State Street Transit Signal Priority Study

DELAWARE VALLEY
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PLANNING COMMISSION

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Introduction

The purpose of this study is to explore the potential for Transit Signal Priority (TSP) in downtown Trenton. TSP is regarded as a favorable investment that can be implemented at relatively low cost. For this project, a section of the State Street corridor was selected for analysis. The application of TSP was tested using the VISSIM microsimulation model. The results of the modeling exercise will inform decision makers about the relative impacts of improvement alternatives on bus operations.

Study Area

State Street is an east-west arterial located in the heart of the Trenton central business district. The corridor consists of seven signalized intersections, from Willow Street to Clinton Avenue. The study area is located just a few blocks from Trenton Transit Center, a regional hub of transportation activity. An overview of the State Street study area is shown in Figure 1 on the following page. Also shown in the highlighted area of Figure 1 are the locations of the traffic signals and bus stops. On State Street, there are six westbound stops and four eastbound stops. Northbound stops on Montgomery Street and Clinton Avenue are also in the study area. The bus stops in Figure 1 are located on the appropriate side of the street to indicate the direction of travel.

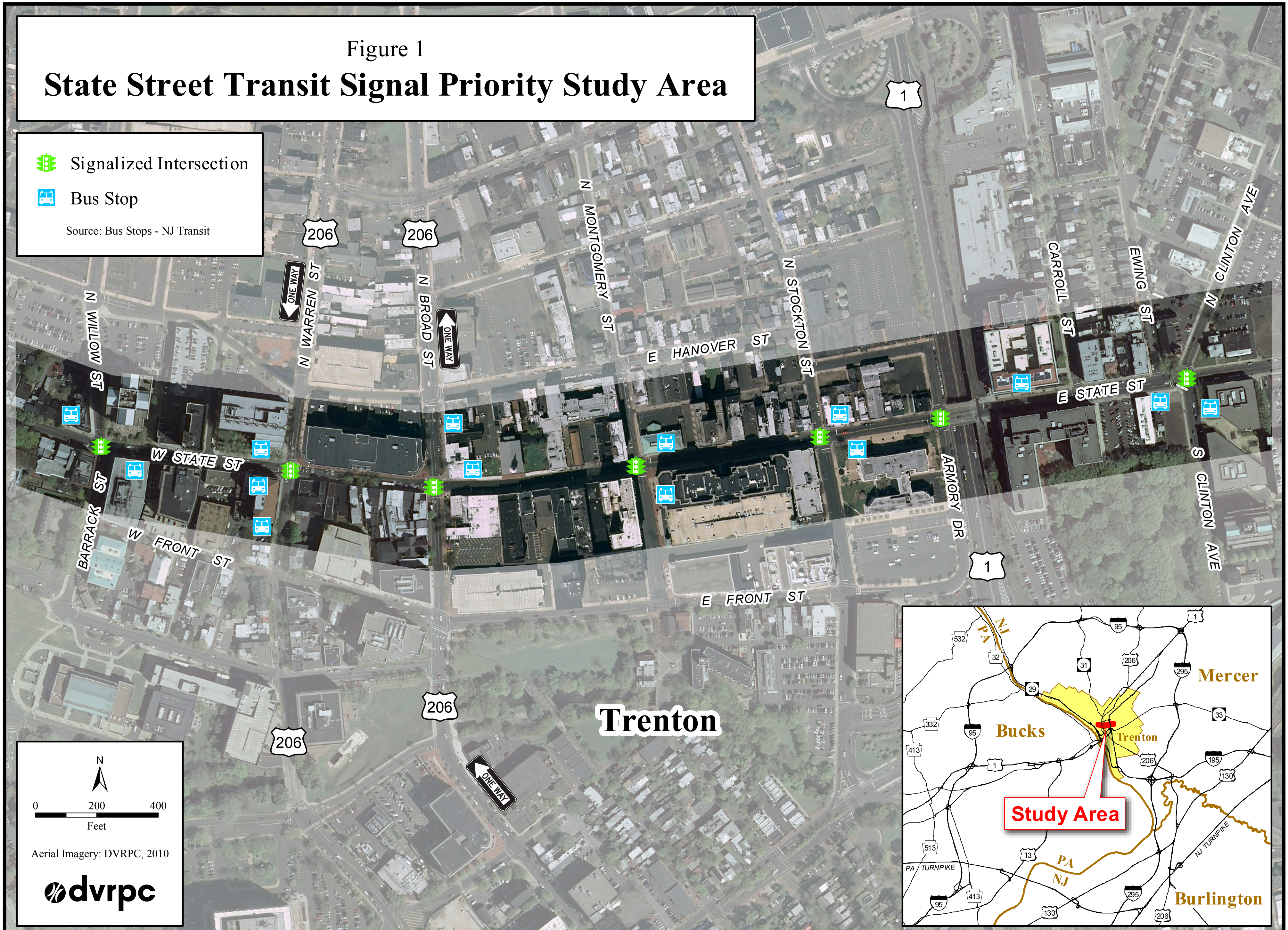
Overall, the corridor can be characterized by:

- High urban density with closely spaced signalized intersections
- Wide sidewalks, marked crosswalks, and high daytime pedestrian activity
- Intermittent curb-side parking
- Frequent bus service in both the eastbound and westbound directions
- A high number of cross-street buses, most notably on Broad Street and Warren Street
- Low traffic congestion, moderate vehicular volumes, and low travel speeds

In April 2014, the Delaware Valley Regional Planning Commission (DVRPC) published *TSP Favorability Score: Development and Application in Philadelphia and Mercer County*. This report developed and analyzed a set of high-level prioritization criteria to evaluate and compare TSP corridors. Eleven criteria were divided into four categories: traffic, transit supply, transit demand, and planning priorities. A weighting scheme was developed to ensure that the criteria deemed most locally meaningful were given the greatest weight in the prioritization. As a result of the analysis, three segments along State Street ranked in the top ten for TSP Favorability. For this reason, through a collaborative effort among relevant stakeholders, the State Street corridor was chosen for further TSP analysis.

Figure 1

State Street Transit Signal Priority Study Area



Transit Signal Priority

TSP is a tool used for enhancing public transportation service by providing transit vehicles with preferential treatment at traffic signals. The primary objectives are to decrease transit travel times, improve schedule adherence, and potentially reduce headways where time savings are sufficient.

TSP is a modification of the phase split times of a traffic signal. In some cases, the approaching transit vehicle receives a green phase when it arrives at the signal (signal preemption). More commonly, however, the green phase is extended and the red phase truncated (signal priority) to provide more time for the transit vehicle to pass through the intersection.

TSP can be implemented at a single intersection or at a number of intersections along a transit corridor. Signal times given to the transit vehicle upon TSP actuation are generally recovered on the following signal cycle or cycles, still allowing for signal coordination. TSP is particularly effective when combined with complementary time-savings strategies such as stop consolidation or the relocation of near-side bus stops to the far side of an intersection.

TSP is often found to work best with far-side transit stops, as this allows the transit vehicle to clear the intersection before stopping to load/unload passengers. As a result, the time it takes the transit vehicle to clear the intersection after being detected by the controller is more predictable. Alternatively, the major benefit of TSP for near-side stops, especially under moderately congested conditions, is the ability to clear the general traffic queue between a transit vehicle and the near-side stop. This allows the transit vehicle to only stop once, if at all, instead of twice—once behind the vehicle queue to reach the stop—, and a second time while waiting to load and unload passengers.

VISSIM Model

In order to fully evaluate traffic and transit operations, an assessment of existing conditions was performed using the VISSIM software package. This multi-modal, micro-simulation tool allows for evaluating network models and comprehensive data collection.

To begin the data collection efforts, Manual Turning Movement Counts (MTMCs) were taken at the seven signalized intersections within the study corridor in April 2014. Pedestrian crossing counts were also collected at all marked crosswalks at the signalized intersections.

The MTMCs were collected between the hours of 6:00 AM to 9:00 AM and 3:00 PM to 6:00 PM during a typical weekday, recording vehicles completing each movement per approach in 15-minute intervals. Via an examination of the turning counts, the network peak hours were determined to be 8:00 to 9:00 in the AM and 4:15 to 5:15 in the PM. The MTMCs were aggregated onto working maps for the respective AM and PM peak-hour conditions. Because the turning movement and Automatic Traffic Recorder counts were not all counted on the same day, efforts were made to keep the integrity of peak-hour conditions. However, small adjustments were made to the raw counts for balance and flow within the network.

The VISSIM software was incorporated for operations testing and to collect intersection and network-wide performance measures. In order to match the geometry on the ground, the VISSIM network was built on top of scaled 2010 aerial photos. Current traffic signal condition diagrams were acquired from Mercer County, and different timing and phasing plans were incorporated for the respective period. A sample of heavy vehicle (non-bus) percentage data was collected and input into the network. This reflects the amount of truck traffic throughout the study area. Stop signs, yield points, conflict areas, reduced speed areas, and desired speed decisions for the street network were all entered into VISSIM to replicate real-world conditions.

It should be noted that the signal timings were verified with field visits. The cycle length and phasing were measured and compared to the timings reflected in signal plans. Isolated discrepancies were found between the two, and where applicable, field-measured timings were entered into VISSIM.

Transit

An inventory of all State Street buses was undertaken. NJ Transit and SEPTA timetables, schedules, and routes were examined to identify which buses utilize the corridor, when the buses enter the study area, and to what extent. Peak-period ridership information was acquired from NJ Transit. This data provided the total number of boardings and alightings throughout the study area. All of the bus stop locations were identified and checked via field views. Given these data sets, the project team was able to extrapolate the boardings and alightings at each State Street study area bus stop, for each individual bus line, for both the AM and PM peak hours. A summary of ridership activity within the study area is shown in Table 1.

It should be noted that an additional bus stop has recently been added to the study area. This stop is located on eastbound State Street nearside at Broad Street. Because this stop was added after this study was completed, it is not included in the analysis.

Table 1: Bus Stop-Level Activity

Stop ID	Direction	Cross Street Location	AM Peak Period		PM Peak Period		All Day Totals	
			Ons	Offs	Ons	Offs	Ons	Offs
22747	Westbound	Canal Street	0	0	0	1	0	1
22748	Westbound	Stockton Street	11	26	12	10	52	63
22749	Westbound	Montgomery Street	10	37	22	17	65	95
22750	Westbound	Broad Street	136	181	147	77	596	450
22751	Westbound	Warren Street	53	72	92	28	316	171
22752	Westbound	Willow Street	3	35	5	3	10	47
22780	Eastbound	Barrack Street	2	19	33	11	41	51
22871	Eastbound	Warren Street	113	233	208	125	631	698
22740	Eastbound	Stockton Street	19	57	55	30	190	205
22648	Northbound	Clinton Avenue	39	25	36	9	148	60
22696	Northbound	Montgomery Street	0	10	0	1	1	26

Source: NJ Transit 2014

Table 1 shows all of the NJ Transit bus stops that were entered into the VISSIM study area model. The data shows the total number of boardings and alightings for each peak period and across the entire day at each stop for all of the New Jersey bus transit routes. The AM period reflects the 6:00—9:00 time block, while the PM represents 3:00—6:00. The All Day Totals reflect a full day's (24-hour) count.

Though not reflected in Table 1, SEPTA boardings and alightings were also collected. SEPTA's route 127 has six stop locations along the State Street corridor. Five stop locations are shared with NJ Transit: 22696, 22747, 22748, 22749, and 22740. Stop 30402, located near Clinton Avenue, is a SEPTA-only stop. It should be noted that although SEPTA boardings and alightings are not exhibited in Table 1, SETPA buses were incorporated into the VISSIM simulations and are included in the performance measure output.

Approximately 30 buses traverse some portion of the State Street corridor during both the AM and PM peak hours. This includes SEPTA's route 127 and NJ Transit Routes 409, 418, 600, 601, 606, 608, 609, 611, and 619.

To input ridership data into VISSIM, boardings and alightings were converted to a dwell time for each stop location. Each boarding and alighting assumed a four-second-per-person service time. A standard delay time of five seconds was added to each stopping bus to account for the doors to open and close, and also as a standard boarding lost time. These calculations yielded a dwell time for each bus stop for a given peak hour. The dwell time was then multiplied by a coefficient of 0.6. This coefficient is based on NJ Transit boarding data and provided in the *Transit Capacity and Quality Service Manual, Third Edition*, published by the Transportation Research Board. This process yielded two dwell times: one for the ons and one for the offs. The higher value between the two was used as input for the dwell time.

Calibration

Once all of the vehicular, transit, and geometric inputs were complete, the base-year VISSIM network was ready to be calibrated. This process involved ensuring that the simulated volumes matched the counted volumes and running the simulations to identify and amend any unusual or unrealistic conditions.

A series of data collection points were inserted on links throughout the VISSIM network. The peak-hour turning movement counts output from VISSIM were copied into spreadsheets and compared to actual volumes. An iterative process, where slight adjustments were made in terms of volumes and routes in order to better replicate reality, was continued until reasonable calibration was achieved.

Modeled Scenarios

In order to test the effectiveness of Transit Signal Priority, four scenarios were modeled in VISSIM for both the AM and PM peak hour:

- Base Year
- Optimized
- Transit Signal Priority
- TSP + Transportation Enhancements

Base Year

The Base Year scenario denotes traffic patterns and volumes as they currently exist. This network represents a typical weekday in 2014 and serves as the present-day conditions from which subsequent scenarios can be compared.

Optimized

To ensure traffic throughout the State Street corridor is moving efficiently, it is necessary to evaluate traffic signals for performance. For this exercise, SYNCHRO software was incorporated to test traffic signal operations under existing volumes and timings. Through an iterative process, traffic signal optimization was performed. The signals were optimized for cycle length, cycle splits, and offsets. A common cycle length of 60 seconds was found to be optimal for the State Street corridor. The new timings were then entered into VISSIM and generated the Optimized scenario. The optimized timings are also used in the Transit Signal Priority and TSP + Transportation Enhancements scenarios.

Transit Signal Priority

At minimum, TSP requires technology to detect an approaching transit vehicle at an intersection, and the ability for signal priority requests to be sent by the transit vehicle to the signal controller. Once the signal controller recognizes an approaching transit vehicle, priority is granted.

For this study, various transit signal priority options were evaluated and tested. However, due to the common 60-second cycle length, it was determined that a 10-second green time extension along State Street would be a feasible TSP application. Any more than a 10-second extension would begin to impede on pedestrian crossing times. TSP detectors were strategically placed 350 feet upstream from the signal. This represents the approximate distance a bus would travel in 10 seconds at a 25-mph rate. It should be noted that this detection precision would be difficult to achieve with an optical TSP system.

Detectors were placed on State Street at all of the signalized intersections, in both the eastbound and westbound directions. It should be noted that detectors were not placed on cross-street approaches. When a transit vehicle is detected approaching an intersection, the green phase is extended by 10 seconds. Over the next two cycles, the signal timing is restored to its original timing. This process ensures that the cycle length, signal coordination, and offsets remain intact.

TSP + Transportation Enhancements

Several factors were considered under this scenario, including adjusting stop locations, consolidating bus stops, and further refining the traffic signal timings. However, limited right-of-way, pedestrian connections to cross-street buses, and the short distance between traffic signals limit transportation enhancement opportunities.

The results of the TSP scenario were thoroughly evaluated, and opportunities to fine-tune the traffic signal timings were identified. To that end, slight adjustments were made to the traffic signal timings for further improvements. These timing adjustments were generally done in the PM peak hour, and did not impede either the operations of TSP or pedestrian activity.

An opportunity to consolidate bus stops was identified. In the westbound direction, the stops at Stockton Street (ID# 22748) and Montgomery Street (ID# 22749) are both near-side stops at their respective intersections and are in close proximity to each other. These two stops were combined into a single stop located at the far side of Stockton Street. The boardings and alightings at the two stops were added together, and the combined total served as the dwell time input at the new stop. This enhancement would have minimal impact on traffic operations as there is ample right-of-way to accommodate a stop at this location.

Results

Performance measures were collected as output from the VISSIM simulations. To replicate conditions for a usual or typical peak period, simulations for 10 random seeds in VISSIM were run and averaged. Performance measures for overall delay (seconds) were collected for the seven signalized study area intersections. Calculations for intersection delay are based on *Highway Capacity Manual* (2010) standards for a signalized intersection. Other measures extracted from VISSIM include vehicle delay, approach delay, travel speeds, and selected bus route travel times. For each of the performance measures, results for each of the four scenarios are shown for quick comparison.

Intersection Delay

Table 2 shows the average delay per vehicle (in seconds) at each of State Street's signalized intersections. This measure takes into account all vehicles entering the functional area of the intersection for all approaches. The results reveal that State Street does not experience intersections with excessive delay. All of the intersection delay is between 10 and 20 seconds, which according to the *Highway Capacity Manual*, would indicate Level of Service B. The information presented in Table 2 demonstrates that traffic signal optimization has the greatest impact on reducing intersection delay.

Table 2: Signalized Intersection Delay

Cross Street Location	Base Year		Optimized		TSP		TSP + Enhancements	
	AM	PM	AM	PM	AM	PM	AM	PM
Willow Street	15.6	15.9	13.6	15.3	13.8	15.5	13.5	15.3
Warren Street	15.6	15.8	14.9	13.0	14.6	14.4	14.2	14.6
Broad Street	12.9	13.1	12.6	12.0	13.4	14.1	13.0	14.1
Montgomery Street	15.6	16.2	13.3	13.2	13.4	14.4	13.0	14.9
Stockton Street	15.9	16.5	12.6	13.7	12.3	14.9	12.4	15.0
Armory Drive	15.6	18.4	13.6	13.6	11.4	14.6	11.6	14.7
Clinton Avenue	15.0	16.1	13.5	13.1	13.7	15.0	13.6	15.1

Source: DVRPC 2014

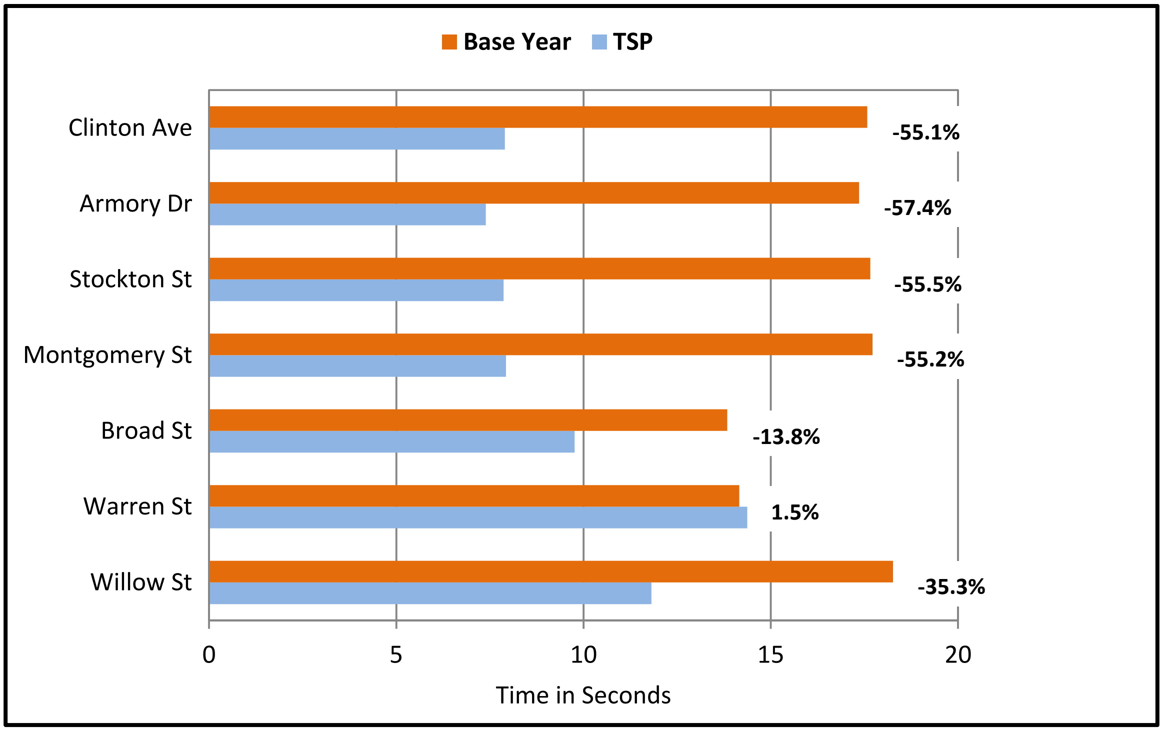
Approach Delay

Delay data was also collected on eastbound and westbound approaches on State Street. This reflects all vehicles utilizing the through movement at the seven signalized intersections. Two scenarios are compared: Base Year and TSP. Figures 2 and 3 displays the AM peak-hour results, while Figures 4 and 5 show the PM results.

These figures graphically show the difference in seconds of delay at each approach, by direction and time period, between the Base Year and the TSP scenarios. A net percentage reduction or increase is also given. Overall, when delay is aggregated for all approaches for each peak hour, TSP (which includes traffic signal optimization) reduces through-movement signal delay by 31.6 percent in the AM and 26.0 percent in the PM.

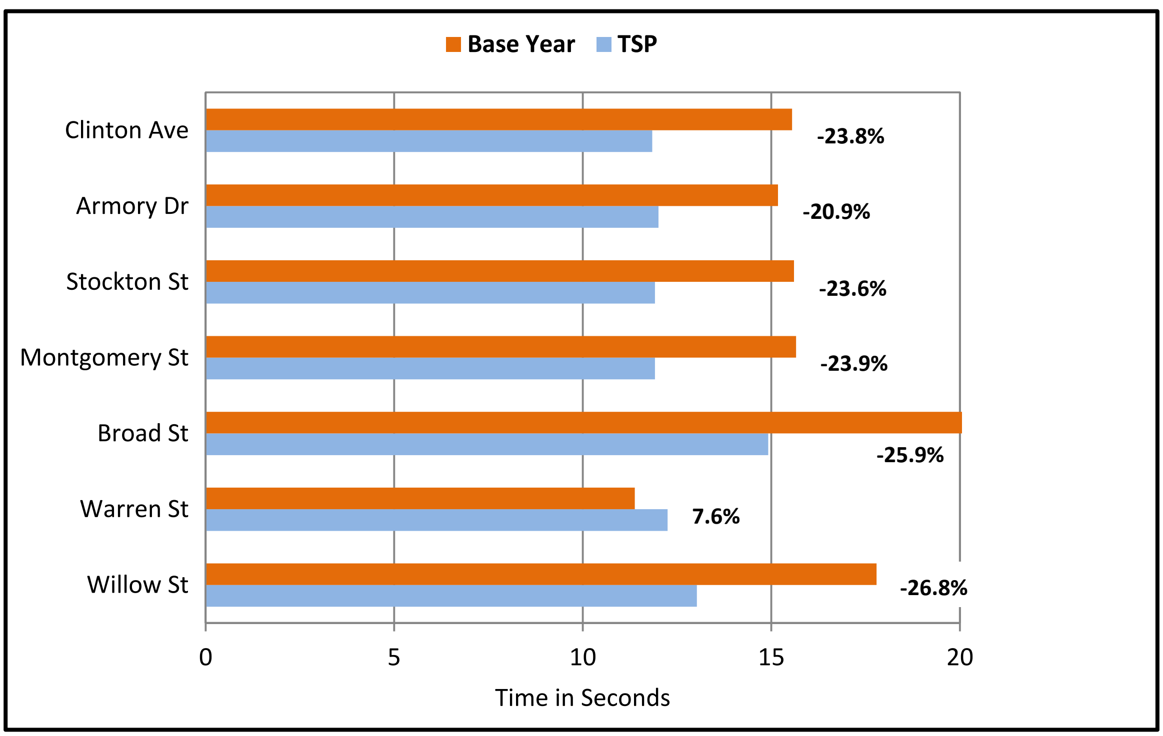
With the exception of Warren Street, all approaches exhibited a decrease in delay for both the AM and PM peak hours. In the Base Year scenario, the Warren Street intersection currently operates on a 90-second cycle length, allowing for 46 seconds of green time on the State Street phase during the PM peak hour. In the Optimized scenario, the 60-second cycle length reduces the State Street green time to 26 seconds, resulting in slightly increased delay.

Figure 2: AM Eastbound State Street Approach Delay



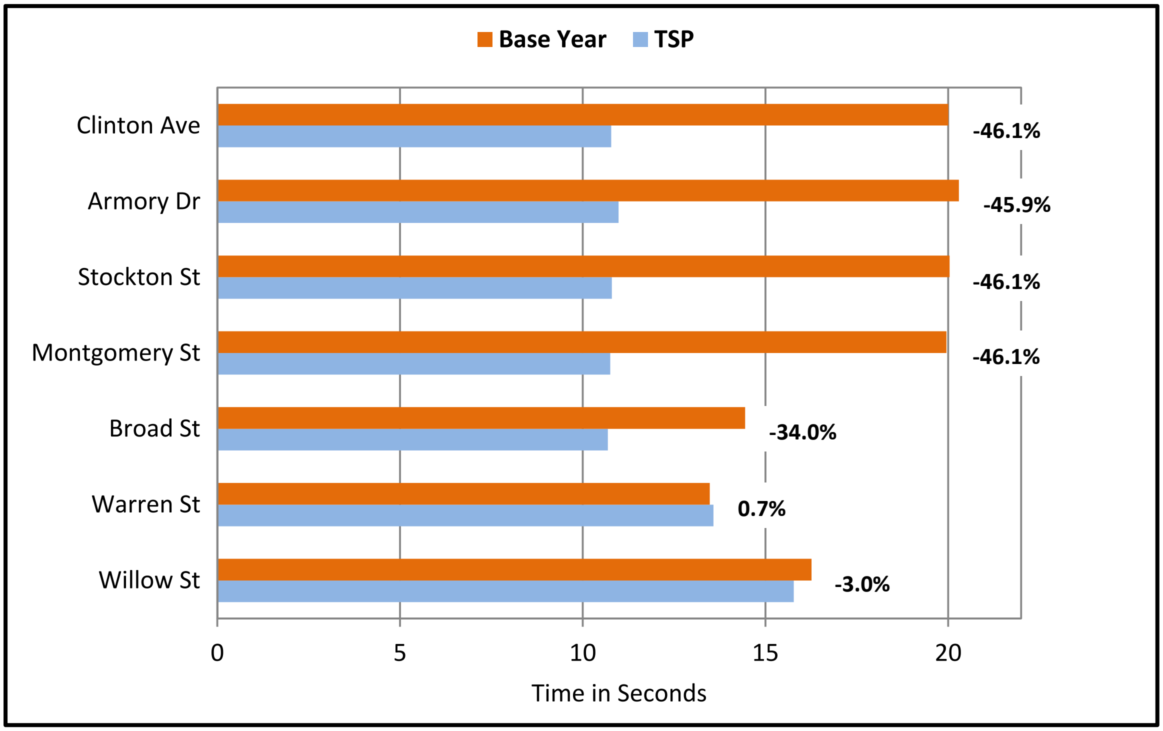
Source: DVRPC 2014

Figure 3: AM Westbound State Street Approach Delay



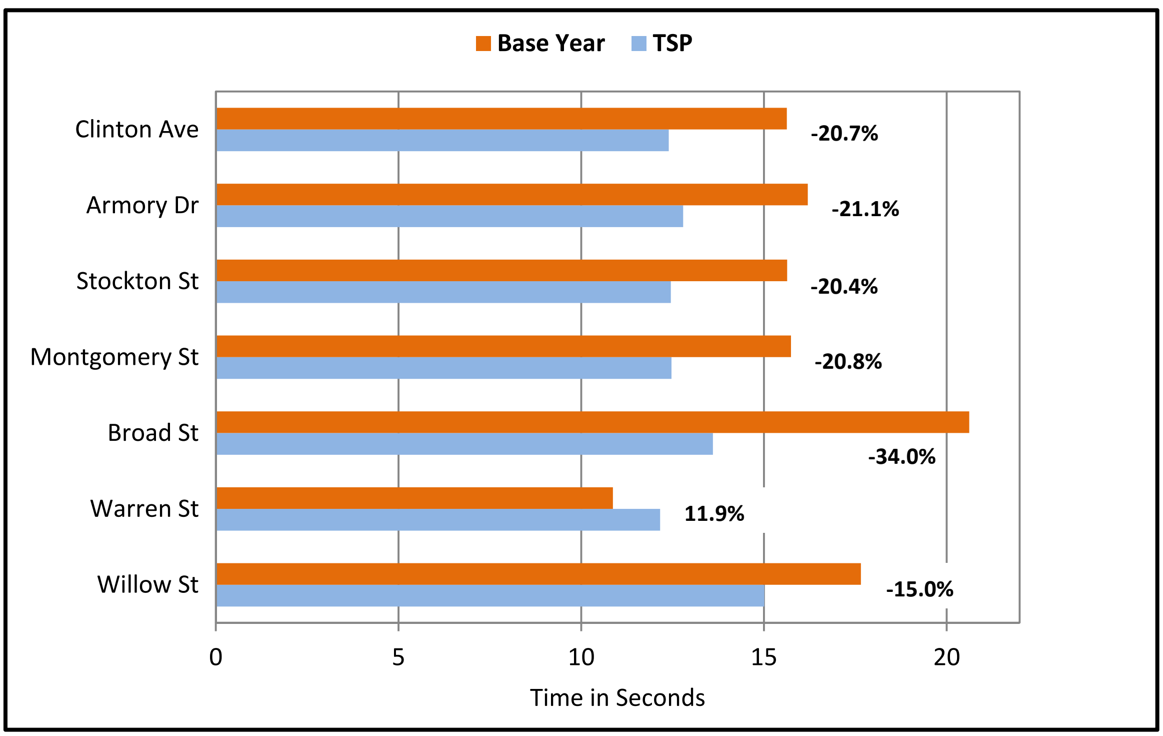
Source: DVRPC 2014

Figure 4: PM Eastbound State Street Approach Delay



Source: DVRPC 2014

Figure 5: PM Westbound State Street Approach Delay



Source: DVRPC 2014

Network Delay

In order to compare scenarios holistically, network-wide data was collected for both average delay and travel speed. Delay represents any independence or deviation from a vehicle's desired speed (or free-flow speed). Unlike the intersection delay, which only takes into account delay incurred at signalized intersections, this delay accounts for any reduction in speed at any location within the network. This also allows an entire network's performance to be compared via a single number.

For both network delay (Table 3) and travel speeds (Table 4), data was collected for passenger vehicles (car), buses, and a combined average for all vehicles including trucks. This highlights what effect TSP and additional enhancements have on the different types of vehicular traffic.

Table 3 shows average delay for cars, buses, and all vehicles. The delay is shown in seconds for each vehicle category. The results reveal a gradual improvement in overall delay across the scenarios. Most notably, the decrease in delay for buses from the Base Year to the TSP and TSP + Enhancement scenario is dramatic. This demonstrates that transit speeds can be improved without having a negative impact on overall traffic flow.

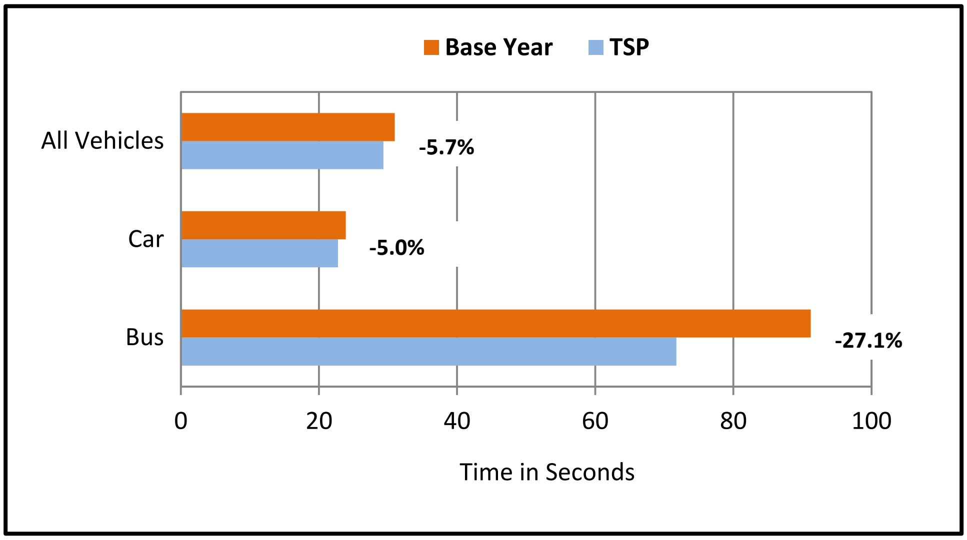
Table 3: Peak-Hour Vehicle Delay

		Base Year		Optimized		TSP		TSP + Enhancements	
		AM	PM	AM	PM	AM	PM	AM	PM
Delay (Seconds)	All Vehicles	31.0	34.3	28.9	31.5	29.3	31.6	28.2	31.4
	Car	23.9	26.6	22.6	24.5	22.7	24.6	22.1	24.4
	Bus	91.2	93.1	83.4	76.2	71.8	73.3	67.4	69.0

Source: DVRPC 2014

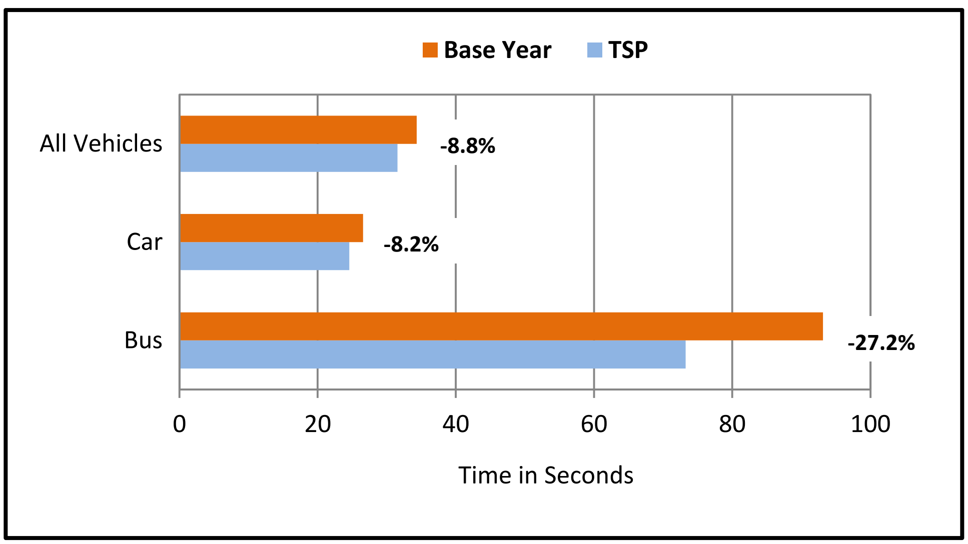
Figures 6 and 7 show the AM and PM network peak hour vehicle delay, respectively. These figures illustrate a comparison between the Base Year and TSP results from Table 3. The percent change between the two scenarios is also provided.

Figure 6: AM Network Peak-Hour Vehicle Delay



Source: DVRPC 2014

Figure 7: PM Network Peak-Hour Vehicle Delay



Source: DVRPC 2014

Travel Speeds

Travel-speed data was collected for passenger vehicles (car), buses, and a combined average for all vehicles including trucks. Table 4 shows overall travel speeds across the four scenarios. While the numbers are not as dramatic as the results from Table 3, overall travel speeds do increase. Travel speeds increase generally 0.5 mph between the Base Year and TSP + Enhancement scenarios for All Vehicles and Cars, and approximately 1 mph for Buses.

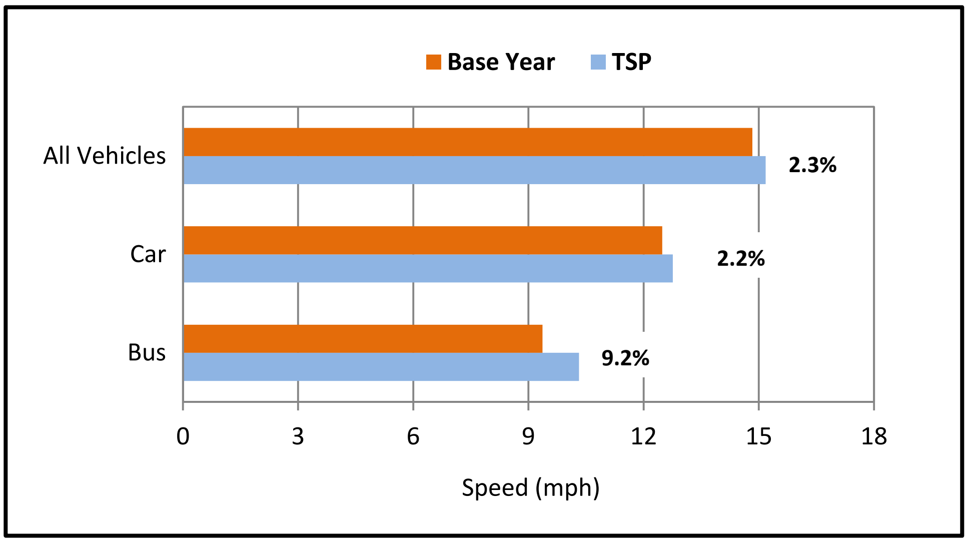
Table 4: Network Travel Speeds

		Base Year		Optimized		TSP		TSP + Enhancements	
		AM	PM	AM	PM	AM	PM	AM	PM
Speed (mph)	All Vehicles	14.8	14.3	15.3	14.8	15.2	14.8	15.4	14.9
	Car	12.5	12.4	12.8	12.8	12.8	12.8	12.9	12.8
	Bus	9.4	9.6	9.8	10.4	10.3	10.5	10.7	10.8

Source: DVRPC 2014

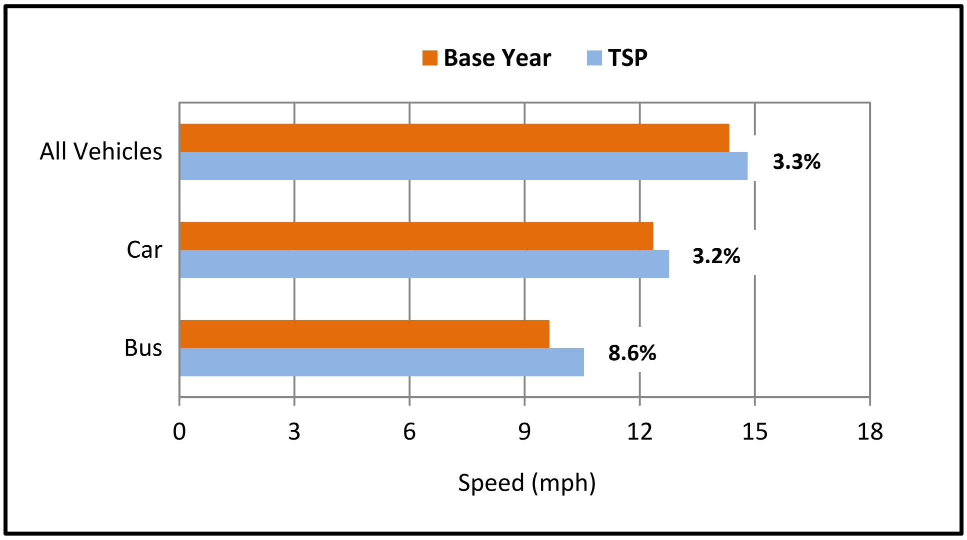
Figures 8 and 9 show the AM and PM peak network travel speeds, respectively. These figures illustrate a comparison between the Base Year and TSP results from Table 4. The percentage change between the two scenarios is also provided.

Figure 8: AM Network Travel Speeds



Source: DVRPC 2014

Figure 9: PM Network Travel Speeds



Source: DVRPC 2014

Travel Times

One indicator used to assess service effectiveness for transit vehicles is operating speed. Faster service makes public transportation more competitive with the automobile, which helps to attract additional riders. Furthermore, when transit vehicles are operating at higher speeds, service becomes less expensive on a per mile basis.

Travel times were set up in the VISSIM simulations to compare operating speeds across the different modeled scenarios. These segments capture travel-time data from three key bus routes and are illustrated in Figure 10 on the following page. These routes represent the travel segments with the highest frequency of buses during the peak hours.

The first travel segment originates at the western edge of the study area on State Street and continues eastbound, turning right onto Armory Drive. The travel segment is approximately 0.757 miles long, and serves 13 buses in the AM and nine buses in the PM. The second segment starts on northbound Clinton Avenue, turns left onto State Street, and continues on State Street through the study area. This travel segment is approximately 0.806 miles long and serves nine buses in the AM and 10 buses in the PM. The last travel segment begins on Montgomery Street, turns right on State Street, and continues on State Street until exiting the study area. The travel segment is approximately 0.421 miles long and serves five buses in the AM and five buses in the PM. The average time for the buses to complete each of their respective travel segments is summarized in Table 5.

Figure 10

Key Bus Travel-Time Segments

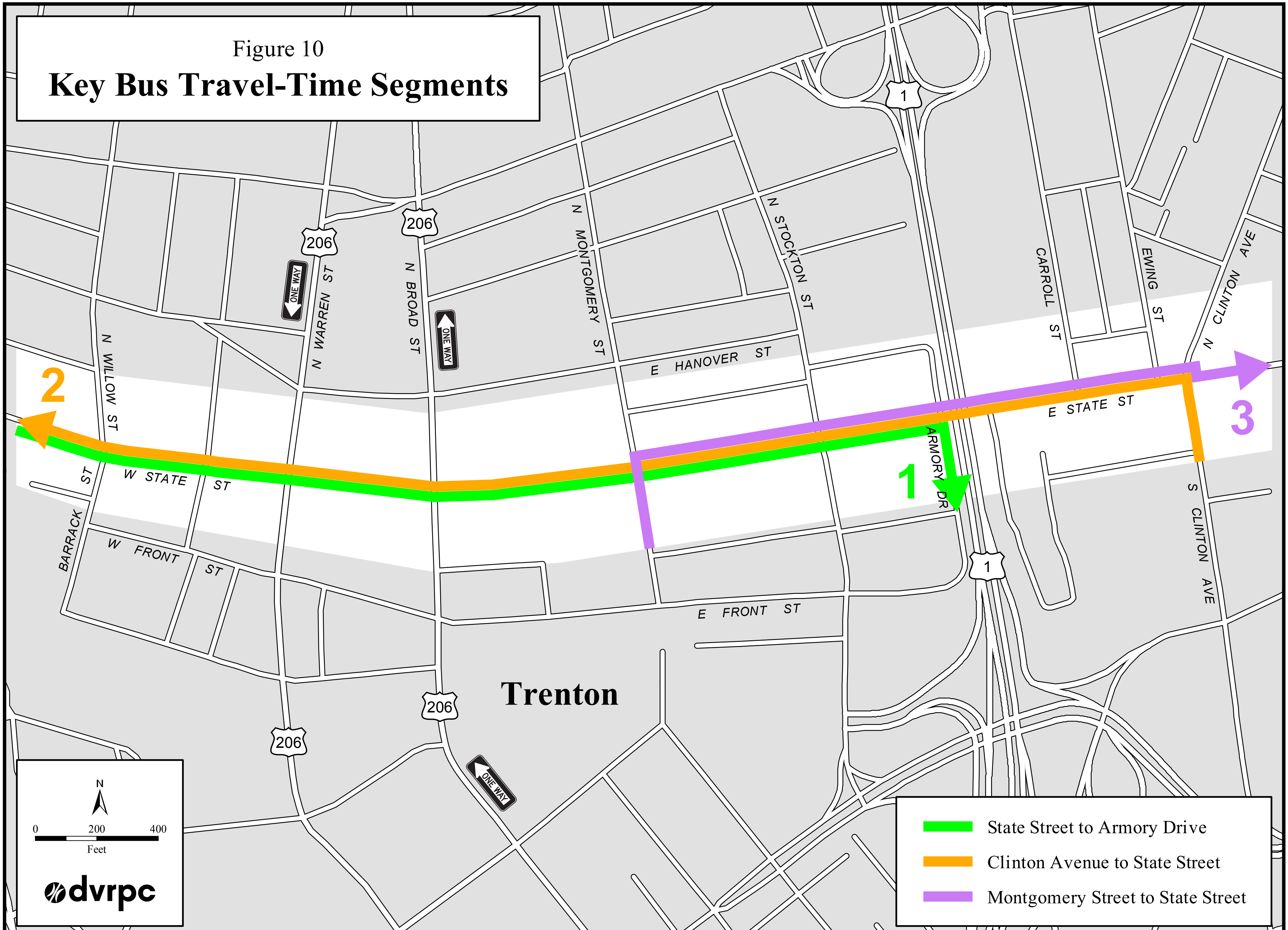


Table 5: Key Bus Travel-Time Segments

Travel-Time Segment	Base Year		Optimized		TSP		TSP + Enhancements	
	AM	PM	AM	PM	AM	PM	AM	PM
State St to Armory Dr	4:59	4:52	4:41	4:30	4:19	4:18	4:13	4:22
Clinton Ave to State St	6:49	6:20	6:25	5:44	5:50	5:35	5:31	5:23
Montgomery St to State St	2:22	2:28	2:32	2:38	2:36	2:30	2:19	2:20

Source: DVRPC 2014

Table 5 represents transit travel time, from when the bus enters the network to when it exits, including all delay and stops. While the Montgomery Street to State Street travel segment remains relatively unchanged across the scenarios, the State Street to Armory Drive and Clinton Avenue to State Street travel segments show more significant time savings.

Conclusions

The performance measures collected in VISSIM for the scenarios consistently show that the implementation of TSP is an effective tool to decrease delay and increase travel speeds for buses on the State Street corridor. Additionally, the following conclusions can be made:

- Traffic signal optimization has a positive impact on traffic flow through the corridor
- Implementing TSP does not negatively impede overall intersection performance
- Implementing TSP does not negatively impact the flow of traffic on State Street
- Combining the westbound bus stops at Stockton Street and Montgomery Street into a single, far-side stop improves overall transit speeds and travel times
- Two of the three highest travel segments in terms of bus frequency show a travel time savings for the Optimized, TSP, and TSP + Enhancements scenarios

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Abstract:
This study examined transit and motorized traffic along the State Street corridor in the central business district of the City of Trenton. The potential for Transit Signal Priority to be implemented on State Street was evaluated as an effective tool to decrease delay and increase travel speeds for buses in the corridor. This study is an extension of the *TSP Favorability Score: Development and Application in Philadelphia and Mercer County* (April 2014, DVRPC Publication No. 13033) as part of a follow-up effort to formalize the study's recommendation into implementation.

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