	172.1	156.7	166.0
Eastbound Travel Times (s)	5600W-5200W	58.7	58.8	57.5
	5200W-4800W	78.1	78.0	73.1
	4800W-4400W	50.2	50.4	48.9
	4400W-4155W	35.7	35.5	35.6
	4155W-4000W	37.8	37.4	36.3
	4000W-Bangerter	67.6	66.6	64.0
	Bangerter-3600W	28.7	23.6	22.9
	3600W-3450W	19.6	20.4	20.4
	3450W-3200W	57.1	56.8	57.0
	3200W-2820W	55.5	56.4	56.5
	2820W-2700W	63.3	66.9	68.0
Total (s)	**2700W-5600W**	**623.3**	**605.1**	**608.7**
	5600W-2700W	**550.1**	**549.9**	**540.4**

The T-test with a level of confidence $\alpha = 0.05$ was used to test if the differences in vehicular travel times are statistically significant. The only difference was observed between the RT 35 and BRT TSP scenarios, while other differences were not statistically significant. Both BRT scenarios have lower vehicular travel times than the RT 35 scenario. The implemented TSP options, in fact, slightly improve vehicular travel times along the corridor.



a) Westbound Travel times



b) Eastbound Travel times

Figure 5.2 Vehicular Travel Times Comparison

As can be seen, the BRT and TSP implementations will have no significant effects on vehicular travel times along the main corridor.

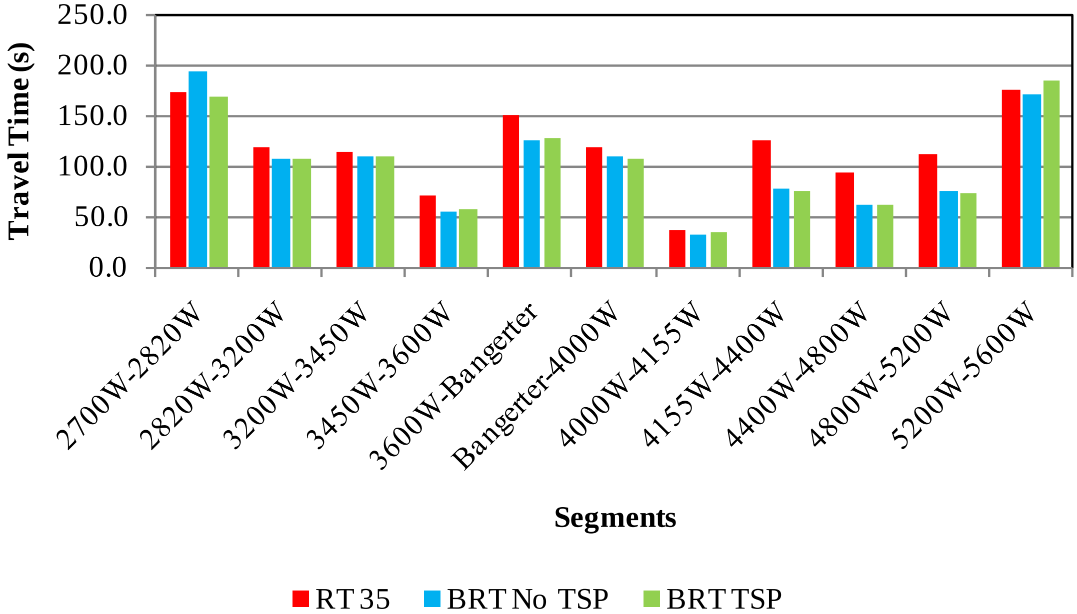
5.3 RT 35 Travel Times

In the new BRT system, the existing RT 35 will continue to operate, but less frequently and without provided TSP. Nevertheless, creating a new BRT system along the same route will have significant impacts on RT 35. The most significant impact is bus ridership reduction for modified RT 35. UTA's prediction is that RT 35 ridership will be reduced about 80% after implementing BRT. This should result in bus stop dwell time reductions. The final result will be a reduction in travel time. Table 5.3 and figure 5.3 show RT 35 travel times comparison. This comparison was performed for all three scenarios.

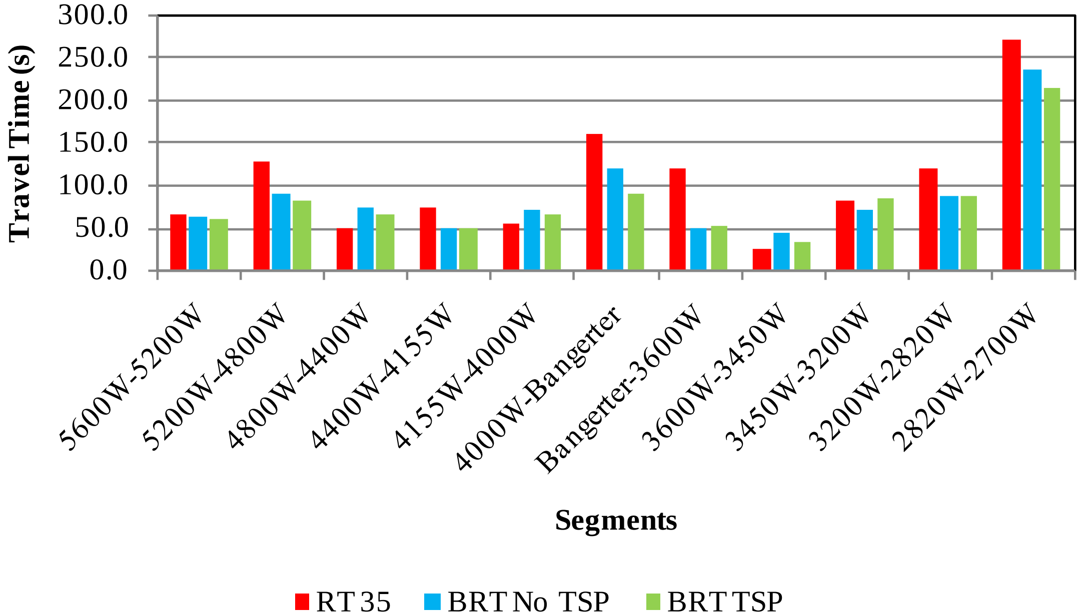
Table 5.3 RT 35 Travel Times Comparison

	Segments	RT 35	BRT No TSP	BRT TSP
Westbound Travel Times (s)	2700W-2820W	172.6	192.5	168.7
	2820W-3200W	118.5	105.9	107.0
	3200W-3450W	113.4	109.2	108.8
	3450W-3600W	71.3	54.4	56.8
	3600W-Bangerter	150.8	125.1	127.8
	Bangerter-4000W	118.7	109.9	106.7
	4000W-4155W	36.4	32.8	34.2
	4155W-4400W	124.4	76.5	75.8
	4400W-4800W	93.4	61.6	61.1
	4800W-5200W	111.2	74.3	73.1
	5200W-5600W	174.0	170.3	184.0
Eastbound Travel Times (s)	5600W-5200W	63.8	62.3	60.0
	5200W-4800W	126.3	89.9	80.8
	4800W-4400W	48.7	71.8	66.1
	4400W-4155W	72.6	48.5	47.9
	4155W-4000W	54.8	69.8	64.9
	4000W-Bangerter	159.5	118.8	90.4
	Bangerter-3600W	118.7	49.1	51.2
	3600W-3450W	25.5	41.9	32.8
	3450W-3200W	82.2	71.0	84.0
	3200W-2820W	118.7	85.9	86.3
	2820W-2700W	270.4	235.3	213.3
Total (s)	**2700W-5600W**	**1278.3**	**1130.2**	**1110.8**
	5600W-2700W	**1139.9**	**946.3**	**879.7**

The T-test for paired samples show statistically significant differences between the RT 35 and both BRT scenarios, while there is no statistically significant difference in RT 35 travel times between the BRT No TSP and BRT TSP scenario. However, the RT 35 travel times are lower in the BRT TSP scenario.



a) Westbound Travel times



b) Eastbound Travel times

Figure 5.3 RT 35 Travel Times Comparison

5.4 Bus Stop Dwell Times and Average Passenger Waiting Times

Bus stop dwell times can also be highly affected by implementation of the BRT system. With the new, low floor BRT buses, boarding and alighting through all three doors and off board fare collection can significantly reduce bus stop dwell times. On the other hand, reduced travel times should also lead to a reduction of passenger waiting times at bus stops. Table 5.4 shows comparisons of bus stop dwell times and passenger waiting times for the three scenarios.

Table 5.4 Bus Stop Dwell Times and Average Passenger Waiting Times

		Dwell times (s)			Average passenger waiting times (s)		
	Bus Stop	RT 35	BRT No TSP	BRT TSP	RT 35	BRT No TSP	BRT TSP
WB	Valley Fair	40.9	15.1	15.1	395.7	368.4	360.7
	4000 W	27.0	17.8	17.7	468.9	394.3	392.0
	5600 W	31.9	14.0	14.2	497.9	347.4	355.8
EB	5600 W	23.6	15.2	15.2	388.3	451.1	451.1
	4000 W	29.9	19.2	29.2	431.4	457.0	457.0
	Valley Fair	49.4	26.5	25.9	484.2	549.7	543.4

Bus stop dwell times will be significantly reduced after the BRT implementation. The estimated total reduction in bus stop dwell times is about 40%. Also, it can be seen that there is no significant difference in dwell times for the two BRT scenarios. The difference that appears when the two BRT scenarios are compared is not a result of bus stops transit operations (passenger boarding and alighting), but a result of a different bus stop departure time. Because of the TSP, the BRT buses in the BRT TSP scenario will have different bus stop departure times than BRT No TSP scenario, which will impact the number of boarding and alighting passengers.

In the westbound direction, the average passenger waiting times are reduced with the new BRT system. In eastbound direction, however, it can be seen that these times have increased. Transit travel time is not the only factor when passenger waiting times are considered. Transit time scheduling and passenger arrival rate are also important.

5.5 Impacts of TSP Implementation on Side Streets Traffic

When TSP is provided along the main corridor, some impacts on side street traffic are expected. The TSP strategies (green extension and red truncation) facilitate transit operations along the main corridor, which increase delays for the traffic on side streets. In order to determine these delays, VISSIM was programmed to calculate delays and average number of stops per vehicle on side street segments (where TSP is provided), so as to determine the increase in delays and average number of stops on side streets.

Table 5.5 and Figures 5.4 and 5.5 show impacts on side street delays and average number of stops per vehicle for the three scenarios.

Table 5.5 Impacts on Side Streets Delays and Average Number of Stops

	RT 35		BRT No TSP		BRT TSP	
Intersection	Average Delay (s)	Average Number of Stops per Vehicle	Average Delay (s)	Average Number of Stops per Vehicle	Average Delay (s)	Average Number of Stops per Vehicle
4000 W	55.6	1.0	61.7	1.1	71.6	1.2
4155 W	29.0	0.9	28.4	0.9	28.9	0.9
4400 W	64.3	1.2	70.5	1.3	74.8	1.3
4800 W	40.4	1.4	41.9	1.3	45.8	1.4
5200 W	23.4	0.9	23.0	0.8	23.1	0.9
5600 W	13.0	0.4	13.9	0.5	14.0	0.5

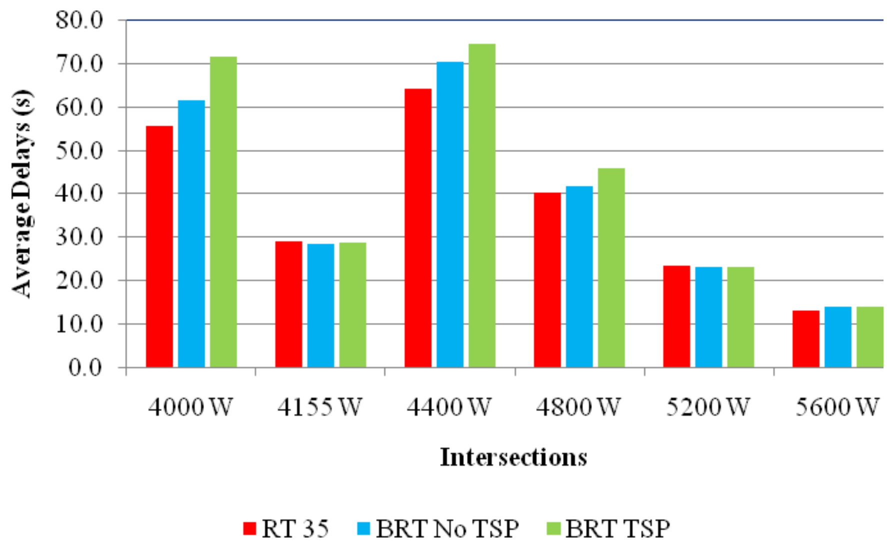


Figure 5.4 Average Side Streets Delays Comparison

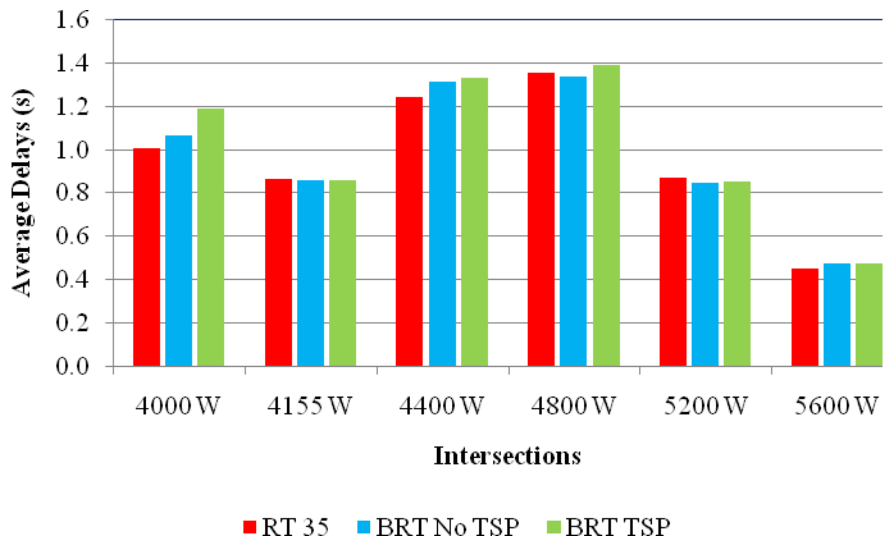


Figure 5.5 Side Streets Average Number of Stops Comparison

The general conclusion is that an increase in delays and average number of stops is directly proportional to traffic volume on side streets. The biggest impacts were on 4000 West and 4400 West, which have the greatest volumes. However, these increased delays were not significant when compared with the benefits for the BRT line.

5.6 Field vs. Simulation Transit Travel Times

Another set of data was used to estimate the accuracy of the simulation models. Those data are transit travel times from the first to the last bus stop within the field of study (Valley Fair to 5600 West and vice versa). The first set of data is RT 35 travel times, before the implementation of BRT operations. The other set of data is BRT travel times. As noted before, UTA started experimental BRT runs along this line in May 2008. The initial results of transit travel times were available for the first comparison.

Table 5.6 shows field vs. simulation transit travel times for RT 35 and BRT TSP scenario.

Table 5.6 Field vs. Simulation Transit Travel Times

		Transit Travel Times (s)			
	Bus Stop to Bus Stop	Field RT 35	Simulation RT 35	Field BRT TSP	Simulation BRT TSP
WB	Valley Fair to 4000 W	623.3	593.2	464.5	462.4
	4000W to 5600W	471.6	648.7	532.0	392.8
	Total WB	1094.9	1241.9	996.5	855.2
EB	5600W to 4000W	452.3	483.9	269.0	341.6
	4000W to Valley Fair	615.1	702.9	289.5	505.1
	Total EB	1067.4	1186.8	558.5	846.8

The RT 35 travel time analyses show that the simulation travel time is within 86%-90% of accuracy when compared with the field travel times. However, some discrepancy exists in BRT travel times. Some reasons for this discrepancy may include:

- BRT is still in the experimental phase
- TSP implementation along this section is still undermined
- RT 35 operates as before, with 15-minute headways, along with the test BRT
- The simulation model was created based on the predicted ridership for the BRT line, while the current ridership is unknown

A quality comparison between field and simulation BRT travel times can be done after the full implementation of the BRT phase one.

6. PASSENGER AND OPERATOR SURVEYS

The first phase of the 3500 South BRT line was launched on July 14, 2008. Two weeks after the launching, a series of operators' and passengers' surveys were conducted. The purpose of the surveys was to get feedback on the new "Van Hool" buses and the new BRT service. The survey was deliberately conducted soon after the start of the BRT service. The intention was to survey passengers and drivers before they get used to the new service and forget their experience with the RT 35 service.
The overall survey was divided into three questionnaires to assess:

- How passengers value specific features of transit service in general
- How passengers compare new "Van Hool" buses with the other UTA buses
- What operators see as differences between the new and the old buses from the driver's perspective

Scales from 0 (no importance) to 10 (the highest importance) were used to record passengers' and operators' responses on given affirmative statements. In addition to the scalar questions, respondents were asked how long they have affiliated with UTA and how often they ride transit. They were also asked to make any comments or suggestions in the provided space at the bottom of the survey forms. Table 6.1 shows the statements that were used in each survey. To avoid confusing passengers, the term "MAX" was used instead of "Van Hool" buses.

Table 6.1 Passenger and Operator Surveys

Passenger Surveys		Operator Survey
Vehicle Attributes	*Comparative Survey*	
A comfortable seat.	Seats on the MAX are more comfortable.	The MAX easier to steer than other local buses.
Accessible seats.	The MAX offers a smoother ride.	The MAX operates more smoothly.
A fast bus.	The MAX has windows with nicer views outside.	The MAX accelerates faster than other buses.
A smooth ride.	The MAX has better seating option (face to face).	The MAX cruises more smoothly at higher speeds.
Windows with nicer views to the outside.	The MAX looks nicer than other buses.	Windows on the MAX offer better views for riders.
A nice looking bus.	There is more standing room on the MAX bus.	The MAX enables easier boarding and alighting.
Leg room.	The MAX is quieter than other buses.	The MAX has better heating and air conditioning.
A quiet ride (no loud engine noise).	The MAX has better air conditioning.	The operator's seat is more comfortable on the MAX.
Good heating and air conditioning system.	Push button in the MAX is better than a pull cord.	The MAX has better mirrors.
Three-door configuration to offer better accessibility.	Three doors provide better accessibility.	TSP service for the MAX is an advantage.
	Overall, the MAX is better than other UTA buses.	Overall, the MAX is better than other UTA buses.

The results of the three surveys are provided in a form of box plots. A box plot gives an excellent visual summary of many important aspects of a distribution. The box stretches from the lower hinge (defined as the 25th percentile – q1) to the upper hinge (the 75th percentile – q3) and therefore contains the middle half of the scores in the distribution. The spread is defined as the difference between the hinges. The median is also shown on the chart, so that 1/4 of the distribution is between the median and the top of the box and 1/4 of the distribution is between the median and the bottom of the box. A box plot also allows the minimum and maximum values to be displayed.

The passenger surveys had responses from a total of 426 passengers. The surveyed passengers consisted mainly of regular transit users. Among respondents, 78% ride more than once per week, and 63% have ridden with UTA for more than one year. The survey on vehicle attributes had 212 respondents. The results from this survey, presented in Figure 6.1, show that climate control is considered the most important factor to the surveyed passengers, with a median score of 10. High outside temperatures in mid-July seems to have biased some respondents when grading importance of the various bus features.

Speed of the bus, smoothness of the ride, and easiness to board/alight to/from buses were also important to passengers. Comfortable and accessible seats, a nice appearance, leg room, and noise control scored relatively high, although distributions of their importance were somewhat increased. Windows and views were considered the least important to the passengers. Some respondents also made unsolicited complaints about an insufficient number of bike racks on the buses.

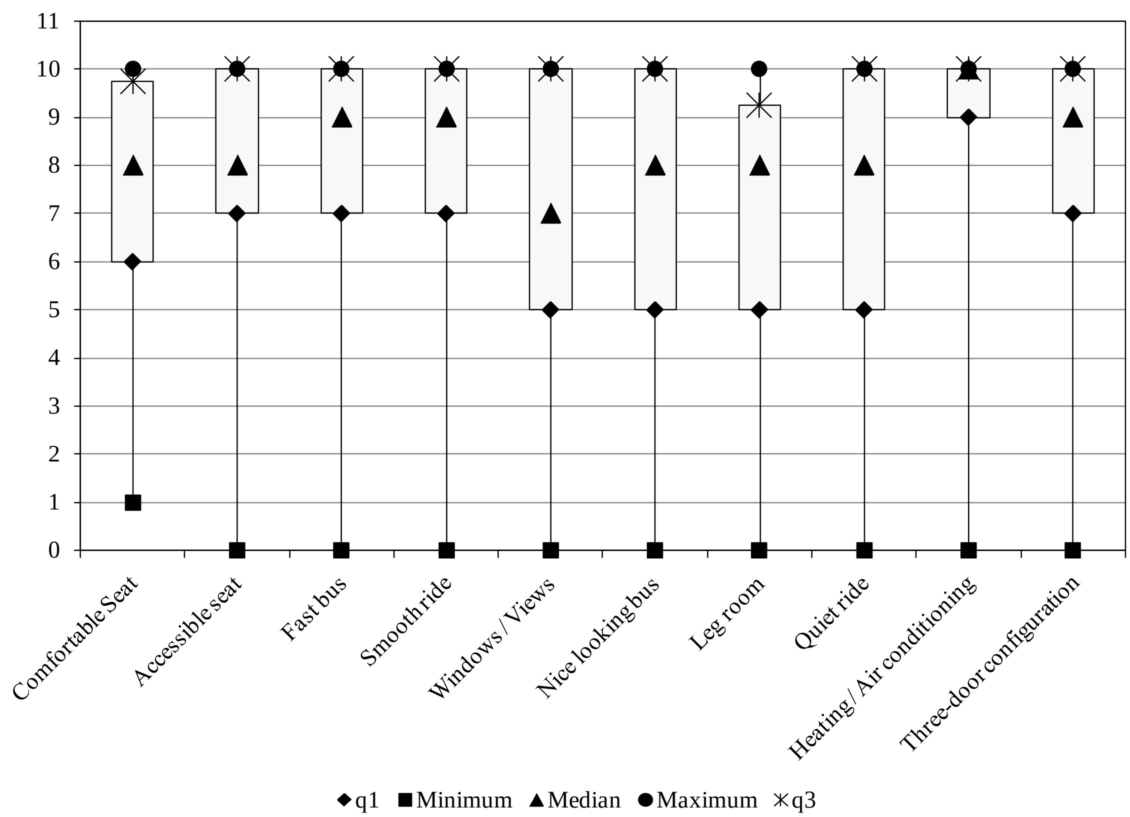


Figure 6.1 Vehicle attributes survey

The comparative survey of passengers included 214 respondents. The results are shown in Figure 6.2. Overall, the "Van Hool" buses scored superior against other UTA buses, with a median score of 10. The features of the new bus that got the highest scores were appearance, the push buttons instead of pull cords, and better accessibility, resulting from the three-door configuration. The median score for all three was 10. The comfort and configuration of the seats have the greatest variation of responses, yet with a relatively high median score. From Figure 6.1 (Passenger Value Ratings) it can be seen that the response for “comfortable seat” and “accessible seat” both had a median score of 8. This relatively high median score shows that Comfort and Accessible seats are of high importance for passengers. Similarly, Figure 6.2 (MAX vs. Other Buses: Passenger Evaluation) shows that the seating options (comfort level/face-to-face configuration) have median scores of 8. Comparatively, the median customer response in Figure 6.2, concerning seating meets the median importance rating of seating as displayed in Figure 6.1 (both scored 8). The responses concerning seating options could be subjected to passengers’ experience while riding other UTA buses. The other buses have different types of seats with higher and with thicker cushions and face-to-back seating options. However, the practice shows that seats of this type are harder to maintain. Use of these seats can also limit arrangement of seating options on the bus. The new seats, introduced on the MAX line, have different design. They are lower, with thinner cushions, easier to maintain (clean and repair), and they can be arranged in such a way to maximize passengers’ flow and comfort on the bus. MAX seating options combine both face-to-back and face-to-face options.

The comments in the comparison survey revealed that, although there are few people who want MAX to have additional bus stops, a large number of passengers understood and liked the fact that having fewer bus stops is one of the key factors for the MAX to be quicker and have reduced travel time. Both surveys have some passengers who requested more bike racks in the MAX, as most of the buses arrive with filled in bike racks, and they have to wait for so long until they find one of the next buses with empty bike racks. They think that an additional bike rack facility would be very helpful. Overall, the majority of the passengers had many more compliments for the new service.

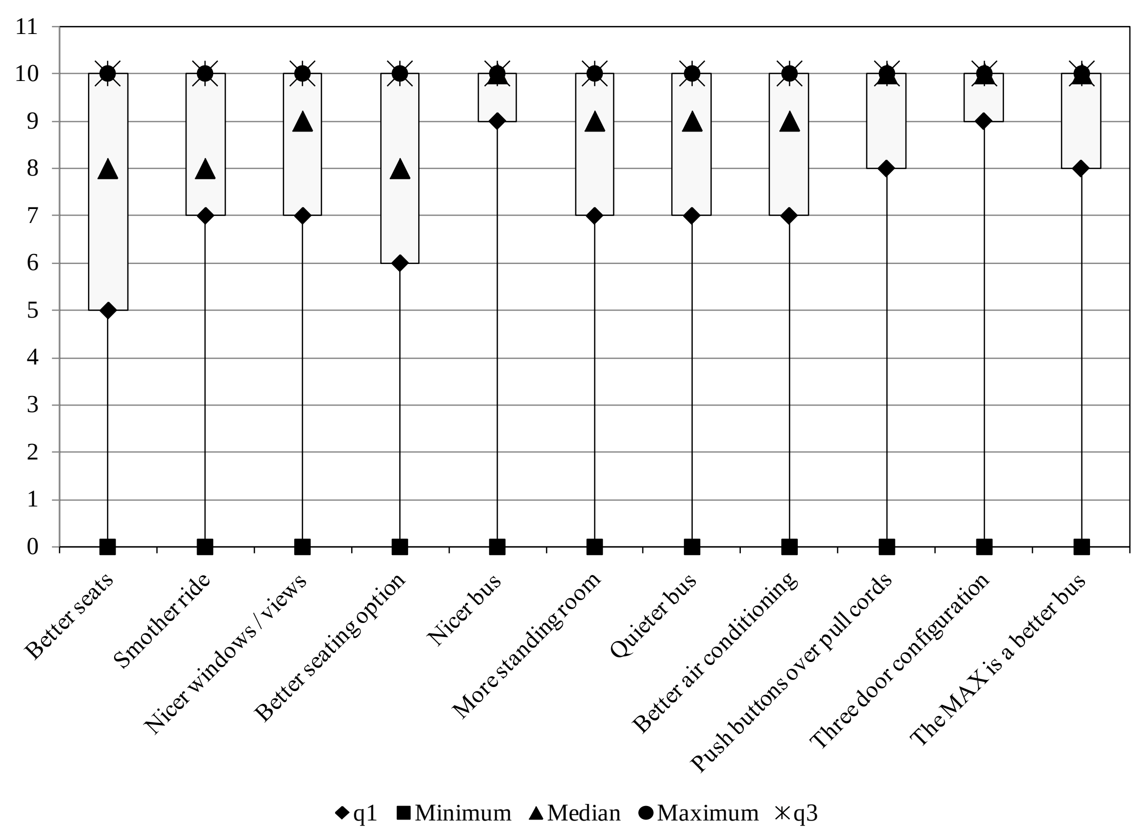


Figure 6.2 Comparative survey

The operator survey questioned 20 UTA bus operators who had an opportunity to drive the new buses for at least a week. The operators expressed a high opinion of the “Van Hool” buses, giving them a median score of 9, which is shown in Figure 6.3. Although most of the statements scored higher than 7, acceleration received a median score of 5.5, while the TSP feature received a median score of 6, with a relatively wide range in scores. Reasons for low scores for TSP implementation seem to be twofold. First, most of the drivers are still not familiar with the implementation of TSP, which is currently active at only six intersections along the route. It is possible that they do not notice TSP benefits at the operating intersections while they notice delays at the intersections with no TSP functionality. Second, it is possible that TSP parameters are still not sufficiently fine-tuned so as to support specific requirements at each TSP-operating intersection. Most of the operators liked the boarding and alighting operations, the big windows, and the operator’s seat. The operators liked boarding and alighting of the new BRT system the most. Their opinions on this matter might be biased by the fact that boarding and alighting through multiple doors release drivers from responsibility of collecting fares. Overall, the drivers had more compliments for the new buses.

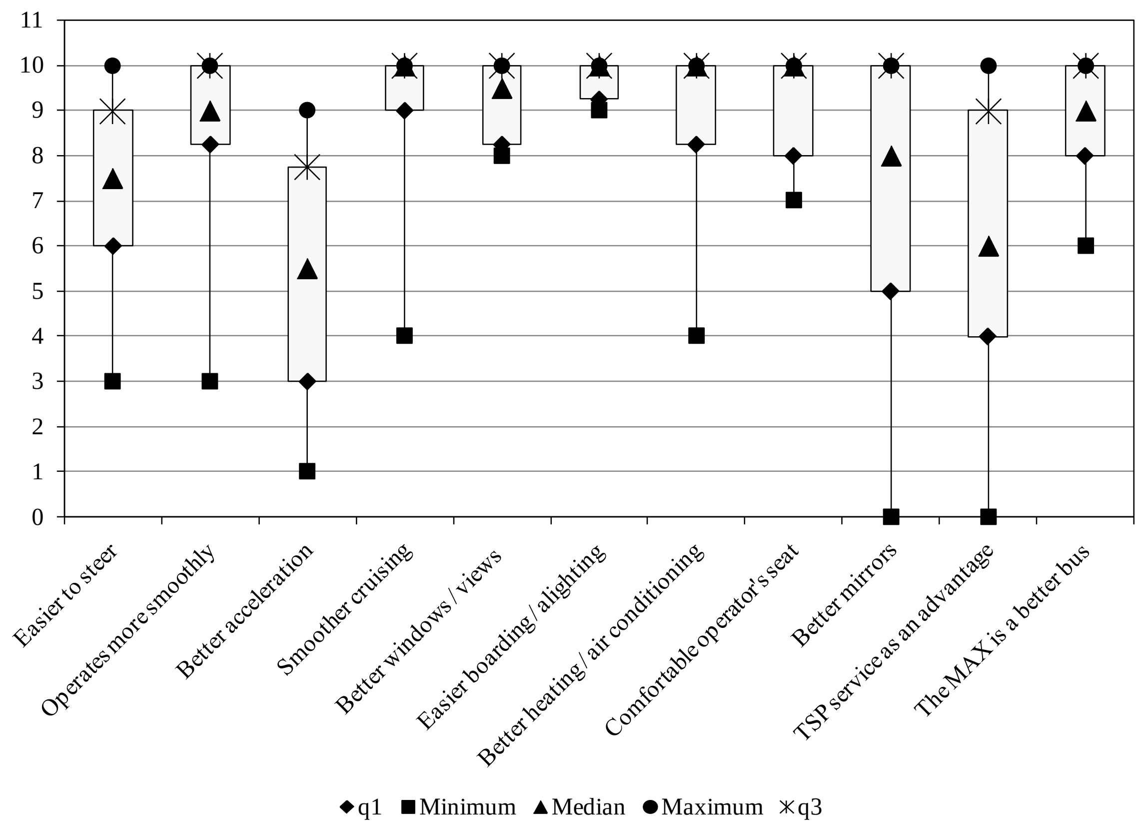


Figure 6.3 Operator survey

7. CONCLUSIONS

The goal of this project was to evaluate BRT operations and the impacts of TSP implementation on BRT and vehicular traffic through microsimulation. The test bed was a planned BRT line along 3500 South in Salt Lake County. Three scenarios were considered:

- Scenario RT 35, which introduces line RT 35 and its transit operations, before the BRT was implemented
- Scenario BRT without TSP, which introduces the new BRT line and modified RT 35, but without TSP provided
- Scenario BRT, the new BRT line, modified RT 35 and TSP provided only for the BRT line

Comparing basic traffic and transit operations from the simulation models, the following conclusions were reached:

- The implementation of BRT operations can reduce transit travel time by approximately 20%, compared with the line RT 35 travel times
- The implementation of BRT operations and TSP strategies on six intersections along the corridor leads to transit travel time reduction of more than 30%, compared with the RT 35 travel times
- The implementation of TSP can lead to BRT travel time reduction of approximately 15%, compared with the scenario where BRT operations are introduced, but TSP is not provided
- TSP implementation will have no impact on vehicular traffic along the main corridor
- TSP implementation will impact general-purpose traffic on side streets directly proportional to traffic volumes, but these impacts will not be significant
- Overall, the users (both passengers and bus operators) see the new “MAX” buses, and the system in general, as an improvement over the old service. While passengers appreciate the new three-door configuration and smoother rides the most, operators see the highest benefits in better windows, more comfortable driver’s seats, and the fact that they do not have to deal with the fare collection

Future work on this project might be to implement some other TSP strategies (such as phase inserting, phase omitting, red truncation for some phases only, etc.) and calculate the impacts on BRT line, vehicular traffic along the main corridor, and traffic on side streets, in order to find the optimal strategy. Also, the AM peak scenario should be evaluated, since the traffic pattern is different in AM and PM peaks.

The entire described process of this report should be repeated after other phases of the BRT implementation are completed (exclusive bus lanes for BRT, new and reconstructed bus stops) in order to see how each might impact the general traffic system along this corridor.

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