# Transit Signal Priority Research in the District of Columbia

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| 16. Abstract<br>The District Depart of Transportation (DDOT) is designing and implementing a transit signal priority (TSP) system at over 190 signalized intersections where many project intersections are located within the downtown core area. This will be the first major bus TSP implementation in an urbanized and grid system in the United States. Most TSP systems are applied to linear roadways, and therefore there is knowledge gap nationally on the effects of multiple bus routes and multiple TSP calls on traffic in a downtown roadway network.<br><br>This project will develop a microsimulation model of a portion of the study area to assess, test, and refine TSP strategies in a dense urban environment. The simulation will assess the application of the District's McCain traffic signal system and how TSP affects system operations within the roadway network. | | | |
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# SECTION 1

# INTRODUCTION

The District Depart of Transportation (DDOT) is designing and implementing a transit signal priority (TSP) system at over 190 signalized intersections where many project intersections are located within the downtown core area. This will be the first major bus TSP implementation in an urbanized and grid system in the United States. Most TSP systems are applied to linear roadways, and therefore there is knowledge gap nationally on the effects of multiple bus routes and multiple TSP calls on traffic in a downtown roadway network.

This project will develop a microsimulation model of a portion of the study area to assess, test, and refine TSP strategies in a dense urban environment. The simulation will assess the application of the District's McCain traffic signal system and how TSP affects system operations within the roadway network.

## PROJECT BACKGROUND

The purpose of this project is to assess opportunities to test TSP strategies and the effects of network multimodal operations in a simulated environment. Additional research opportunities include:

- Confirm capabilities and functionality of a VISSIM traffic signal controller module similar to DDOT's field equipment,
- Evaluate performance of recommended and alternate TSP strategies, and
- Identify future research and project opportunities.

### EXPECTED OUTCOMES OF THE RESEARCH

There are two anticipated and expected outcomes of this research project. First, it will verify the TSP Design Team's approach to implement TSP in the downtown. The simulation is expected to validate the development and selection of the strategies and to illustrate the effectiveness on transit and identify anticipated impacts to auto users within the study area. The evaluation of the alternative strategies provides a mechanism to quantify expected impacts on the network. It also allows us to see if there is added benefit of providing priority to busses on all approaches, or maybe just implementing Green Extension to minimize unwanted impacts to other users. The project will also identify where the original assumptions made in the design project no longer hold true and must be adjusted to meet the needs of the network-wide TSP implementation. The second expected outcome of the project is that it provides a feed-back loop to signal operations planning and design activities. Lessons learned in this research project will guide design and implementation activities in the downtown and on future corridors for both general signal timing and TSP strategies.

# METHODOLOGY

This section describes the overarching methodology to the research project. There are three (3) main tasks as part of the project. Details and findings are provided in the summary report.

- Develop a defined sub-area network model in Vissim
- Test Software in the Loop (SIL) modules
- Test Signal Timing and TSP Conditions

Each of the main tasks serve as a steppingstone for the subsequent research and analysis. Outcomes of the overall project are adjusted based on the interim findings while confirming that overall project expectations are still maintained. Findings and calibration efforts from the first task provide a base for the second task and so forth.

The first two tasks are focused on developing the model framework with the last task focusing on the operations. The process begins with the existing signal timing to provide a baseline analysis. Using the revised timings of the optimization effort, the evaluation would be able to provide comparison results for the subarea of the overall network. Layered with on the optimized timings, various TSP strategies can be layered to identify and evaluate how TSP implementation can affect the network and transit operations.

### Condition 1 – Signal Timing Optimization: Baseline Conditions

This evaluation is the base condition, with signal timing and performance prior to implementation of Transit Signal Priority. As mentioned earlier, all TSP evaluations will be compared against this Case Study scenario.

### Condition 2 – Transit Signal Priority Analysis

This Case Study scenario will evaluate the TSP Strategies as recommended in the DDOT TSP Design Project. The evaluation will include the Peak Hour directional priorities, meaning the TSP request will be constrained to either main-street or side street buses, but not both. Additionally, this case will evaluate the recommended signal controller and TSP settings. This evaluation will include both Green Extension and Early Green TSP parameters.

# SECTION 2

## SYSTEM/NETWORK DEVELOPMENT

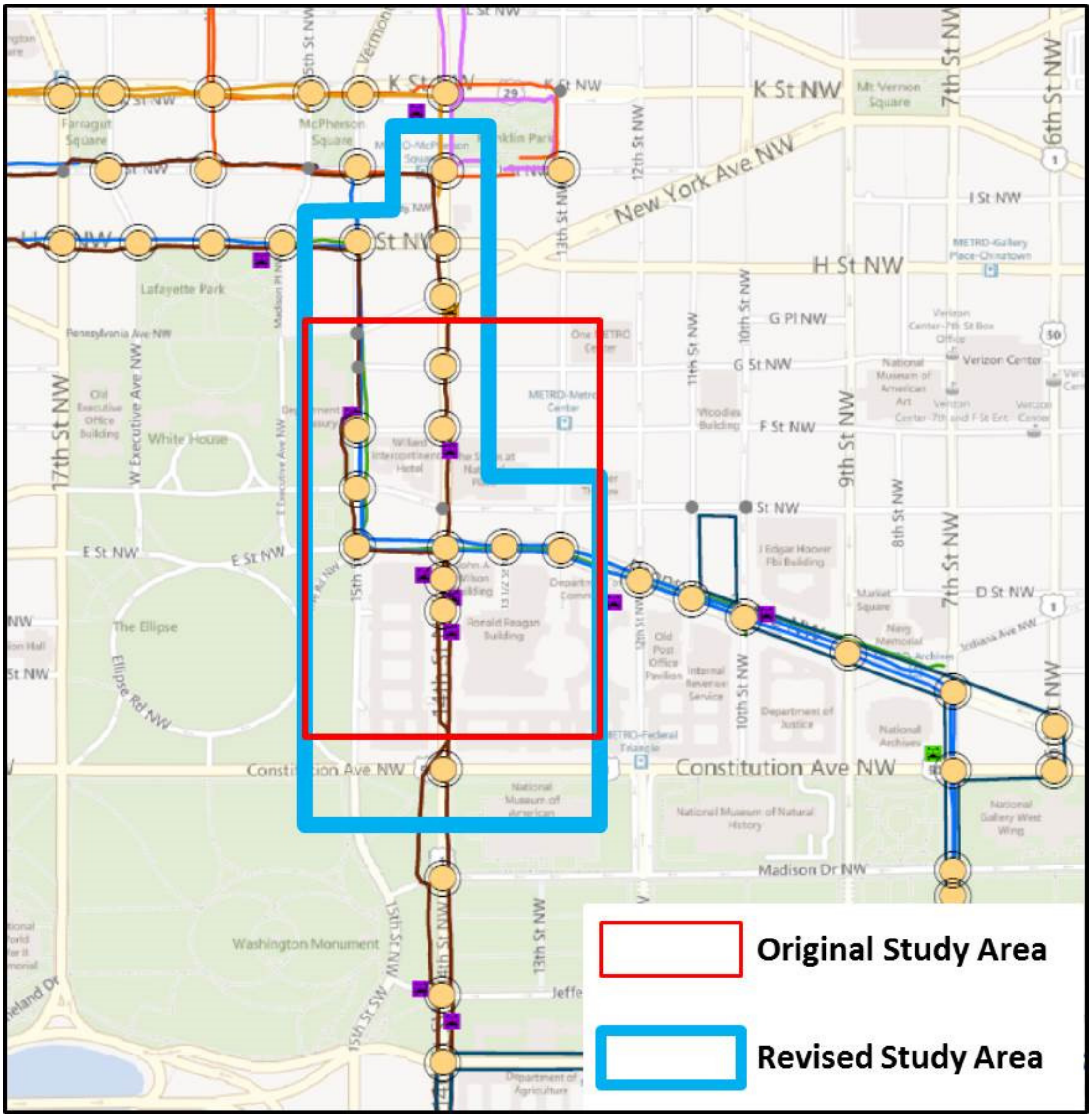
In order to evaluate how TSP is implemented in a downtown area, such an environment needs to be identified and/or developed to provide a serviceable testing ground. Reviewing potential locations within the District, an area within downtown just east of the White House was selected. The study area network is shown in Figure 1and is comprised of the following:

- North-South Streets
  - 15th Street
  - 14th Street
  - 13th Street
- East-West Streets
  - Eye Street
  - H Street
  - New York Avenue
  - G Street
  - F Street
  - Upper E Street
  - Lower E (Pennsylvania) Avenue
  - D Street  (Federal Triangle)
  - Constitution Avenue

Figure 1 shows two highlighted areas, Original and Revised. The original network was bounded by New York Ave (to the north), mid-block between D Street and Constitution Avenue (to the south) and primarily along 14th Street and 15th Street. The Revised Study Area extents will be discussed later. This particular location was selected for the following attributes:

- The area is most notably representative of a downtown network environment. Shorter block spacing, congested traffic conditions, heavy pedestrian activity and pedestrian signals across nearly all approaches at all intersections. Additionally, the area has notable bicycle facilities and activity increasing exposure to a multi-modal environment.
- According to the TSP design and implementation project, the area provides a good representation of proposed TSP routes and non-TSP routes. Additionally, the subarea contains buses on turning routes.
  - Approximately 10 intersections intended to be TSP enabled.
  - Recommended TSP strategies included Peak Hour directions or Route preferences.

Figure 1. **Original and Revised Study Area Extents**




## STUDY AREA CHARACTERISTICS

The study area is located just east of the White House property and north of the National Mall. The subarea is located on auto commuter routes in the north-south direction. The east-west routes terminate to the west at 15th Street due to the White House property, resulting in the nearest through streets as Eye Street, H Street (to the north), and Constitution Avenue (to the south). Most streets within the area (aside from 14th Street) have on-street parking.

### REGIONAL TRAFFIC DEMANDS

AM and PM peak periods demonstrate notably different traffic patterns.

AM peak hour traffic is uncongested and has prevailing northbound movements. These northbound movements are facilitated via 14$^{th}$ and 15$^{th}$ Streets. 14$^{th}$ Street carries northbound traffic originating from Virginia along US 1. The northbound traffic carried by 15$^{th}$ Street is largely originating from Virginia along I-66 and Constitution Avenue. The eastbound left movement at Constitution Avenue/15$^{th}$ Street is particularly heavy, requiring a double left-turn lane configuration. Traffic typically travels in smaller platoons along these north-south streets and rarely experiences queue spillback within the block spacing.

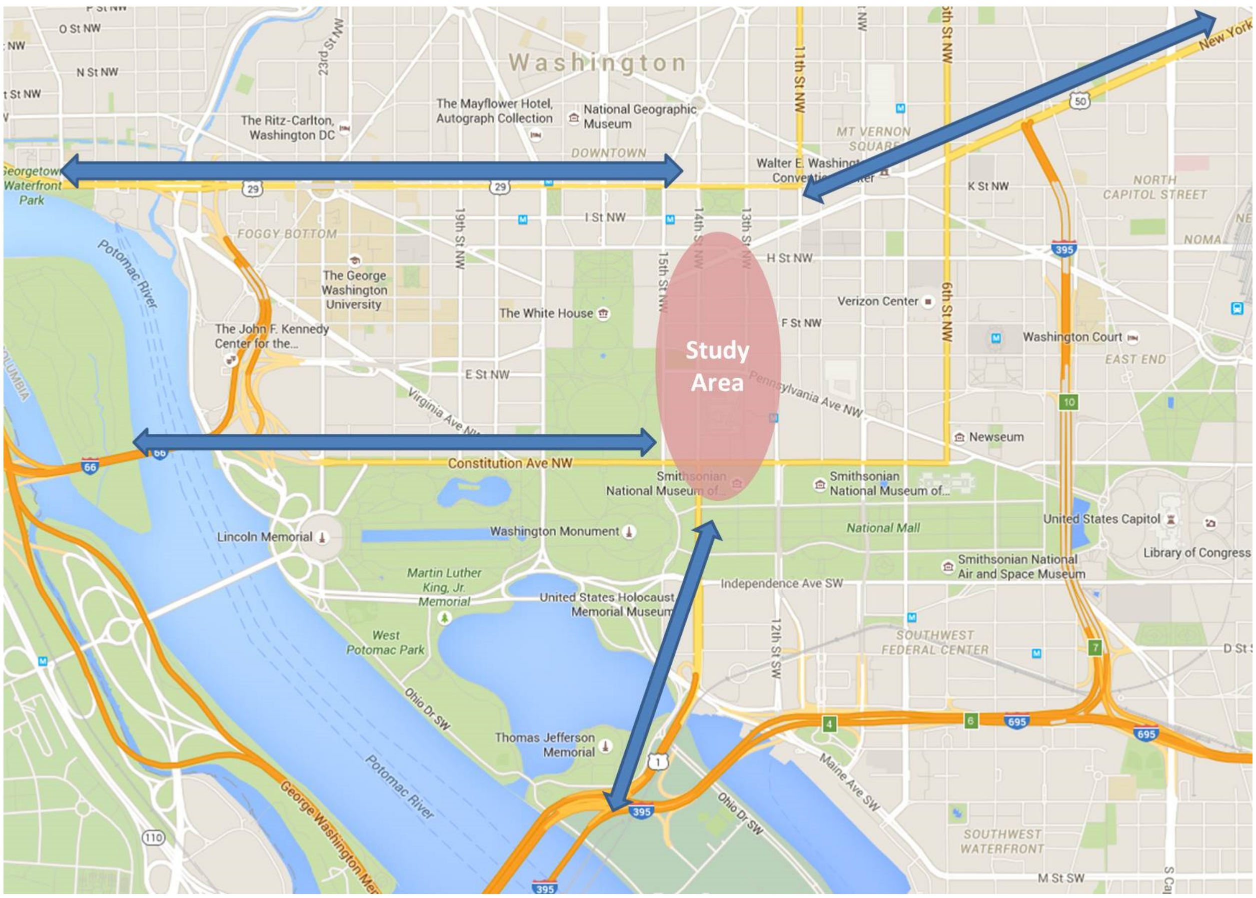
PM peak hour traffic is congested and has prevailing southbound movement. The southbound movements are largely the inverse of the AM peak hour period pattern with being generated from the central business district and surrounding areas attempting to reach destinations south and west to US 1 (via 14th Street) and I-66 (via 15th Street). Traffic is additionally generated from within the study area, which hosts numerous underground garages for the commercial and institutional uses located there. Queue spillback is a recurring issue among most blocks (including some east-west streets) and requires traffic police to ensure traffic does not block the intersections.

Additional corridors that are used to supply traffic from the north are K Street (US 29) and New York Avenue (US 5). These corridors do not carry as much traffic to the study area as those generated from the south and west.

East-west streets within study area are mostly access streets and are not as heavily traveled due to the lack of connectivity to the western parts of the city.

Figure 2 shows the major corridors used to access the study area.

Figure 2. **Regional Traffic Access to Study Area**




## TRANSIT

The study area is serviced by MetroRail and MetroBus Routes. The area is serviced by the Red, Blue, and Orange lines at the Metro Center transfer station, and additionally the Federal Triangle station (servicing only Blue and Orange). A total of 23 MetroBus routes run through the study area during the AM and PM peak hour periods.

### BICYCLE FACILITIES

The study area has bicycle facilities are located on:

- 15th Street
  - Protected two-way bike lanes on west side of the street
  - From H Street to Pennsylvania Ave
  - Bike signals facilitate 15th St cyclists to/from Pennsylvania Ave
- Pennsylvania Ave
  - Protected two-way median bike lanes
  - From 15th Street to beyond 13th St (terminates at 3rd St)
  - Bikes use concurrent thru vehicle phases to proceed; any turns off Pennsylvania are to utilize cross pedestrian phases
- New York Ave
  - Bike lanes for both eastbound and westbound directions
  - From 15th Street to beyond 14th (terminates at 9th St)
  - No special bike signalization
- G Street
  - Bike lanes for both eastbound and westbound
  - From 15th Street to beyond 14th (terminates at 10th St)
  - No special bike signalization

## STUDY AREA EXPANSION

Reviewing the original study area and initial simulation testing determined that the area extents may not provide the most intuitive results when compared to traffic patterns two streets to the north (H Street and Eye Street) and one street to the south (Constitution Avenue) were added to provide more realistic platooned vehicle arrivals to the original network intersections.

## MODELING LIMITATIONS

Constraints of the modeling effort do not allow results to reflect a 1:1 comparison with real world conditions. Additionally the network itself is not intended to replicate existing conditions but rather serves as a template to test TSP parameters without having to generate a transportation network from scratch. The subarea, rather, allows for guidance to real world conditions and activity in terms of:

- Signal timing
- Bus routes/service
- Pedestrian activity
- Traffic activity
- Roadway geometry

There are several notable reasons the model will deviate from what is experienced in the field:

- *Congestion* - Sources (i.e. locations) of congestion are well outside the study area and are difficult to accurately model. These points of congestion would not be used for analysis and would not be good candidates for analysis based on the above-mentioned reasons for selecting the study area.

- *Parking* – On-street parking activity is prevalent within the subarea, as is off-street garage parking. Traffic data collected for this effort was limited to traffic turning movement counts and does not account for traffic generated from parking activity.

- *Temporary Closures* – The capacity of the downtown network is often altered due to external activities including construction, special events, and emergency incidents. While common in downtown areas, the modeling effort does not account for these.

The study area was expanded to the north and south to better assess the operations at the original study intersections. Adding upstream intersections was intended to provide the appropriate platooning of vehicles arriving at intersections and adding downstream intersections was intended to provide the friction/congestion observed in the field. However, expansion to the point of including sources of congestion would have substantially increased the time and effort needed to work towards a more accurate model. However, the added complexity of adding more intersections to an already complicated network likely decreases how accurate the model represents existing conditions.

## SECTION 3

# CONTROLLER TESTING

Simulating TSP operations within the Vissim software requires the use of programmable signals that are virtually represented. Best reflecting the TSP operation begins with what hardware currently exists in the field and will be likely used for TSP signal control in the District. The challenge in simulating the existing field controller, is identifying a comparable software-in-the-loop (SIL) that is compatible with the Vissim program. Currently DDOT utilizes McCain 170 controllers which run the BiTran 233 firmware. The BiTran 233 firmware is not an available SIL to use during simulation; however, the BiTran 2033 firmware (which is run on the McCain 2070 controllers) has been developed by PTV as a viable SIL.

This scenario presents three (3) controllers in the discussion:

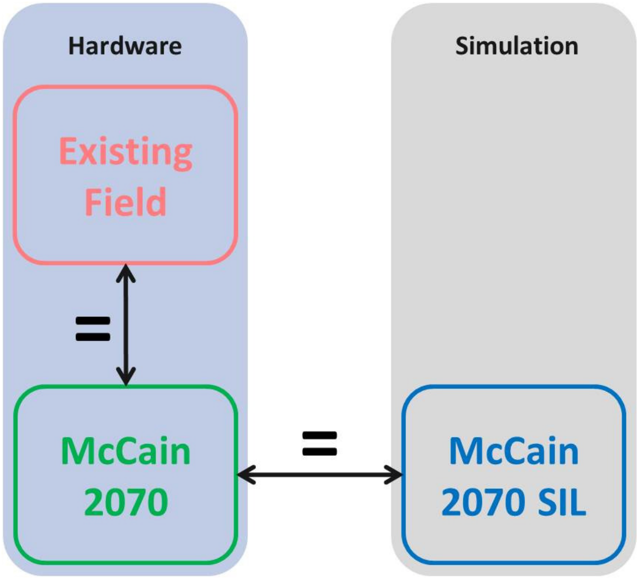
1. **Existing Field** - McCain BiTran 233 firmware as run on the McCain 170 controllers existing in the field today.
2. **McCain 2070** - McCain BiTran 2033 firmware as run on the McCain 2070 controller, which is the new version of McCain signal controller technology.
3. **McCain 2070 SIL** - McCain BiTran 2033 firmware SIL as operated in Vissim.

Considering the continuity of manufacturer and programming of these controllers, connection between the 2033 SIL and the field controller through the following hypotheses:

1. *The **McCain 2070** operates typical signal timing and transit signal priority similar to the **Existing Field**.*
2. *The **McCain 2070 SIL** operates typical signal timing and transit signal priority similar to the **McCain 2070**.*
3. *The **McCain 2070 SIL** is a suitable controller to simulate typical and TSP operations in an effort to replicate that of the **Existing Field**.*

This relationship hypothesis is illustrated in Figure 3.

Figure 3. **Initial Controller Relationship Hypothesis**



Testing these three hypotheses required vetting the both relationships (between **Existing Field** and **McCain 2070** and between **McCain 2070** and **McCain 2070 SIL**). Vetting these relationships required development of a series of traffic controller operations that the three controllers would be required to implement under various programming conditions.

## RING-BARRIER DIAGRAMS/TIMING PLANS

To evaluate how the individual controllers functioned, specified timing plans needed to be used to test across each controller for each scenario. Reviewing typical phasing/timing in the study area, two intersections within the District were selected as examples. These base operations were selected because they were common to the study intersections signal operations.

1. ACISA 5123 Georgia/Decatur - 3- Φ operation (coordinated phases Φ2 and Φ 6)

| | |
|---|---|
| **Φ2 (sync)** | **Φ4** |
| **Φ6 (sync)** | |

2. ACISA 5143 Georgia/Princeton 5- Φ (lagging left turn; coordinated phases Φ1and Φ 6)

| | | |
|---|---|---|
| **Φ2** | **Φ1 (sync)** | **Φ4** |
| **Φ6 (sync)** | | **Φ8** |

## TESTING SCENARIOS

- Base Operations – Testing scenarios evaluating how a signal controller cycles through a timing plan with no TSP calls.
- TSP Operations – These testing scenarios evaluate controller performance regarding TSP operations, either green extension or early green. TSP calls for these tests were placed during "bus phases" (phases that are aligned with the subject bus route) and "non-bus phases" (phases that are conflicting with the subject bus route). Table 1 details the testing scenarios used to evaluate these controllers with the assumed baseline being the operation of the **Existing Field** controller (i.e. McCain 170 Controller/BiTran 233 firmware).

**Table 1. Controller Testing Scenarios**

| Operations | Scenario | Ring-Barrier Diagram | Description | Expected Outcome (McCain 233 Operation) |
|---|---|---|---|---|
| Typical Operations | Base Operations 3-phases | Φ2 (sync) / Φ6 (sync) \| Φ4 | Test for base operations in coordination (i.e. no TSP calls). | Splits and intervals for all phases are the same for each cycle. |
| | Base Operations 5-phases (lagging left turn) | Φ2, Φ1 (sync) / Φ6 (sync) \| Φ4 / Φ8 | Test for base operations in coordination (i.e. no TSP calls). | Splits and intervals for all phases are the same for each cycle. |
| TSP Operations | Green Extension TSP Call (two sync phases) | Φ2 (sync) / Φ6 (sync) \| Φ4 | Extension request is placed during the bus phase (Φ2) and held until the yield point is reached. Call is dropped near the end of the extension. | Green on Φ2 & Φ6 extends for as long as the call is held. |
| | Early Green TSP Call | Φ2 (sync) / Φ6 (sync) \| Φ4 | TSP request is placed during the non-bus phase and held until bus phase gets green. | Green uses variable green time to truncate non-priority phases up to max early green |
| | TSP Call That Drops Before Yield Point (Do Nothing) | Φ2 (sync) / Φ6 (sync) \| Φ4 | Extension request is placed during the bus phase and dropped before the yield point is reached. | No TSP implemented |
| | Extension TSP Call That Extends Into Non Bus Phase | Φ2 (sync) / Φ6 (sync) \| Φ4 | Extension request is placed during the bus phase and continued after a green extension is provided. Call is dropped during the non-bus phase prior to variable green. | Green extends to max green extension and then terminates, recovers within one cycle |
| | Green Extension TSP Call (concurrent phase) | Φ2, Φ1 (sync) / Φ6 (sync) \| Φ4 / Φ8 | Extension request is placed during the bus phase (Φ6) and held until the yield point is reached. Call is dropped near the end of the extension. | Green on Φ1 & Φ6 extends for as long as the call is held. |
| | Green Extension TSP Call (phase pair extension) | Φ2, Φ1 (sync) / Φ6 (sync) \| Φ4 / Φ8 | Extension request is placed during the bus phase (Φ2) and held until the yield point is reached. Call is dropped near the end of the extension. | Green on Φ2 & Φ6 extends for as long as the call is held. |
| | Early Green TSP Call | Φ2, Φ1 (sync) / Φ6 (sync) \| Φ4 / Φ8 | TSP request is placed during the non-bus phase and held until bus phase gets green. | Green uses variable green time to truncate non-priority phases up to max early green |

Note: Expected Outcome was assumed to be the operational result of how the McCain 170 controller using the BiTran 233 firmware would respond to the specific test.

# CONTROLLER EVALUATIONS

## McCain 2070 vs McCain 2070 SIL

Conducting controller testing between the **McCain 2070** and **McCain 2070 SIL** determined that both controllers produced the identical results across all test scenarios. This finding indicates that the **McCain 2070 SIL** is a close representation of the actual hardware operation of the **McCain 2070** controller. See Appendix 1 for testing matrix.

**Existing Field** vs **McCain 2070**

When evaluating controller results between the **Existing Field** and **McCain 2070** determined that both controllers produced identical results for base operations. However, when evaluating the TSP scenarios, some very notable differences were observed between the both controllers' TSP functions. The notable deviation between the two controllers was the implementation green extensions. For the **Existing Field** controller, the duration extension is determined by the "max extension" parameter and when the TSP call is dropped. For the **McCain 2070** controller, the duration of the extension is determined by the "max extension" parameter and when the call is received in the controller. Early green operations were comparable between both controllers, as long as the "early green" parameters were coded per the unique implementation of each controller (i.e. the TSP function would operate the same, but inputs required for each controller differed). The differences are summarized in Appendix 1 for testing. For more details regarding the differences between the TSP operation of **Existing Field** and **McCain 2070** (and therefore **McCain 2070 SIL**), see Appendix 1.

**PTV SIL**

The differing operations for the TSP scenarios lead to the speculation that another simulated controller alternative should be considered. This speculation introduces a fourth controller to the discussion:

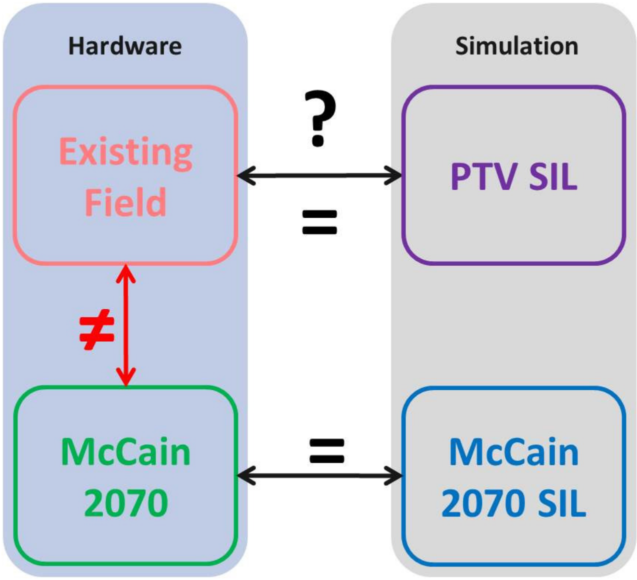
4. **PTV SIL** – PTV Vissim Ring Barrier Controller (RBC) is a generic signal controller commonly used in Vissim simulation models.

The potential of the **PTV SIL** to be a better option than the **McCain 2070 SIL** presents an additional hypothesis to test:

4. *The **PTV SIL** operates typical signal timing and transit signal priority similar to the **Existing Field**.*

This revised relationship hypothesis is illustrated in Figure 4.

Figure 4. **Revised Controller Relationship Hypothesis, including PTV SIL**



Using the **PTV SIL** controller, the evaluation was completed for all scenarios listed in Table X. The results show that the **PTV SIL** produces identical results for base operations and more similar results for TSP scenarios. The results are summarized in Appendix 1 for testing matrix.

### PRETIMED VERSUS MAX RECALL

An observation during the testing determined the significance of signal operation under "Pretimed" or "Max Recall" timing configurations. These differences were made evident in the controllers using the 2033 firmware (i.e. **McCain 2070** and **McCain 2070 SIL**). The differences were found when testing early green TSP calls both controllers. As a result, all controllers were subsequently evaluated across all scenarios to compare their "Pretimed" versus "Max Recall" operation. For more details, see Appendix 1.

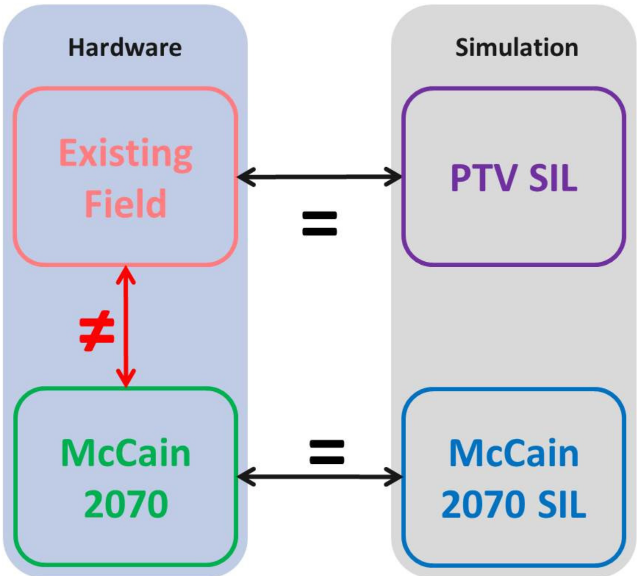
## FINDINGS

After completion of the controller testing for all four controllers, key findings included:

- All controllers operate similarly for base operations.
- McCain 2070 SIL is a serviceable virtual representation of the McCain 2070 hardware, both operating the BiTran 2033 firmware.
- **McCain 2070** and **McCain 2070 SIL** does not replicate **Existing Field** controller TSP operations.
- The **PTV SIL** better replicates the **Existing Field** controller TSP operations.
- DECISION – utilize RBC controller for simulation effort

The concluding relationship between the four controllers is illustrated in Figure 5.

Figure 5. **Concluded Controller Relationship**




## OUTCOMES

The controller testing revealed fundamental differences in TSP operations between the 233 and 2033 firmware and hence, the respective controllers that utilized them. Base operations were consistent between all controllers. The green extension function proved to be the un-mitigatable difference between **Existing Field** and the originally proposed **McCain 2070 SIL**. When comparing the **PTV SIL** to the **Existing Field**, it was found to better replicate the TSP operations for green extension and early green functionalities.

### DIFFERENCES IN GREEN EXTENSION

The TSP functionality of the 2033 firmware controllers (**McCain 2070** and **McCain 2070 SIL**) would not produce the same green extension as the 233 firmware controller (**Existing Field)** or the **PTV SIL**. This discrepancy was notable due to the green extension implemented by the **McCain 2070** or **McCain 2070 SIL** could never provide "full extension" anticipated.

## DIFFERENCES IN EARLY GREEN

The TSP functionality for early green could be implemented identically for all controllers tested but required alternative inputs to account for the functionality difference between them.

## SIGNIFICANCE OF DIFFERENCE

Identifying the differences between all controllers required evaluating how significant those differences are and the expected impacts they could have on the simulation analysis. While the simulation is not a direct 1-to-1 comparison between the real world network and the simulated network, effort was made to minimize the differences in an attempt to improve interpretability of model results. It was determined from a signal controller standpoint, considering the aims of the project are to evaluate the impacts of TSP operation that the controller that better replicated the **Existing Field** controller would be selected. As a result, the **PTV SIL** was used.

### Caveats of the PTV SIL Controller

While the **PTV SIL** controller operated closer to the **Existing Field** controller than the 2033 firmware controllers, the **PTV SIL** comes with its own set of caveats.

The **Existing Field** controller utilizes forces-offs to determine phase changes in a timing cycle. The **PTV SIL** controller's force-off functionality is a fault. Using force-offs typically results in cycle drift and often inaccurately implements the force-offs programmed in a particular signal. This issue requires the use of split timing as opposed to fixed force-offs. Given that the downtown network during both analysis periods operates as a pretimed environment, phase lengths and cycle lengths are identical between the use of force-offs or splits. Therefore, calculating splits and offsets from the force-offs detailed in the signal timing sheets will result in an operation that should not differ from a functioning force-off signal.

# SECTION 4

# STRATEGY DEVELOPMENT AND CONDITION TESTS

After development of the model network and selecting the traffic controller to be used, the TSP evaluation requires examining the operations of the network. The process for this began with the existing signal timing to provide a baseline analysis.

Using the revised timings of the optimization effort, the evaluation would be able to provide comparison results for the subarea of the overall network.

Layered with on the optimized timings, various TSP strategies can be layered in order to identify and evaluate how TSP implementation can affect the network and transit operations.

## TIMING PLANS

The following timing plans were modeled and evaluated:

- **Original** – timing plan used prior to recent optimization plan
- **Optimized** – the optimization plan recently implemented by SW
    - **FIFO TSP** – using the optimization plan as a base, TSP was overlaid on intersections within the study area for all approaches TSP-enabled routes would use. TSP was implemented with a maximum 10-second extension or early green as variable green time was available.
    - **Alternate TSP Strategy** – using the optimized timing plan as a base, TSP was implemented based on FIFO findings and initial strategy developed for both AM and PM plans. The 10-second maximums were also implemented for extensions and early greens.

## CONDITION 1 TESTING

Condition 1 is the baseline traffic timing conditions for the network. The evaluation examined two distinct traffic conditions:

- The AM peak hour conditions are uncongested and largely process traffic demand.
- The PM peak hour conditions are oversaturated which results in a reduction of traffic throughput and leads to unintuitive operational results.

Additionally, there are two distinct "base" condition:

- Original - 2014 signal timing plans
- Optimized – 2015 optimized signal timing plans

The oversaturated conditions suggest that individual intersection performance metrics become confounding when overcapacity. Network-wide and corridor focus results should provide more of the explanatory meaning than intersection-level analysis. With corridors and intersections experiencing residual queues and delays, the area is difficult to model PM peak hour conditions with confidence. Quantifying the traffic network MOE's become difficult and unintuitive.

As a result, it becomes better to focus on the AM conditions to evaluate TSP. Table 2 shows which conditions receive the focus for different timing plans:

**Table 2. Evaluation Conditions**

| TIME PERIOD | BASE | OPTIMIZED | TSP-FIFO | TSP – ALTERNATE STRATEGY |
|---|---|---|---|---|
| AM Peak | X | X | X | X |
| PM Peak | X | X | | |

# BASELINE ANALYSIS

The following details the primary findings of the baseline analysis which focuses on the original 2014 signal timing plans and the 2015 optimized signal timing plans.

## SIGNAL OPTIMIZATION STRATEGIES

Modifying signal plans to be "optimized" have the potential to fulfill various goals or desired outcomes related to traffic operations. Some strategies of optimization focus on reducing delay at various levels (e.g. intersection-specific, corridor-specific, network-wide). The environment of a downtown network provides many constraints when attempting to provide and optimized network. Short block spacing provides minimal queue storage likely in demand for heavy main street and heavy side street demands. For this particular study area, the strategy appeared to focus on:

- Progression focused
- Corridor focused
- Reduced the number of stops network-wide

Focusing signal timing strategy on minimizing the number of stops vehicles are required to make could maximize throughput of the main arteries of the network. Essentially, as soon as vehicles are on the mainline, there is a long travel period between stops. Once stopped, they duration of the stop could be longer than a strategy which balances shorter travel periods and subsequent shorter stops (a kind of stop-go-stop-go phenomenon). Focusing on the progression of specific corridors (ideally the primary commuter routes) could help ease congestion within the network at the expense of the lower demanded side streets.

## RESULTS

The high-level results can be viewed from two levels: network-level and corridor-level.

### Network Level Results

There are two main findings from the network level performance metrics.

1. Increased overall network-wide delay
2. Reduced number of network-wide stops

The overall increase in network-wide delay is likely result of the corridor/progression focused strategy and the relative high demands of side street traffic within the subarea. An important note is to recognize that these results are only representative of the modeled subarea and do not necessarily imply that the total network is affected in the same way. The subarea is likely to have subtleties and limitations that do not capture the over-arching performance of the optimization strategy. For example, the combination of specific intersections used in the subarea analysis may experience lesser benefits than an entire network programmed with the same strategy.

The reduction in the number of network-wide stops is a finding that again shows that the optimization prioritizes a "momentum" of traffic where once traffic is moving, the timing allows such traffic to keep moving until platoons are required to stop. These stops are likely longer in duration and could contribute to the increase in overall network-wide delay.

### Corridor Level Results

The corridor level findings notably revealed a collection of reduced travel times for major corridors. These reduced travel times a likely attributed to the progression-focused strategy of the optimization effort, where lost time is minimized for individual vehicles that no longer experience as frequent stops than under the original timing plan.

When looking at modal performance, it is clear that there are notable differences between the experience of cars and buses. Table 3 summarizes results comparison between Original and Optimized Timing strategies during the AM Peak hour.

**Table 3. Network-wide Results Comparison between Original and Optimized Timings**

| METRIC | ALL TRAFFIC | CARS | BUSES |
| --- | --- | --- | --- |
| Network Delay | +11.3% | +12.2% | -8.8% |
| Network Stops | -2.8% | -4.3% | -6.1% |
| Network Travel Time | +5.6% | +6.2% | -3.9% |

Cars (specifically referring to all non-transit, non-active vehicles on the roadway network) show:

- Increased in network delay/travel time
- Reduction in network stops

The increase in network delay and network travel time can be attributed to cars being the most pervasive mode in the modeled subarea and provide demands from all approaches in the network, including those that are not prioritized in the optimization strategy. As a result, the experiences of car users within the subarea are likely to have higher delays from side streets and other lower prioritized movements. Considering the nature of the downtown area, these lower prioritized movements are still relatively high in demand by car users and therefore increase the delays experienced. Cars also experience a reduction in corridor-specific travel time which will be elaborated later.

Transit vehicles (buses) largely benefit across the three network-wide metrics shown in Table X. Buses shows:

- Reduction in network delay/stops/travel time
- Reduction in corridor travel time

These results are likely attributed to an alignment of prioritized corridors and movements under the optimization strategy and existing bus routes. For example, 14th Street is a highly prioritized corridor within the subarea for all traffic and happens to be a primary route for many buses. Additionally, bus routes are not navigated through some of the lower prioritized corridors and movements and therefore do not suffer the additional delay experienced by those users.

## TRANSIT SIGNAL PRIORITY ANALYSIS

The following details the primary findings of the transit signal priority analysis which focuses on the AM peak model and is overlaid on the 2015 optimized signal timing plans. Two strategies were evaluated for this study, FIFO and Alternate generated strategies.

- FIFO (First-in, First-out) – This strategy grants signal priority to any TSP enabled bus that registers its call in the controller first. The strategy assumes both a 10-second green extension and 10-second early green function where available. There was no restriction on direction to grant priority.

- Alternate Strategy – This strategy utilized previously developed prioritization strategies to be used in the District. The strategy is highlighted by selective extensions and/or early green enabling with specific directions programmed for its operation.

The first comparison was to examine how overlaying the TSP strategies over the optimization plan (i.e. implementing TSP functionality with the optimization signal timing plan) would result. Table X summarizes the network-wide results comparisons of the two TSP strategies versus the optimization plan during the AM Peak hour.

**Table 4. Network-wide Results Comparison of TSP Strategies by Mode**

| METRIC | ALL TRAFFIC | CARS | BUSES |
|---|---|---|---|
| **Network Delay** | | | |
| FIFO | -0.8% | -1.1% | -2.2% |
| Alternate | -12.7% | -15.6% | -0.6% |
| **Network Stops** | | | |
| FIFO | -0.4% | -0.7% | -3.6% |
| Alternate | -12.4% | -15.7% | 0.0% |
| **Network Travel Time** | | | |
| FIFO | -0.4% | -0.6% | -0.9% |
| Alternate | -6.8% | -8.6% | -0.3% |

As shown in Table 4, overlaying either TSP strategy over the optimization plan universally improves network-wide delay, stops, and travel time for all modes. This finding can likely be attributed to heavier demanded movements being given additional green-time. The flexibility of the signal to utilize the variable green time during an uncongested hour (i.e. the AM peak hour) allows TSP intersections to be…

Examining specific travel times along individual corridors has shown that TSP overlays also provide travel time benefits all traffic in addition to transit. Notably, the positives are gained in the north-south directions while compromised more in the east-west directions. This is consistent with expectations considering TSP functions are much more likely to be used on the north-south approaches under both TSP strategies. Table 5 summarizes travel time comparison results of TSP implemented travel times versus the optimized timing plan.

**Table 5. Corridor Results – All Traffic AM Results vs Optimized Timing Plan**

| CORRIDOR | FIFO | Alternate |
|---|---|---|
| 1: SB 15th (H St-Constitution) | -2.3% | +0.1% |
| 2: NB 15th (Constitution-H St) | 0.0% | 0.0% |
| 3: SB 14th (Eye St to Constitution) | -1.9% | -0.4% |
| 4: NB 14th (Constitution to Eye St) | -0.9% | -11.3% |
| 5: EB Constitution (15th to 4th) | -0.6% | -0.4% |
| 6: WB Constitution (14th to 15th) | -13.6% | -8.0% |
| 7: EB Pennsylvania (15th to 13th) | -1.1% | +1.2% |
| 8: WB Pennsylvania (13th to 15th) | +0.2% | +1.5% |

During the AM peak hour, the prevailing traffic movement in the subarea is northbound traffic on 14th Street which is shown under the Alternate strategy to gain the most travel time benefit.

When looking at transit specifically, the results do not show such sweeping improvements. Table 6 summarizes transit travel time comparison results of TSP implemented travel times versus the optimized timing plan.

**Table 6. Corridor Results – Transit AM Results vs Optimized Timing Plan**

| CORRIDOR | FIFO | Alternate |
|---|---|---|
| 3: SB 14th (Eye St to Constitution) | +1.1% | +1.5% |
| 4: NB 14th (Constitution to Eye St) | -1.0% | -5.1% |
| 5: EB Constitution (15th to 4th) | +3.7% | +0.2% |
| 6: WB Constitution (14th to 15th) | -0.7% | +2.9% |
| 7: EB Pennsylvania (15th to 13th) | -1.2% | +0.1% |
| 8: WB Pennsylvania (13th to 15th) | 0.0% | +3.1% |

As shown, the corridor that mostly benefit from TSP implementation is the northbound 14$^{th}$ Street corridor. The largest travel time gains for transit are had on this prevailing traffic movement under both the FIFO and Alternate TSP strategies. The result is compromised travel time results on the east-west routes within the subarea.

SECTION 5

# SUMMARY OF KEY FINDINGS

A review of the performance metrics comes down to determining the most significant findings of the model analysis. The complexity of the downtown environment and the varieties of competing demands of various modes makes it difficult to parse out meaningful takeaways at the intersection-level and so analysis has mostly been focused on deriving findings from the network- and corridor-level.

## OVERALL FINDINGS

Reviewing the analyses from a higher-level perspective provides several key findings about the project overall:

1. TSP implementation in a downtown network can be deployed without adversely affecting traffic operations.
2. Signal timing optimization delivers the most benefit to traffic operations.
3. Different TSP strategies provide value, but a directional TSP strategy (Alternate) offers a more balanced approach than FIFO.

### 1. DOWNTOWN NETWORK TSP IMPLEMENTATION

Analysis findings have shown that there is no significant network degradation with TSP implementation. One of the principle concerns about implementing TSP strategies in a downtown network grid is the potential to severely degrade network operations. Considering the time and effort required to coordinate signal timings in a downtown environment requires delicate balancing of green time for all approaches, deviation from such coordination (e.g. TSP functions) have been considered unfavorable for agencies to implement. There are no documented projects for TSP implementations in an urbanized/downtown environment and many TSP implementations are on arterials and typically in a suburban environment. The more balanced traffic demands in a downtown network increases the difficulty to prioritize directions without suffering notable degradations overall compared to the more typical environments TSP is implemented. This finding is important to dispel the notion that downtown networks cannot implement TSP without significant disruptions to already constrained traffic flows.

### 2. OPERATIONS IMPROVEMENT THROUGH SIGNAL TIMING OPTIMIZATION

The optimization has the best improvements to all vehicles with higher benefit on main corridors. Comprehensively looking at the analyses, the optimization effort is generally shown to be an improvement to traffic conditions, particularly on the main corridors where progression is favored. Signal timing strategies focused on corridor progression and resulted in improved performance for buses, specifically on the prevailing transit demand routes. Since key transit corridors overlap with prioritized corridors for progression, transit reaps more relative benefit from these improvements.

### 3. TSP-SPECIFIC FINDINGS

The analysis findings have shown modest benefits with TSP implementation. The TSP strategies were found to be beneficial to TSP specific routes, however network-wide have shown to increase travel times on non-TSP bus routes. This finding confirms that TSP can be beneficially directed on approaches in an effort to prioritize bus mobility and reliability in a downtown network.

FIFO results show bus performance benefits and slightly better than engineering judgement (Alternate strategy) along corridors. Allowing all TSP buses to activate TSP calls from any approach has shown to have a network-wide improvement over the specified Alternate strategy suggests that the focused strategy should be explored. A TSP cap of 10 seconds is reasonable for both extension and truncation. The 10 seconds is also a somewhat constrained cap in a downtown environment due to the likely limited variable green time available at intersections to accommodate pedestrians. These findings support the proposed parameters for the implementation project.

## PROJECT ASSESSMENT

When holistically reflecting on the project, results, and findings, there are some notable takeaways that should be considered for any future work.

- Results are better evaluated on network and corridor level. Individual intersections in a downtown environment could vary widely in terms of performance metrics when certain signal timing changes are made. Therefore, the response to traffic in transit experience through the network due to signal timing/TSP changes in aggregate are a better indication of the real impact.
- Vissim (and all simulation models) are an approximation of the various dynamics of a downtown network and traffic behavior of congested conditions.
- Modeled network is a piece of the larger network. The subarea identified served as a model template to provide many important details that otherwise would have needed to be newly generated.
- All results reflect use of the RBC controller, which is similar to the DDOT controller, but not exactly.

## LESSONS LEARNED

Reflecting on the findings and challenges, the research effort has provided a number of lessons learned regarding research development with TSP simulation.

- *Network selection and modeling downtown environments* – As previously noted, the study area (which is subarea of a greater urban network) can be difficult to model, particularly when trying to replicate congested conditions. While the model developed for this research effort is not intended to serve as replicating a one-to-one comparison with field conditions, network congestion is still a tricky phenomenon to accurately capture. The study area modeled had a prominent north-south traffic pattern, largely because the east-west connectivity was terminated to the west. One of the difficulties of capturing traffic in this region is the large number of circulating routes drivers will use to find parking. Should a network have been modeled after a downtown network with prevailing north-south and east-west traffic patterns, the model could potentially yield notably different results.
- *Controller selection is crucial, even in pretimed environments* – One of the notable findings through this research effort were the fundamental differences between the BiTran 233 and 2033 firmwares in how they each implemented TSP functions. A pretimed network can be replicated across all controllers tested for typical operations. Considering TSP is a more advanced function of a traffic controller, determining the specific controller and firmware used will have notable impact on operations. The evaluation of all controller types (hardware, firmware, and SIL) for this effort uncovered these fundamental differences and impact those differences.
- *Optimization provides the most benefits to all traffic and transit* – As has been identified in previous research, adjustments to signal timing (i.e. signal optimization) has a much more profound impact on traffic operations than implementing TSP functionality at intersections. The optimization plan implemented within the modeled network revealed how progression was prioritized on main corridors and improved traffic operations across several metrics, including travel time, delay, and total stops.

## FUTURE RESEARCH

This research effort was primarily aimed at assessing the effects of TSP in a downtown network environment. The effects were assessed by selecting a subarea network as a basis for a model and compare traffic operations under different timing conditions. The parameters used to conduct such an analysis are numerous, and many needed to be limited to reduce the number of condition permutations to develop and manageable research effort. As a result, there are still many other conditions and future research questions that should be investigated:

- *Alternative TSP Corridors* – The research effort attempted to develop a strategy for specified TSP enable bus routes (specifically intersection approaches utilized by buses on those routes). Considering the number of routes within the study area network, alternative TSP strategies could be developed and tested to minimize the effect on non-TSP enabled transit vehicles, or investigating where more efficient TSP enabled routes could be found, given the model network configurations.
- *Alternative Network Model* – One of the lessons learned revealed that the specific modeled network only had prevailing north-south movements due to the east-west connectivity being limited. Expanding the current modeled network to include more prominent east-west traffic patterns could provide more insight to the effects of TSP on a more balanced network with major movements from all approaches.
- *Assess Transit Headway Reliability* – While TSP may not provide as much benefit as overall signal timing adjustments, evaluating headway reliability may be a performance measure that can be improved through TSP implementation. Strategies could be investigated to see if there are elements that can implemented to improve the reliability of bus headways, and therefore improve on-time performance of transit routes.
- *Minimize Non-TSP Transit Impacts* – While TSP enabled transit were recipients of operational benefits, having multiple routes on non-TSP approaches are impacted by the TSP functions. Additional research could be performed to evaluate how non-TSP enabled transit is affected by TSP implementation strategies.
- *TSP Parameter Sensitivity Testing* – The research effort largely limited the parameters tested to reduce conditions permutations. Additional research could be used to learn the sensitivity of various TSP function parameters including:
    - Green extension duration
    - Red truncation duration
    - TSP "Lock-out" duration

## APPENDIX 1

# CONTROLLER TESTING MATRIX AND NOTES

## Controller Testing Matrix

**LEGEND**

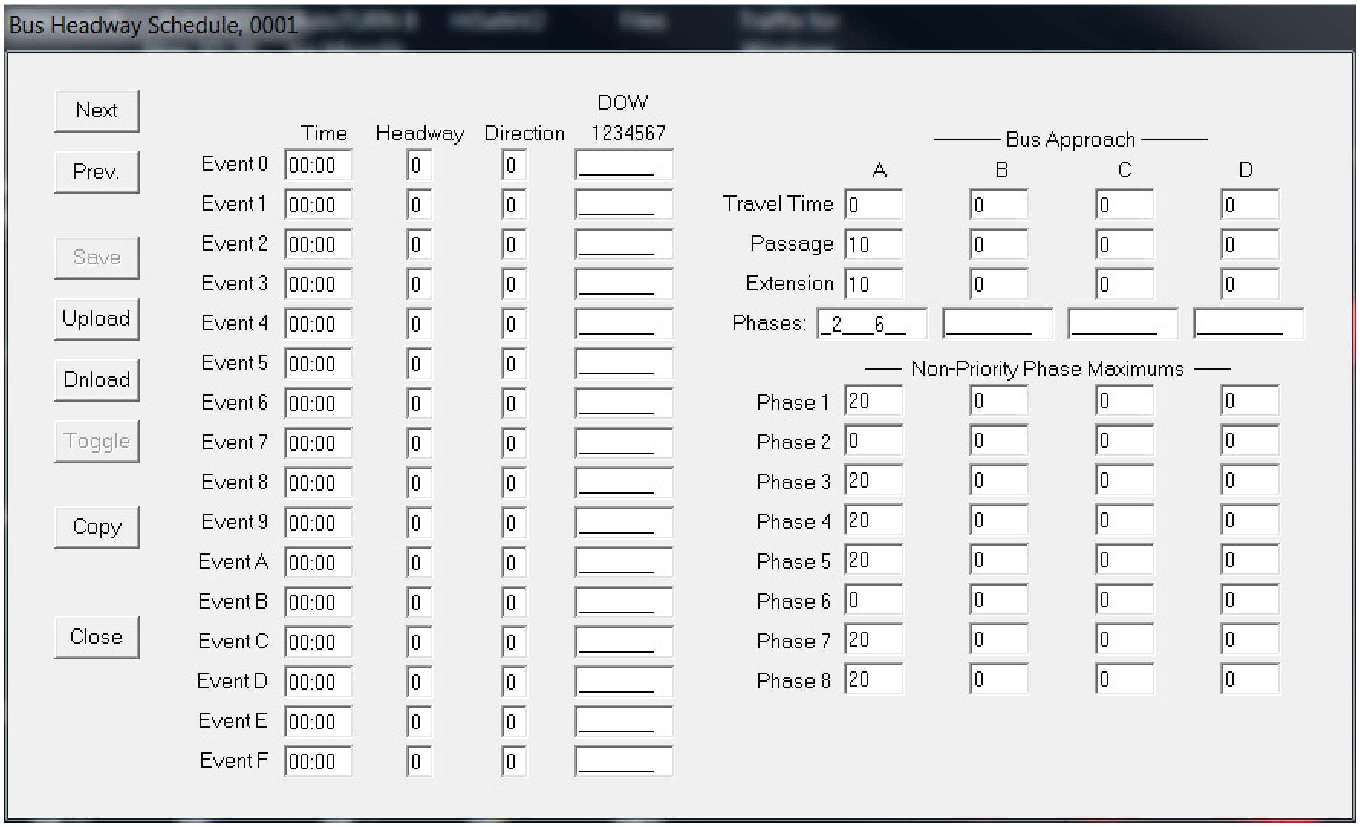
- Green: Outcome is as expected
- Yellow: Outcome is as expected, but with notable caveat
- Orange: Outcome is notably different from expected

| Operations | Scenario | Ring-Barrier Diagram | Description | Expected Outcome (McCain 233 Operation) | Existing Field – McCain 233 Controller – Pretimed | Existing Field – McCain 233 Controller – Max Recall | McCain Test – McCain 2033 Controller – Pretimed | McCain Test – McCain 2033 Controller – Max Recall | McCain Test SIL – McCain 2033 SIL – Pretimed | McCain Test SIL – McCain 2033 SIL – Max Recall | PTV SIL – VISSIM Ring Barrier Controller (RBC) – Pretimed (Walk Expand) | PTV SIL – VISSIM Ring Barrier Controller (RBC) – Max Recall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Typical Operations** | Base Operations 3-phases | Φ2 (sync) / Φ6 (sync) ‖ Φ4 | Test for base operations in coordination (i.e. no TSP calls). | Splits and intervals for all phases are the same for each cycle. | **Passed** | **Passed** | **Passed** | **Passed** | **Passed** | **Passed** | **Passed** | **Passed** |
| | Base Operations 5-phases (lagging left turn) | Φ2, Φ1 (sync) / Φ6 (sync) ‖ Φ4 / Φ8 | Test for base operations in coordination (i.e. no TSP calls). | Splits and intervals for all phases are the same for each cycle. | **Passed** | **Passed** | **Passed** | **Passed** | **Passed** | **Passed** | **Passed** | **Passed** |
| **TSP Operations** | Green Extension TSP Call (two sync phases) | Φ2 (sync) / Φ6 (sync) ‖ Φ4 | Extension request is placed during the bus phase (Φ2) and held until the yield point is reached. Call is dropped near the end of the extension. | Green on Φ2 & Φ6 extends for as long as the call is held. | **Passed** | **Passed** | Extension provided is (max extension programmed) after the call is recognized in the controller in the "potential extension window" | Extension provided is (max extension programmed) after the call is recognized in the controller in the "potential extension window" | Extension provided is (max extension programmed) after the call is recognized in the controller in the "potential extension window" | Extension provided is (max extension programmed) after the call is recognized in the controller in the "potential extension window" | **Passed** | **Passed** |
| | Early Green TSP Call | Φ2 (sync) / Φ6 (sync) ‖ Φ4 | TSP request is placed during the non-bus phase and held until bus phase gets green. | Green uses variable green time to truncate non-priority phases up to max early green | **Passed** | **Passed** | Early Green parameter must exceed FDW time | **Passed** | Early Green parameter must exceed FDW time | **Passed** | **Passed** | **Passed** |
| | TSP Call That Drops Before Yield Point (Do Nothing) | Φ2 (sync) / Φ6 (sync) ‖ Φ4 | Extension request is placed during the bus phase and dropped before the yield point is reached. | No TSP implemented | **Passed** | **Passed** | As expected (as long as not within "potential extension window" | As expected (as long as not within "potential extension window" | As expected (as long as not within "potential extension window" | As expected (as long as not within "potential extension window" | **Passed** | **Passed** |
| | Extension TSP Call That Extends Into Non Bus Phase | Φ2 (sync) / Φ6 (sync) ‖ Φ4 | Extension request is placed during the bus phase and continued after a green extension is provided. Call is dropped during the non-bus phase prior to variable green. | Green extends to max green extension and then terminates, recovers within one cycle | **Passed** | **Passed** | Extension provided is (max extension programmed) after the call is recognized in the controller in the "potential extension window" | Extension provided is (max extension programmed) after the call is recognized in the controller in the "potential extension window" | Extension provided is (max extension programmed) after the call is recognized in the controller in the "potential extension window" | Extension provided is (max extension programmed) after the call is recognized in the controller in the "potential extension window" | As expected, longer extension (10s full extension) req 2-cycle recovery | As expected, longer extension (10s full extension) req 2-cycle recovery |
| | Green Extension TSP Call (concurrent phase) | Φ2, Φ1 (sync) / Φ6 (sync) ‖ Φ4 / Φ8 | Extension request is placed during the bus phase (Φ6) and held until the yield point is reached. Call is dropped near the end of the extension. | Green on Φ1 & Φ6 extends for as long as the call is held. | **Passed** | **Passed** | Extension provided is (max extension programmed) after the call is recognized in the controller in the "potential extension window" | Extension provided is (max extension programmed) after the call is recognized in the controller in the "potential extension window" | Extension provided is (max extension programmed) after the call is recognized in the controller in the "potential extension window" | Extension provided is (max extension programmed) after the call is recognized in the controller in the "potential extension window" | **Passed** | **Passed** |
| | Green Extension TSP Call (phase pair extension) | Φ2, Φ1 (sync) / Φ6 (sync) ‖ Φ4 / Φ8 | Extension request is placed during the bus phase (Φ2) and held until the yield point is reached. Call is dropped near the end of the extension. | Green on Φ2 & Φ6 extends for as long as the call is held. | **Passed** | **Passed** | **Passed** | **Passed** | **Passed** | **Passed** | **Passed** | **Passed** |
| | Early Green TSP Call | Φ2, Φ1 (sync) / Φ6 (sync) ‖ Φ4 / Φ8 | TSP request is placed during the non-bus phase and held until bus phase gets green. | Green uses variable green time to truncate non-priority phases up to max early green | **Passed** | **Passed** | Early Green parameter must exceed FDW time | **Passed** | Early Green parameter must exceed FDW time | **Passed** | **Passed** | **Passed** |

These notes/questions relate to the differences between the McCain Program 2033 User Manual and the McCain 2033RV/CF750 programming in QuicLoad. There are slight organizational differences between the manual and input interface and this write-up is intended to identify those differences for clarification with certain 2033 capabilities/functionalities.

**Bus Priority/Low Priority Preempt – TSP**

The QuicLoad input is shown below for Bus Priority Parameters:



Bus Headway Schedule, 0001

Next | Prev. | Save | Upload | Dnload | Toggle | Copy | Close

| | Time | Headway | Direction | DOW 1234567 |
|---|---|---|---|---|
| Event 0 | 00:00 | 0 | 0 | _______ |
| Event 1 | 00:00 | 0 | 0 | _______ |
| Event 2 | 00:00 | 0 | 0 | _______ |
| Event 3 | 00:00 | 0 | 0 | _______ |
| Event 4 | 00:00 | 0 | 0 | _______ |
| Event 5 | 00:00 | 0 | 0 | _______ |
| Event 6 | 00:00 | 0 | 0 | _______ |
| Event 7 | 00:00 | 0 | 0 | _______ |
| Event 8 | 00:00 | 0 | 0 | _______ |
| Event 9 | 00:00 | 0 | 0 | _______ |
| Event A | 00:00 | 0 | 0 | _______ |
| Event B | 00:00 | 0 | 0 | _______ |
| Event C | 00:00 | 0 | 0 | _______ |
| Event D | 00:00 | 0 | 0 | _______ |
| Event E | 00:00 | 0 | 0 | _______ |
| Event F | 00:00 | 0 | 0 | _______ |

Bus Approach

| | A | B | C | D |
|---|---|---|---|---|
| Travel Time | 0 | 0 | 0 | 0 |
| Passage | 10 | 0 | 0 | 0 |
| Extension | 10 | 0 | 0 | 0 |
| Phases: | _2___6__ | ________ | ________ | ________ |

Non-Priority Phase Maximums

| | A | B | C | D |
|---|---|---|---|---|
| Phase 1 | 20 | 0 | 0 | 0 |
| Phase 2 | 0 | 0 | 0 | 0 |
| Phase 3 | 20 | 0 | 0 | 0 |
| Phase 4 | 20 | 0 | 0 | 0 |
| Phase 5 | 20 | 0 | 0 | 0 |
| Phase 6 | 0 | 0 | 0 | 0 |
| Phase 7 | 20 | 0 | 0 | 0 |
| Phase 8 | 20 | 0 | 0 | 0 |

Compared to the <u>2033 manual</u> organization and nomenclature:

```
BUS PRIORITY TIMING

DIRECTION--->      A    B    C    D
Delay              0    0    0    0
Early Green        0    0    0    0
Green Extension    0    0    0    0
```

```
BUS PRIORITY PHASES

DIRECTION
    A    ........
    B    ........
    C    ........
    D    ........
```

```
BUS PRIORITY NON-PRIORITY PHASES MAX ADJ

PHASE---> 1    2    3    4    5    6    7    8
    A     0    0    0    0    0    0    0    0
    B     0    0    0    0    0    0    0    0
    C     0    0    0    0    0    0    0    0
    D     0    0    0    0    0    0    0    0
```

- *Travel Time* – Is this parameter related to "Delay" in the 2033 manual, where the priority phase is delayed before the extension is given?
- *Passage* – Is this parameter a unique green extension, or does this parameter equate to "Early Green" in the 2033 manual?
- *Extension* – Assumed to be "Green Extension" as described in the 2033 manual.
- *Phases* – Assumed to be the "Bus Priority Phases" in the 2033 manual. Is there the ability to implement the Solid or Pulsing input here? (EVP/TSP)? Is this simply done in the detector settings?
- *Non-Priority Phase Maximums* – Assumed to be the input to code early green by determining the maximum green time that can be taken from any particular phase. It is described in the 2033 manual as:

  "This adjustment is only applied during free operation."

  This suggests there is an ability to code for coordinated operation? How does coordinated operation get implemented and reflected in VISSIM?