NATIONAL INSTITUTE FOR CONGESTION REDUCTION

FINAL REPORT
12/31/2021

Supply-Side Management of Auto Traffic

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
Supply-Side Management of Auto Traffic	December 31st 2021
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Samira Ziyadidegan, David Florence P.E., and Srinivasa Sunkari, P.E., PMP	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Texas A&M Transportation Institute 1111 RELLIS Parkway, Suite 3342 Bryan, Texas 77807	11. Contract or Grant No. 69A3551947136, #79070-00-B
12. Sponsoring Organization Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation University Transportation Centers 1200 New Jersey Avenue, SE Washington, DC 20590 United States National Institute for Congestion Reduction 4202 E. Fowler Avenue Tampa, FL 33620-5375 United States	Final Report (9/1/2020 to 2/28/2022)
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Traffic congestion is challenging to resolve at closely spaced oversaturated intersections. This condition leads to underutilization of green time at upstream intersections due to queue spill back from downstream traffic signals (green starvation). The research team developed a microsimulation model near Texas A&M University campus to simulate a network of traffic signals which included a pair of closely spaced signals that experience the green starvation frequently. The research team investigated two treatments to alleviate this condition when a queue spillback was detected: one, a low-level preemption at one or both intersections and two, a preemption at one or both intersections to call the phases to meter or service the saturated link to clear the queues. The research team analyzed these treatments with various combinations using the simulation model. Based on the study, the research team recommends the scenario with a treatment at both closely spaced intersection with a 250 second reservice setting for preemption as the best alternative for addressing the queueing problem.

17. Key Words	18. Distribution Statement
Green starvation, Saturated intersections, VISSIM, Preemption, Priority	

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified.	Unclassified.	75	

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Executive Summary

Traffic congestion is especially challenging to resolve at closely spaced intersections with high demands from conflicting directions. This condition leads to large queue spillbacks and underutilization of green time since the road between the intersections does not have storage for vehicles that are serviced by the green indication. This report covers some literature on queue and gridlock management strategies and proposes a strategy that adaptively helps clear queues while maintaining a traditional coordination plan operating at the intersection. The research team developed a microsimulation model of an intersection pair close to the Texas A&M University campus where eastbound traffic and southbound traffic at one intersection experience the starvation of green condition described. These intersections were along George Bush Dr. at Olsen Blvd and Wellborn Rd. Increased service at these intersections would impact adjacent intersections, so the research team modeled intersections around the key intersections in the model to capture any adverse effects in the network. The simulation inputs came from data provided by the City of College Station and their automated traffic signal performance measure system. The research team also adjusted the parameters so that the baseline condition in the simulation produced an oversaturated condition at George Bush and Olsen. The simulation experiment involved 5 simulation runs of 4500 seconds (900 seconds of warm up period and 3600 seconds of analysis period) for each scenario involving different queueing management strategies.

The proposed treatment for the queueing problem involves using a low-level preemption at one or both intersections to either reduce the service or increase the service at George Bush and Olsen or George Bush and Wellborn, respectively. Treatment at George Bush and Olsen would use a preemption to call the phases that conflict with the link that is completely full to give the upstream intersection a chance to clear the queue. Alternatively, the treatment at George Bush and Wellborn used a preemption to call the phases to service the saturated link to clear the queue with priority. In each case the preemption utilized a detector to measure the occupancy at the downstream edge of the link and a delay for exiting the preemption call. Furthermore, the preemptions used settings so the signal could exit preemption directly back into coordination and a reservice setting so the preemption would not go right back into effect immediately if the detector occupancy calls a preemption soon after the treatment ends. The research team analyzed these treatments with various combinations using the simulation model. The team considered scenarios with treatments at the two intersections individually and with a treatment at both intersections at the same time. In addition, the team considered a short and long reservice time of 5 seconds or 250 seconds. These parameters generated six different treatment scenarios in addition to the baseline scenario.

The simulation experiment results indicate that the five second reservice option provides the most relief for the target movements at George Bush and Olsen, but the conditions for southbound traffic at George Bush and Wellborn and the intersection north of George Bush and Wellborn experience large increases in average queue lengths and delays. The 250 second reservice setting also increases delays at George Bush and Wellborn, but the increase is not at large and the intersection north of George Bush and Wellborn is not impacted by any of the 250 second reservice options. Treatment at George Bush and Olsen alone did reduce some delays but did not have much of an overall impact. Treatment at George Bush and Wellborn alone relieved the oversaturated eastbound direction the best since it could clear a queue that extended past the downstream intersection, but this treatment caused the largest

increases in queues for traffic along Wellborn Rd. Treatment at both intersections significantly relieved the traffic at George Bush and Olsen and did not cause as large of a negative effect on conflicting traffic, especially with the 250 second reservice setting. The research team analyzed the network wide total delays, including latent delay from vehicles that could not enter the oversaturated network. This analysis showed that the treatment at George Bush and Olsen alone had no real effect on the network delay with either reservice setting. The 250 second reservice setting did the best job reducing the network wide delays with a treatment at George Bush and Wellborn where the treatment at George Bush and Wellborn alone and both intersections experienced about the same amount of cumulative delays. Given that the treatment at both intersections did not impact the traffic along Wellborn Rd as much as the treatment at George Bush and Wellborn alone, the research team ultimately recommends the scenario with a treatment at both George Bush and Olsen and George Bush and Wellborn with a 250 second reservice setting as the best alternative for addressing the queueing problem analyzed in this experiment.

Introduction

Traffic congestion is a major issue in cities, particularly at closely spaced intersections. Traffic congestion increases delay, travel time, and reduces the level of service of a road. When traffic congestion causes queue spill-back between intersections, traffic cannot be completely clear during the green time. The green time is wasted because the arriving traffic does not have storage past the intersection. This issue is magnified when there are multiple approaches to the intersection with high demands.

The City of College Station, Texas has a corridor that suffers from this particular issue. George Bush Dr. goes along the south edge of the Texas A&M University campus. George Bush Dr, Olsen Blvd, and Wellborn Rd are three main roads in the area and they each intersect George Bush Dr. close together, shown in Figure 1. This area suffers from the traffic congestion and queue spill-back during the PM peak period when the classes are over, and students and staff are going to their homes from the university campus.

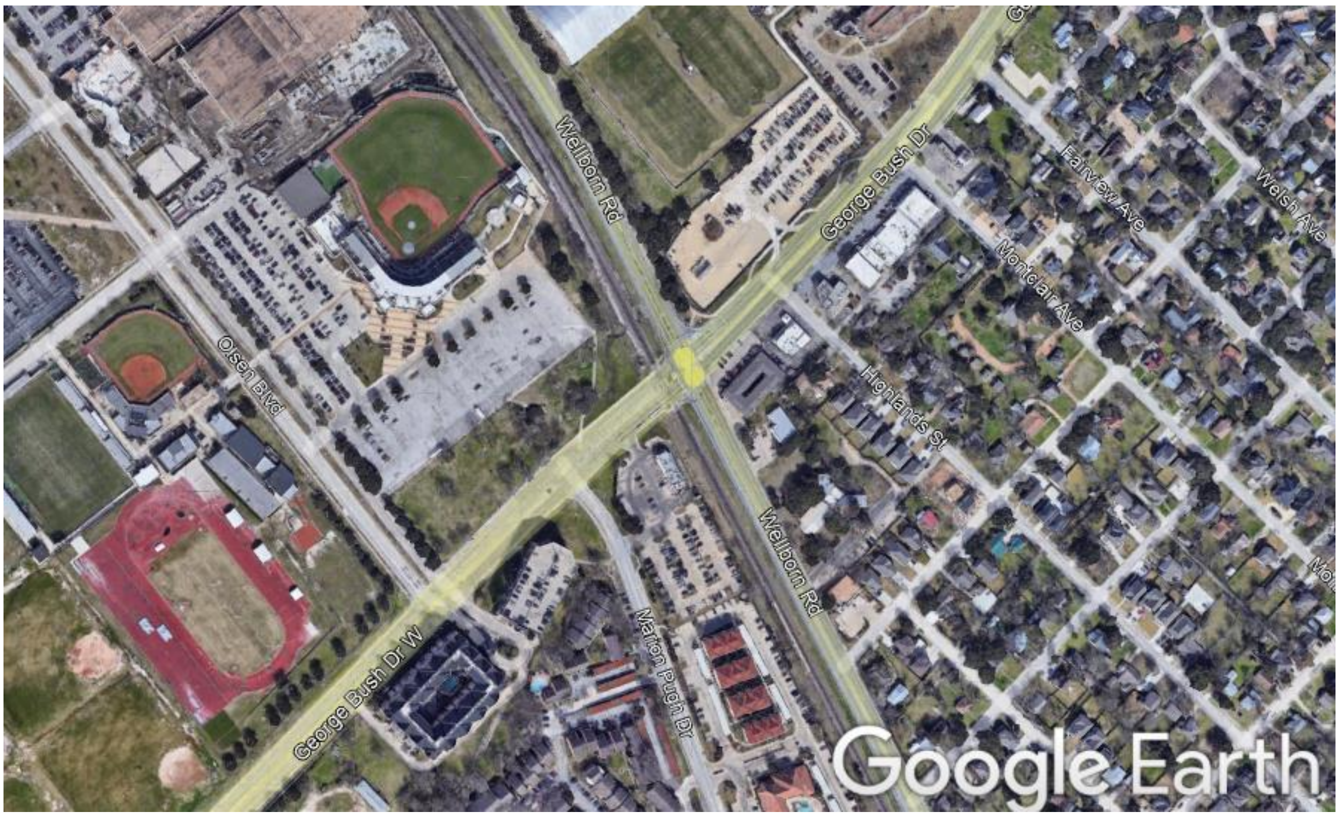


Figure 1. Map of George Bush Dr. and Wellborn Rd. Area in College Station, TX (Source Google Earth)

In this report, the research team analyzes the queueing problems faced by closely spaced intersections using simulation and advanced traffic control strategies. The team first constructs a simulation network including the mentioned three main roads and five main intersections (introduced later in this study) using the real volume data, geometric information, and signal timing data. Next, the team implements a metering strategy with several scenarios to test the efficiency of each of them in reducing the delay and queue length. A sensitivity analysis on each scenario is also performed.

Background

Solutions to traffic congestion issue include enhancing the supply by widening the roads or constructing new ones, which would help to increase the capacity. However, higher capacity is known to increase the demand on roads approaching intersections and cause queues and bottlenecks. When demand is larger than the intersection capacity, queues cannot completely clear in the allotted green time, generating an oversaturated condition at the signal. The resulting queue can spill back and block the downstream intersection, especially between closely spaced intersections. Some traffic control systems are designed to resolve those issues and to manage the queues and gridlocks and are documented in this section.

In case of having stable conditions, fixed time or pre-timed signalized intersections are designed based on the prevalent demand of the network to decrease the traffic issues at intersections. However, if an unexpected high demand event occurs within the area, the demand in different intersection approaches changes such that the discharge would not be compatible with the pre-timed signalization design. Hence, an actuated signalization is proposed to consider the dynamic demand of the intersection based on the real volume data of each approach (Araghi et al., 2015).

Actuated traffic signal control (Koonce et al., 2010) uses real-time data to control each phase timing. Based on real-time demand driven from detector actuations, phases are called or extended. Actuated traffic signal can be divided into semi-actuated and fully actuated depending on the number of traffic movements being instrumented with detectors.

In a network with closely-spaced intersections, if the downstream light is red, and there is a queue behind the stop line, a string of vehicles crossing the upstream intersection might encounter extra delay and a longer queue at the downstream intersection (Z. Zhang & Tian, 2013). In such network, coordinated actuated traffic signal control is a viable choice for traffic control, as well as queue and gridlock management. In a coordinated signal control, closely spaced intersections are synchronized and coordinated to enhance mobility by reducing the delay. In coordination, a string of vehicles which passes one intersection can pass through multiple succeeding signalized intersections without being stopped (encountered with green phase at all intersections). This is achieved by the timing offsets between intersections which are based on progression speed and expected queues. Several studies used optimization methods to optimize the parameters of coordinated actuated traffic signal control (B. (Brian) Park et al., 2006; B. B. Park & Schneeberger, 2002; Byungkyu Park et al., 2001; Yun & Park, 2012). However, coordinated actuated control does not address large queueing in two directions and it can only allot a longer amount of green time to a phase, which does not ensure storage for that traffic upstream of the intersection.

Factors such as weather, accidents, seasons, or unpredictable occurrences might also affect the demand and intersection discharge unexpectedly, and form queues and gridlocks. To take these elements into account, adaptive traffic control systems have been introduced to monitor the real-time demand and the mentioned elements continuously to adjust the signalization timing (Araghi et al., 2015).

It should be noted that actuated signalization and adaptive traffic control system are not exactly the same. In actuated traffic signalization, the real and updated volume data is used to update the signal phases. However, in a traffic-adaptive control system, a parameterized function is used to design an intersection's signals. In this method, the continuous data is used to not only update the signal timing design, but also to change the parameters of the function and the internal logic behind the signalization design (Araghi et al., 2015).

Artificial intelligence is a method that can be used to optimize the parameters of traffic control systems to address unpredictable traffic condition issues. The artificial intelligence methods can be divided into "Reinforcement learning," "Neural Network," "Fuzzy Logic Systems," and "Self-organizing." Literature showed that artificial intelligent methods have higher performance compared to the traditional controlling methods (Araghi et al., 2015).

In the following, the previous studies on the queue management and gridlock phenomena are discussed; some studies used traditional controlling methods, while others utilized artificial intelligence methods.

Queue Management

Traditional Methods

Michalopoulos and Stephanopoulos (Michalopoulos & Stephanopoulos, 1977) studied a control strategy using state variable constraints to minimize intersection delay considering queue length constraints, travel time between intersections, and turning movements. Regarding the queue constraints, the signal would be switched as soon as the queues are at their limits to balance the input and output flows. If only one queue length constraint is imposed, the cycle length would not be changed. However, in the case of imposing the length limits in more than one queue, the cycle length is free to vary.

Abu-Lebdeh and Benekohal (G. Abu-Lebdeh & Benekohal, 2000; Ghassan Abu-Lebdeh & Benekohal, 1997) developed a dynamic traffic signal control procedure which produced real-time signal timing that managed queue formation and dissipation dynamically for oversaturated arterials. In this method, offsets and green times were changed dynamically as a function of queue lengths and demand.

Li (Z. Li, 2011) suggested an arterial signal optimization model which considered queue blockage under oversaturated conditions. The model could capture the traffic dynamics using the cell transmission concept and could yield an effective signal plan using the embedded formulation for forward wave, backward wave, and horizontal queue. Results showed the better performance of the suggested method compared to signal plans from TRANSYT-7F.

Hajbabaie and Benekohal (Hajbabaie & Benekohal, 2013) developed a methodology to select the appropriate objective function for signal timing optimization. Five candidates for the objective functions used were minimizing delay, minimizing travel time, maximizing throughput-minus-queue, maximizing number of completed trips, and maximizing weighted number of completed trips. Results revealed that weighted trip maximization is the best one and throughput-minus-queue and trip maximizing were the second suitable objectives in oversaturated conditions.

Xin et al. (Xin et al., 2010) developed a new integrated adaptive signal control decision support system (ACDSS). The results showed that using the proposed model would make the queue distribution more balanced.

Girianna and Benekohal (Girianna & Benekohal, 2002) proposed dynamic signal coordination models for oversaturated transportation networks. The model objectives were maximizing the total number of vehicles released by the network and minimizing the queue accumulation along the arterials. Using a genetic algorithm, results revealed that this model could manage queues along the coordinated network.

Hajbabaie and Benekohal (Hajbabaie et al., 2011) evaluated three methods to optimize the signal timing for two different networks: Genetic Algorithm, Evolution Strategies, and Approximated Dynamic Programming. Queue management was evaluated using a series of MOPs which accounted for the probability of upstream queue overflows and the efficient utilization of green time simultaneously. Results showed that to get the best performance in oversaturated conditions, the green utilization efficiency for protected movements should be close to saturation headway (1.9 seconds).

Ezzat et al. (Ezzat et al., 2014) formulated an objective function representing the traffic control stochastic environment, including vehicular waiting time and queue length. Optimizing the model using a Genetic Algorithm showed a significant enhancement in traffic performance.

Park, Messer, and Urbanik (B. Park et al., 2000) suggested an enhanced Genetic Algorithm-based program to optimize traffic signals in oversaturated conditions. Three criteria include throughput maximization, average delay minimization, and modified average delay minimization. Results revealed that average delay minimization had better performance in designing the signal plan in terms of queue time.

Nguyen (Nguyen, 2019) developed a multi-objective optimization problem for signal control considering throughput maximization and queue minimization for oversaturated condition, and resolved it by NSGA-II algorithm.

Abu-Lebdeh and Benekohal (Ghassan Abu-Lebdeh & Benekohal, 2003) combined a dynamic control algorithm and a disutility function to design and analyze the traffic in oversaturated conditions. A dynamic algorithm was proposed to manage queue formation and dissipation considering current and future queue length and demands. The disutility function measured the relative performance of the dynamic control system based on the current performance goals. Four traffic management strategies were evaluated (e.g., the first strategy is to ensure gridlock does not occur). Results revealed that the generated signal control schemes were agreeable to satisfy the desired management goals.

Longley (Longley, 1968) proposed a traffic control strategy which adjusted the green phases in each intersection's leg based on the queue length ratios. This approach could respond to factors (e.g., breakdown) which could affect saturation flow rates. Since the signal design was based on the queue ratios, if disturbances occurred in any leg, it would add an extra queue in that leg, and increase the queue that would be shared with other legs, and so, postpone interference with other intersections in that network.

Rathi (Rathi, 1988) has developed a control traffic scheme based on spillback avoidance instead of a progressive movement approach. Using this approach, in minor approaches, a backward progression is demonstrated by signal offsets. A simulation was performed using Netsim. Results showed a reduction in the number and duration of spillback blockages.

Artificial Intelligence

Araghi et al. (Araghi et al., 2015) used neural network (NN), fuzzy logic controller (FLC), Q-learning and fixed time methods to optimize the signal timing of an isolated intersection using PARAMICS. Using the NN or FLC, the queue lengths were fed to the NN or FLC. Suggested green times were generated and given to PARAMICS. A simulation is run, and the total average delay is determined to be used in the optimization function. Considering the optimization function and Genetic algorithm (GA), new NN or FLC parameters are generated. This would be repeated until the stopping criteria are reached (Figure 1). For Q-learning method, the states are formed from the average queue length on each lane of each intersection approach. The actions are set to be a combination of green phase timing. The reward was the total average delay. In this study, two scenarios of peak and off-peak hours (five hours of simulation with 3000 vs. 5500 vehicles, respectively) are analyzed. Results indicated that all three approaches outperform fixed-time controller; Q-learning has 66%, NN has 71%, and FLC has 74% higher performance.

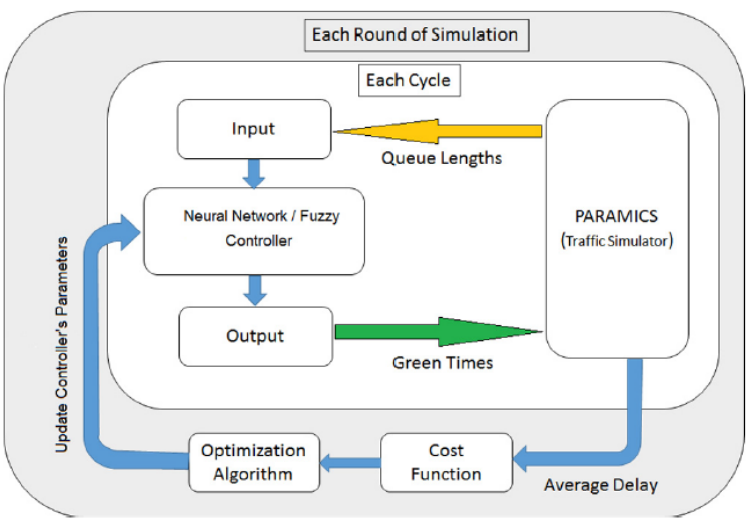


Figure 2 Neural Network and Fuzzy Logic Controller approach (Araghi et al., 2015)

Cesme and Furth (Cesme & Furth, 2013) proposed a self-organizing signal control and developed several rules, including green hold for intersection spillback, and early green and double realization for left turn phases prone to pocket spillback. They also developed dynamic coordination for multiple intersections, which are spaced closely together and allowing temporary spillback and starvation at upstream and downstream intersections respectively. Cesme and Furth (Cesme & Furth, 2014) have introduced a new rule (secondary green extension) to their previous study, and suggested a transit signal priority with self-organizing control. Day and Bullock (Day & Bullock, 2017) investigated the self-organizing control performance using graphical signal performance. Simulations results for (Cesme & Furth, 2013, 2014; Day & Bullock, 2017) show a better performance of self-organizing signal control over actuated and coordinated signal traffic control in terms of vehicular and pedestrian delay.

Bi et al. (Bi et al., 2014) utilized a multi-agent type-2 FLC for a multi-intersection network. They used differential evolution to optimize the fuzzy logic control parameters. Their study showed that this method would enhance the intersection throughput and decrease the delay and queue length. Zhang et al. (W. Zhang et al., 2008) have suggested an approach using a two-layer fuzzy control algorithm for an oversaturated intersection which decides whether to terminate or extend the current green time.

Wunderlich et al. (Wunderlich et al., 2008) proposed Longest Queue First Maximal Weight Matching (LQF-MWM) algorithm. This proposed approach uses a maximum weight matching framework drawn from the data packet switching field to minimize the queue size on each intersection approach. (Wunderlich et al., 2008). The study aimed to maximize the intersection throughput and maximize the delay. Arel et al. (Arel et al., 2010) applied the LQF to a multi-intersection network. They introduced an innovative application of a multi-agent system and reinforcement Q-learning framework by employing a central agent and an outbound agent. States were defined as the relative traffic flow of all lanes. Actions were the combination of all phases. The reward was a value between -1 and +1 determined based on the differences between the current delay and the delay of the previous time step. Results showed that the suggested model (using the LQF considering a multi-agent Q-learning approach) outperformed the basic LQF algorithm (considers isolated single intersection) in terms of average time delay and cross-blocking (the total time units imposed on vehicles when they cannot cross the intersection during the green phase due to a blockage in their desired lane, divided by 20 times units).

Abdulhai et al. (Abdulhai et al., 2003) performed an experiment using Q-learning as a traffic controller on an isolated intersection. States were the length of queues on intersection approaches and the elapsed phase time. The action was set to whether extending or changing the current signal light. The reward was defined in the concept of total delay in the queue formed behind each stop line (penalty). In this study, a power function was introduced to modify the reward proportional to the queue length to balance the queue sizes. To extend the suggested approach to be applied on a multi-intersections network, new states such as the split between two intersections can be added, and for the reward, the weighted value can be used. The result showed that for a single intersection, Q-learning has better performance than a pre-timed controller for variable traffic flows. In the case of uniform flows, Q-learning is slightly better or is equal to the pre-timed controller.

Prashanth and Bhatnager (Prashanth & Bhatnagar, 2011) suggested a feature-based reinforcement learning algorithm for signal timing design appropriate for multi-intersection network. Although accurate elapsed time and queue length information were needed in the methods suggested by Abdulhai et al. (Abdulhai et al., 2003), in this study, they divided the queue length into three groups of low, medium, and high, and for elapsed time, they defined a threshold and determine if the elapsed time is less or higher than the threshold. Results showed that the suggested approach outperformed fixed-time method, longest queue method (switching the signal light to green for the lanes with longest queue length), and the method suggested by Abdulhai et al. (Abdulhai et al., 2003).

Gridlock

Kerner (Kerner, 2011) studied the gridlock occurrence in an urban area using the simulation of two-phase and three-phase traffic flow models. He mentioned that a queue formed during the red light should be served and fully cleaned during the next green light (under small link inflow rates). Hence, no gridlock would be expected. However, due to a random time delay, spontaneous breakdown with gridlock might be occurred. The reason for most cases is the changeover from free flow to synchronized flow. Results showed that the probability of gridlock occurrences positively correlated with link inflow rate and the red-light duration.

Daganzo (Daganzo, 2007) proposed dynamic aggregate models of the gridlock phenomenon at single and interconnected neighborhoods. The model only needs observable inputs; so, it can be applied to an instrumented neighborhood which can obtain real-time data. Hence, the model can be used for an adaptive traffic control system.

Mahmassani et al. (Mahmassani et al., 2013) studied the characteristics of gridlock and its dynamics under heavily congested conditions. They proposed a model to reproduce gridlock and hysteresis when there is heterogeneity and non-steady-state conditions. They evaluated the occurrence of gridlock in different configurations of the congested links' dynamic arrangements. The study revealed that gridlock size, propagation speed, and recovery speed are affected by demand management and adaptive driving. The results of this study can help in developing dynamic control systems and in reducing traffic congestion.

Li and Zhao (N. Li & Zhao, 2016) proposed a model to characterize the risk of gridlock to be used in measuring the spillover probability under different traffic conditions. The gridlock risk and the traffic randomness are incorporated in the control algorithm within a decentralized agent-based framework to minimize the average waiting time. The proposed control algorithm can be used for an early detection of the gridlock.

Daganzo 2005 (Daganzo, 2005) defined gridlocks and demonstrated that this phenomena can be modeled, monitored, and controlled with parsimonious models which do not depend on detailed forecasts in large urban mobility. He developed a macroscopic fundamental diagram (MFD) in case the neighborhood is congested uniformly, and all links are loaded similarly. The suggested model should be more effective in case of having real-time observations of needed spatially aggregated traffic performance features. The suggested model is tested and verified in the study conducted by Daganzo and Geroliminis (Daganzo & Geroliminis, 2008).

Lo 1999 (Lo, 1999) applied a mixed integer programming technique to develop an innovative traffic signal control formulation which considers dynamic traffic. For unsaturated traffic conditions, a plan with progressive green time is produced. For gridlock conditions, the formulation can untie it without needing to tune the model or switch the model for gridlock conditions.

Huang (Huang, 2015) proposed a cellular automation model to study different traffic states around a roundabout. Four different phases, including free flow, congestion, bottleneck, and gridlock, and some transitions between these phases were analyzed. Their studies showed that since the traffic interweave causes the bottleneck and gridlock, their suggested model can use a parameter to characterize them well.

The research project covered in this report aims to provide a queue management strategy that will complement an existing transportation system running a traditional actuated coordinated control strategy.

Network Construction and Data Preparation

The research team generated a VISSIM model of the area around George Bush Dr from Olsen Blvd to Wellborn Rd. The evaluation network consists of six intersections in College Station, TX. Five intersections are signalized, and one is one-way stop controlled, as shown in Figure 3. The network has volumes that generate a queueing issue on George Bush Dr. between Olsen Blvd. and Wellborn Rd. The network includes Joe Route Blvd, Houston, and Holleman Dr, so the research team can analyze the impacts of the queue management strategy on other intersections in the network. This will help the research team quantify any negative impacts on these intersections because of the queue management strategies analyzed between Olsen and Wellborn. The goal of the considered queue management strategies is to relieve the queueing on George Bush Dr. between Olsen and Wellborn, without greatly impacting operations at the other intersections in the network. Overall, this simulation study aims to quantify the impacts of several queue management strategies that cause reduced network-wide delay.

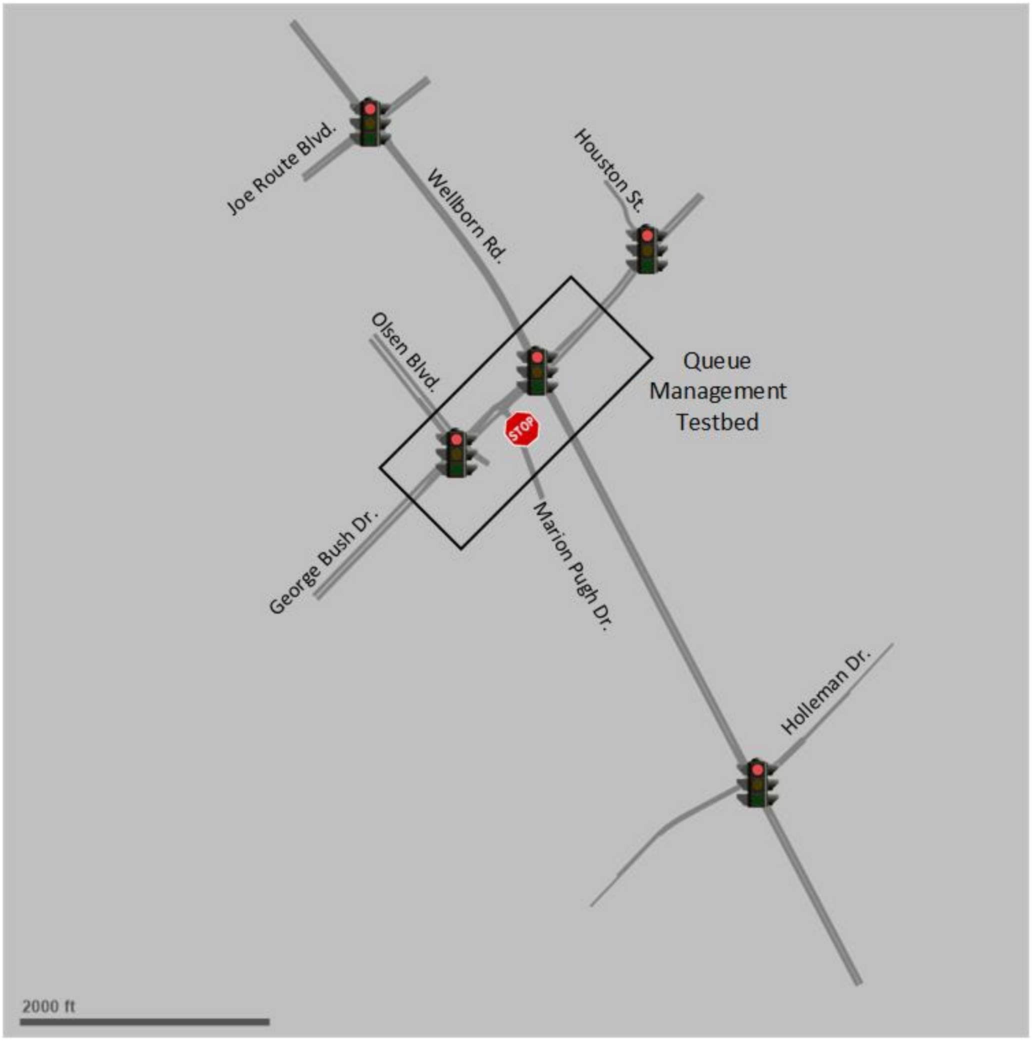


Figure 3. VISSIM Testbed for Queue Control Strategy

Network Components

The studied network is an area including all the following Intersections:

1. George Bush – Olsen (GBO)
2. George Bush – Marion Pugh Dr.
3. George Bush – Wellborn (WGB)
4. George Bush – Houston (GBH)
5. Wellborn – Joe Routt (WJ)
6. Wellborn – Holleman (WHO)

Volume Preparation

To extract the volume and turning movements for each intersection, the research team extracted Excel files from the city's automated traffic signal performance measure system. The team extracted volume data for Tuesday, April 13, 2021, to use as volume input into the mode. In each excel file (which is given for each intersection), turning movements for each 15-minute interval are given. Multiplying them by four, the hourly volume could be determined.

Peak period determination

To determine the peak period, consecutive 15-minute volumes are aggregated over each one-hour period for all intersections. We then determined the peak periods considering the peak hour factors. For more information, see Appendix B.

Relative Traffic Flow

Based on the values of the turning movements presented in the excel files and for PM and AM peak separately, relative traffic flow for each static vehicle route is defined. To calculate each relative flow rate, the volume of each movement is divided into the total volume of the static vehicle route. For more information, please see Appendix B.

One limitation of VISSIM in congested networks is strange behavior at intersections with significant queueing. In some cases, vehicles will fail to change lanes before the queue and block a lane to wait to merge into the queue in an unrealistic way. To mitigate this unusual behavior the research team identified movements with unusual behavior by observing the animation. The close proximity of Olsen Blvd. and Wellborn Rd along George Bush Dr. lead to the research team combining the routing decisions for these intersections to effectively give the vehicle additional distance to change lanes for their respective route. This makes one routing decision cover all the turning movements for two intersections for the closely spaced intersections. Intersections with more space allow for more realistic lane change behavior with the traditional routing decisions. In addition, the team adjusted the "lane change distance" from the default values of 656.2 feet (200 meters) to much large values of 1500 feet (457.2 meters) or 2000 feet (609.6 meters) per lane. The last strategy the research team imposed to reduce unrealistic lane changes is enabling cooperative lane changes. This setting essentially increases the propensity for vehicle to adjust their speed or remain stopped for another vehicle to merge.

Volume Adjustment

Turning movements provided in the Excel files are the number of vehicles which could finish the movement. However, due to the traffic congestion in the network and vehicle queue, some vehicles could not finish their movements or even enter the network. So, the real demand is higher than the numbers mentioned in the Excel files. The team imports current turning movement volumes to VISSIM and used the VISSIM animation to adjust the volumes. Based on the animation and results, we decided to increase some "Input Volumes", which are as follows:

- Marion Pugh Dr. northbound
- Olsen Blvd. southbound
- George Bush Dr. eastbound

- George Bush Dr. westbound
- Wellborn Rd northbound
- Wellborn Rd southbound
- Joe Routt Blvd. westbound
- Jim Kimbrough Blvd eastbound
- Holleman Dr. eastbound
- Holleman Dr. westbound
- Houston St southbound

Network Construction

The analyst coded all intersections' signal timing parameters into the network based on data provided from the City of College Station on the signal timing operations at these intersections. The simulation model utilized the Econolite ASC/3 software in the loop API as the signal controller used for all the signalized intersections. The VISSIM model included conflict areas, and priority rules defined specifically to model the gaps drivers will leave to avoid blocking an intersection or to allow traffic on the cross street to turn out onto the main street. The research team watched the animation to ensure that the logic to avoid collisions and model yielding behavior of a turning movement where the main street has the right of way but will stop with enough space for vehicles on the cross street to turn in front of them functioned without collisions. The simulation period is defined as 4500 seconds, and the first 900 seconds are defined as the warm-up period. The number of runs is defined to be 5.

Methodology

This section outlines the control strategies analyzed in the simulation experiment.

Proposed Queue Management Strategy

To overcome the current network's issues, a metering strategy with different scenarios is defined to see how much each scenario can relieve the traffic congestion and manage the queue spillback. The control strategy analyzed in this project utilized a low-level preemption called by detectors placed in the model at key locations to indicate long queues. The detector occupancy indicates the current queue length on the key approach and is tied to a preempt for key phases. The preempt can be placed upstream or downstream of the queue location, or both. The typical preempt settings are shown in Figure 4. The preemption will call key phases to either meter traffic or increase service to the queued movements. The preemption uses an extension to ensure that the detector occupancy is below the threshold occupancy for some time before ending the preemption. The dwell phases are given the same clearance values as the phases have in the timing plans. There are two additional key parameters to this queue management strategy: the exit option and the reservice value. The exit option determines how the controller status will return to normal operations after the preemption ends. Since the testbed operates a coordination plan during the analysis period, the exit option is set to "CRD" which means that the controller will return directly to the coordination plan when the preemption is complete. No transition period is necessary. The reservice value helps ensure that the preemption is treated as a low value preemption. The reservice value is the number of seconds that must pass between preemption calls. A value of zero, as in the figure, means that preemptions can occur back-to-back without any time in between. A value of 5 means that 5 seconds must pass between preemptions.

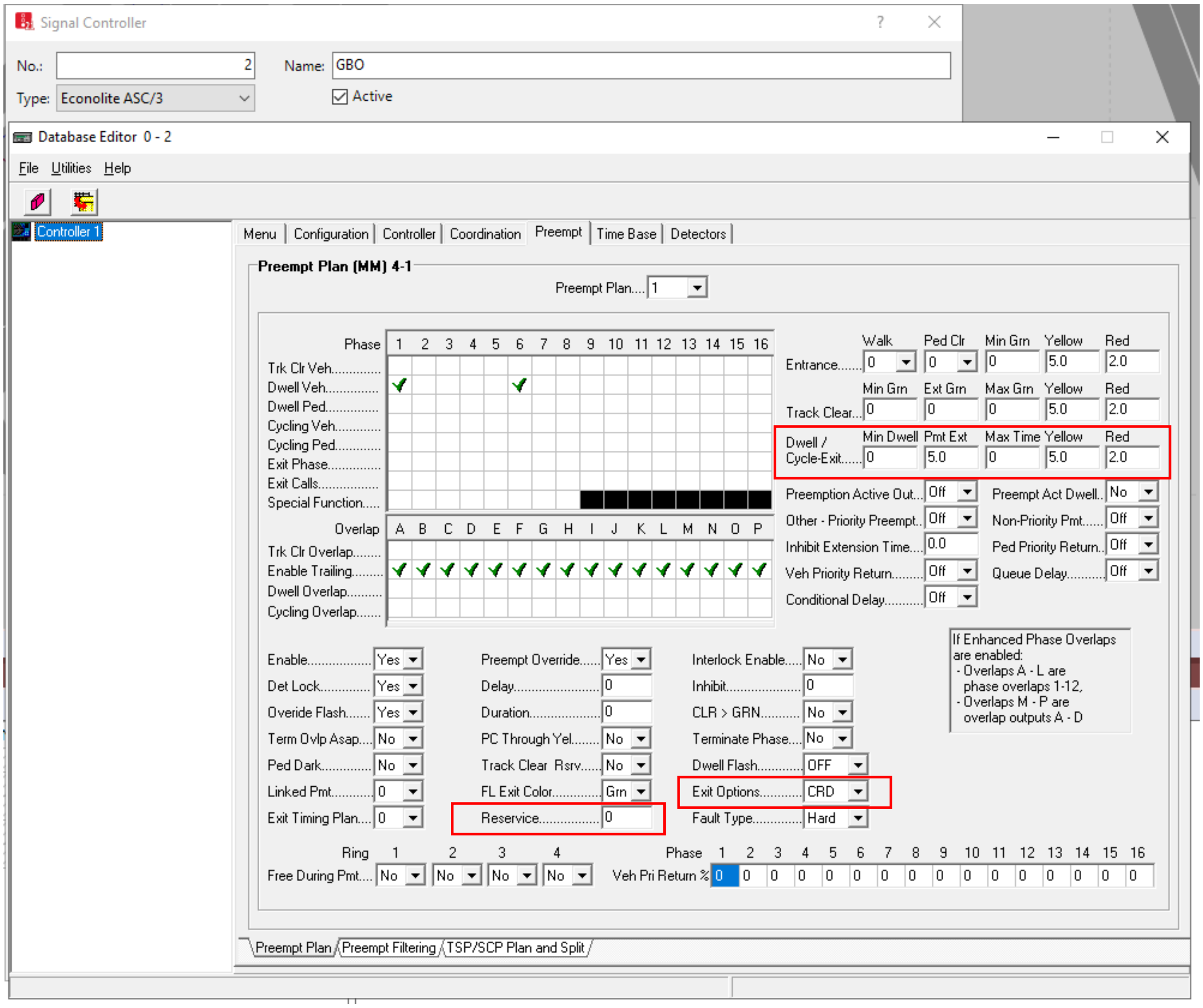


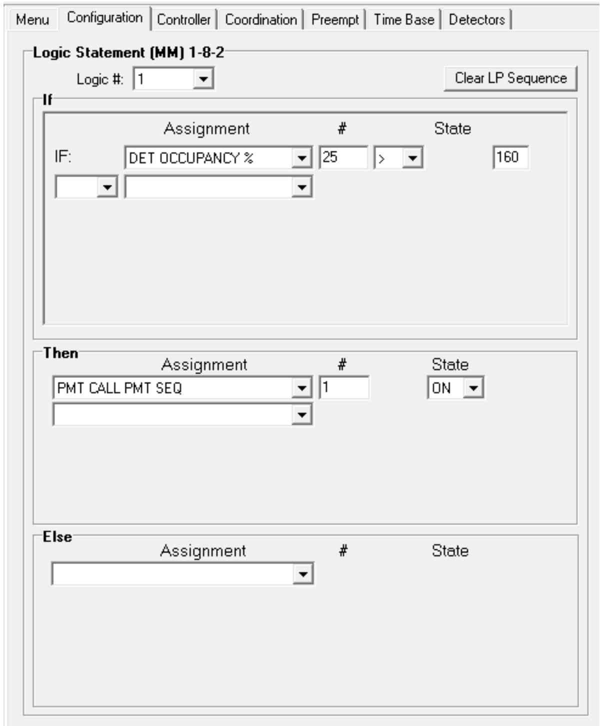
Figure 4. Queue Management Preemption Settings

The research team coded all the scenarios in VISSIM and strategies into the ASC/3 controllers using the preemption and the logic rules. To call the preemptions, the logical processor and two sets of detectors are defined (Detectors Channel 25) for George Bush Dr – Olsen Blvd southbound left turn movement and George Bush Dr – Wellborn Rd eastbound through movement, see Figure 5 (a) and (b), respectively. The analyst used a detector occupancy threshold of 80 percent over 5 seconds for detector channel 25 as the threshold for calling the preemption. Note the channel number used to call the detection is arbitrary and could be any channel value available in the controller. Another relevant note is that the logic rule under the tab of the “Logic Statement MM (1-8-2)” received the desired detector occupancy for the statement in 0.5 percent values, meaning that a value of 1 corresponds to a detector occupancy of 0.5% and 160 corresponds to a detector occupancy of 80%. The controller will call the preempt number according to the “PMT CALL PMT SEQ” assignment value.

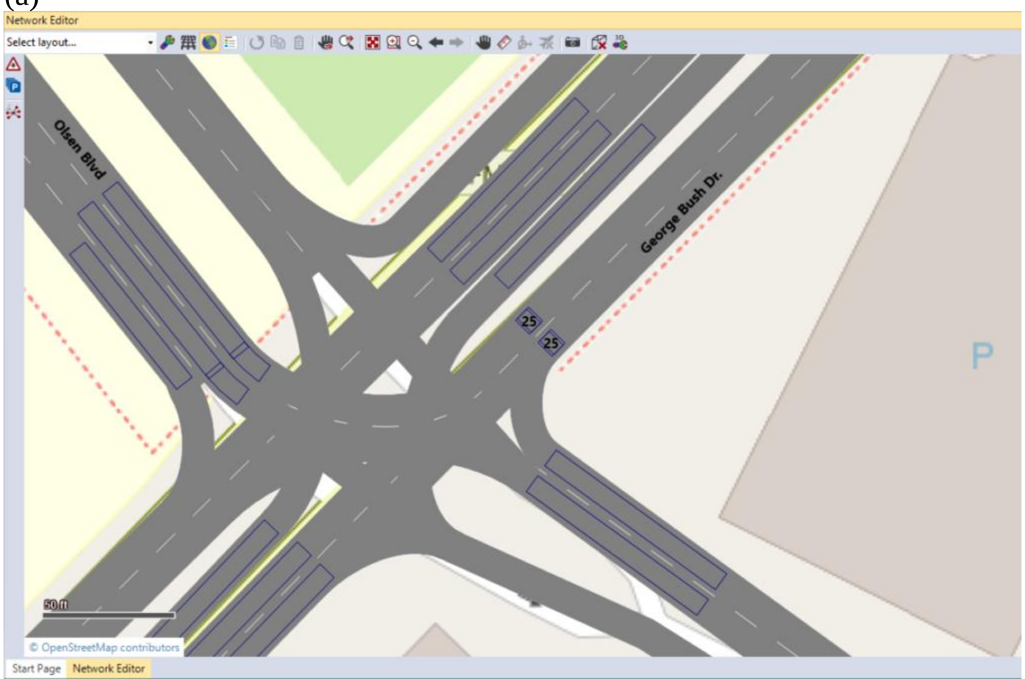
The preemption could be placed for each approach separately (GBO treatment and WGB treatment) or for both approaches at the same time (GBO and WGB treatment). The GBO treatment calls the through and left turn phase opposite to the queue to cut off the demand to the link with the queue. The WGB treatment calls the phases that service the queue to flush the queue. A sensitivity analysis is also done on the preemption reservice value (5 seconds versus 250 seconds). Total scenarios studied are as follows:

1. Baseline Scenario
2. GBO Treatment, 5-second reservice
3. GBO Treatment, 250-second reservice
4. WGB Treatment, 5-second reservice
5. WGB Treatment, 250-second reservice
6. GBO & WGB Treatment, 5-second reservice
7. GBO & WGB Treatment, 250-second reservice

All these scenarios are run in VISSIM in the duration of one hour with 15 minutes warm-up period (totally, 4500 seconds). Furthermore, five nodes are defined in the network (one for each intersection), and four delay measurements are defined for the Wellborn Rd. southbound approach, Wellborn Rd. northbound approach, George Bush Dr. eastbound approach, and George Bush Dr. westbound approach. All the Delay, vehicle network performance, and node results (for one hour of the simulation, from the time of 900 seconds to 4500 seconds) are extracted and evaluated to find which scenario would resolve the issue better.



(a)



(b)

Figure 5 (a) the logic statement used in VISSIM; (b) the location of detector #25

VISSIM Signal Controller Detector Record Analysis

This section describes steps to analyze the modified detector record generated from VISSIM based on the Econolite ASC/3 software controllers. VISSIM allows the user to customize the contents of the detector record based on inputs from the controller. The simulation software uses some conventions to report the data describing the controller, such as special characters to represent different phases and detector statuses such as a period, ".", to represent a red status for a phase. The research team developed a script to convert this data into a more readable format based on the guidance provided by VISSIM. Unfortunately, the guidance from VISSIM on this data output is incomplete. The research team did not find any information on how to understand some key metrics such as "coordination status" or "holds." To understand these fields, an analyst identified time in the simulation where key transitions were made in coordination status and watched the animation in the simulation, especially the status menu of the Econolite controller. For example, the analyst identified a point where the coordination strategy transitioned from "0" to "1" and watched the status menu on the Econolite ASC/3 software controller screen, shown below.

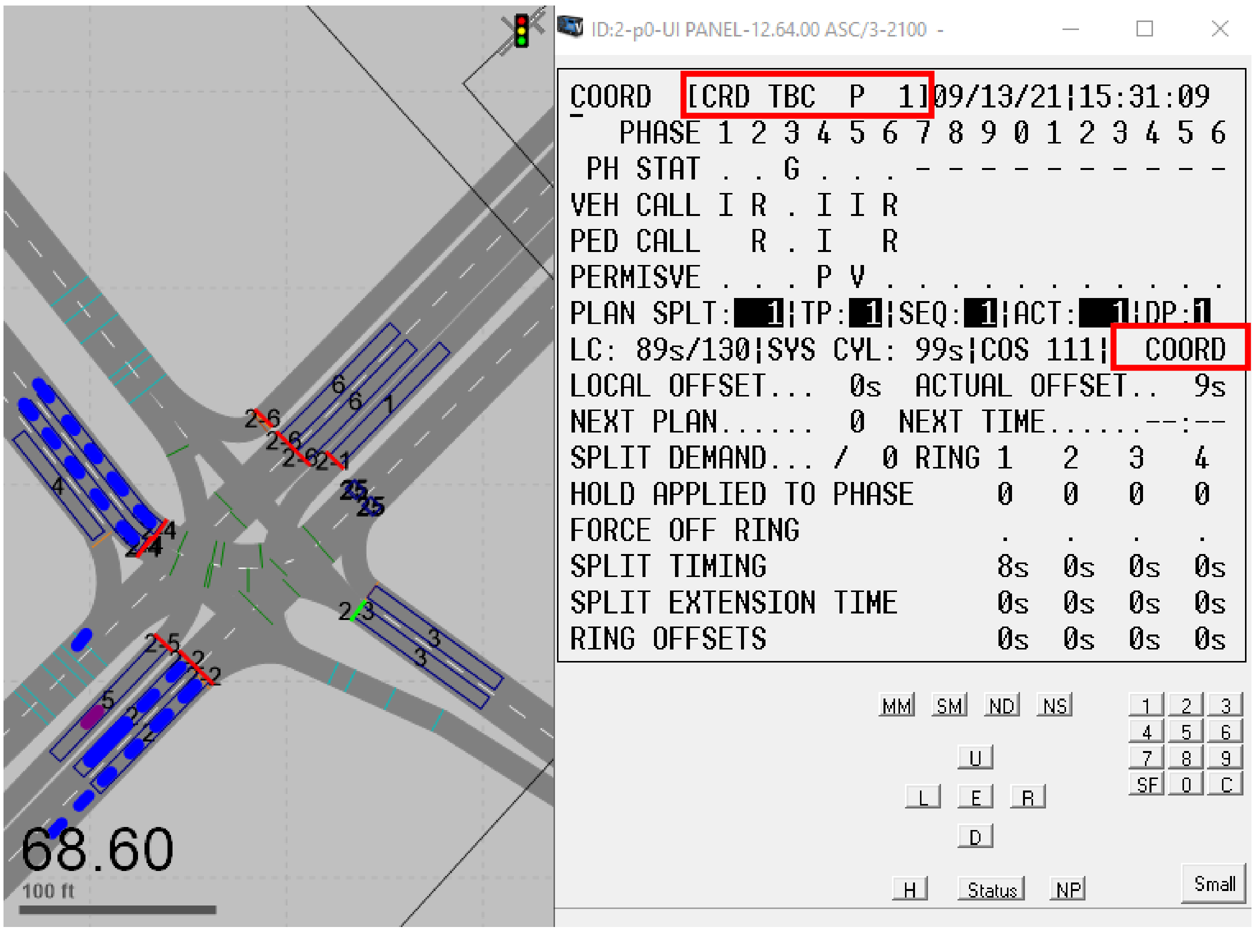


Figure 6. Screenshot of the ASC/3 software controller and the corresponding intersection in simulation

The status messages in the red boxes in the figure highlight two key messages used to understand the coordination status of the intersection. This is a case where the detector record reported a status of "1". The research team identified that this message means the controller is in coordination. The other status message meanings identified are listed below.

Table 1 Detector Status Clarification

Value Found in VISSIM Detector Record	Corresponding Status Message	Meaning
0	FREE	The controller is operating in a fully actuated fashion, usually meaning the metering technique is active
1	COORD	The intersection is in coordination according to the active plan
4	DWELL	The controller is using the “dwell” transition technique to adjust the coordination offset
5	SYNC	Sync Pulse according to ASC/3 Controller Menu. Checking the clock synchronization
6	PICKUP	Pickup mode according to ASC/3 Controller Menu. Startup mode.

The team used this detector record information to help generate performance metrics on the number of times the controller changed from normal operations to the queue flushing technique used in this experiment.

Results

In this section, we import the figures to show the results for all the scenarios we have considered and to compare them with the baseline scenario (in each figure, the red bar is the baseline scenario. Check the legend for more information). Moreover, to evaluate the results for the sensitivity analysis for each category of the results, two figures are provided (reservice: 5 seconds versus reservice: 250 seconds).

Figure 7 to Figure 14 shows the results for delay measurement results and for both preemption reservice time values (5 seconds versus 250 seconds). In these figures, the average delay and total number of vehicles for each delay measurement are presented which are including: George Bush Dr westbound, George Bush Dr eastbound, Wellborn Rd northbound, Wellborn Rd southbound. In each figure, the effects of each treatment on the measurements are compared to the baseline scenario.

Figure 7 and Figure 8 show the delay results for the George Bush Dr eastbound approach. Based on the results, WGB treatment and GBO & WGB treatment reduce the delay significantly, particularly for 5-second reservice scenario. Applying these scenarios, total number of vehicles in George Bush Dr eastbound approach increases.

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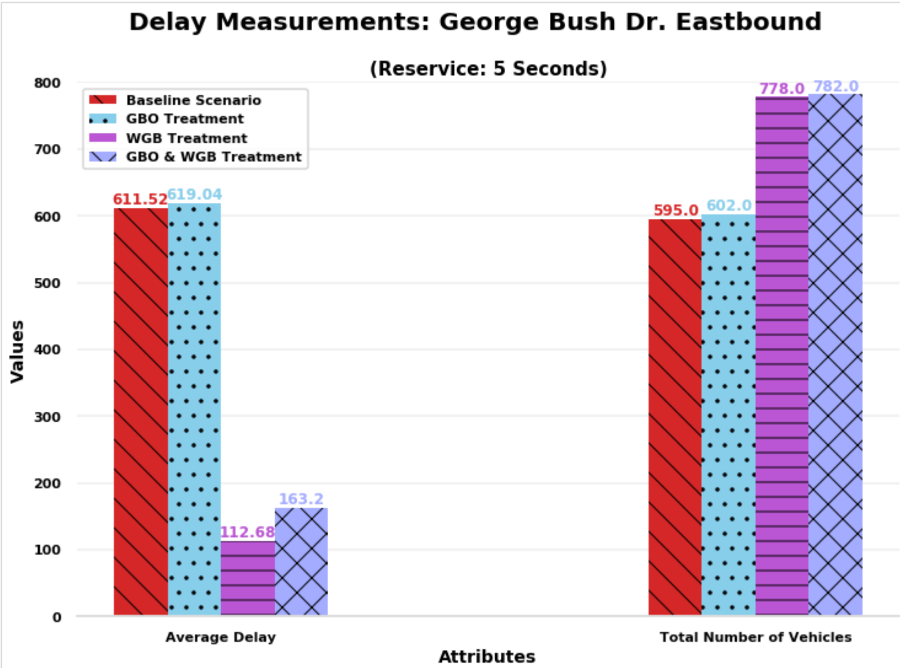

Figure 7. Eastbound Route Delay Along George Bush Dr.5-Second Reservice Settings for Metering

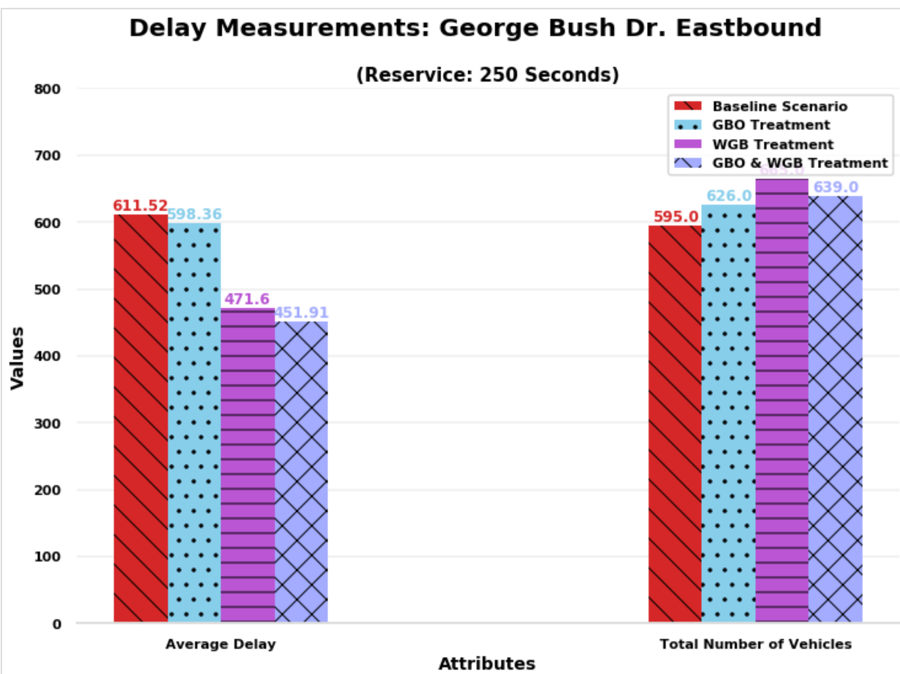

Figure 8. Eastbound Route Delay Along George Bush Dr. 250-Second Reservice for Metering

Figure 9 and Figure 10 present the delay results for George Bush Dr westbound. As it can be seen, the treatments do not affect the results meaningfully. GBO treatment in 5-second reservice scenario has better results compared to the other treatments and scenarios.

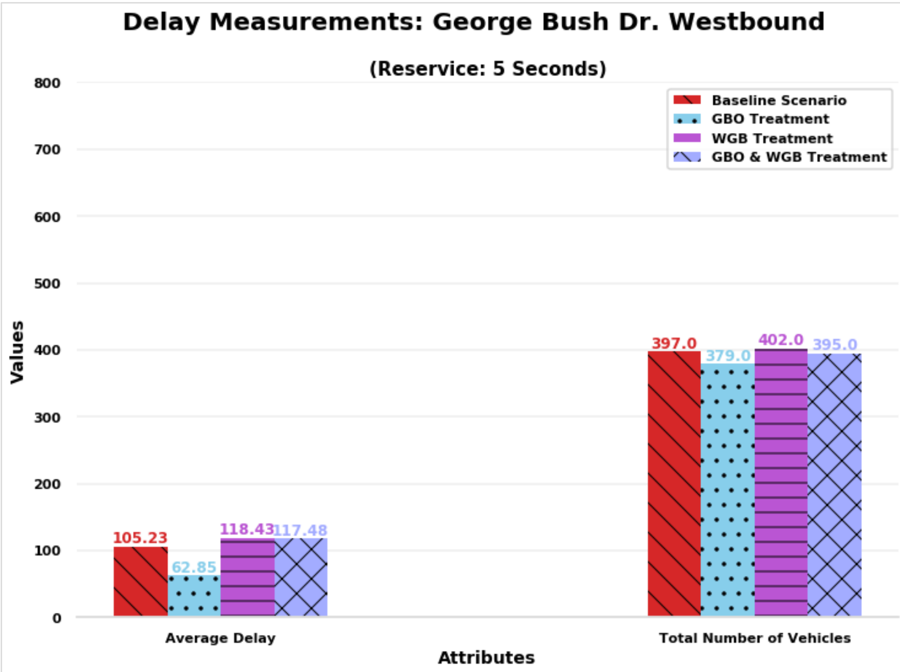

Figure 9. Westbound Route Delay Along George Bush 5-Second Reservice Settings for Metering

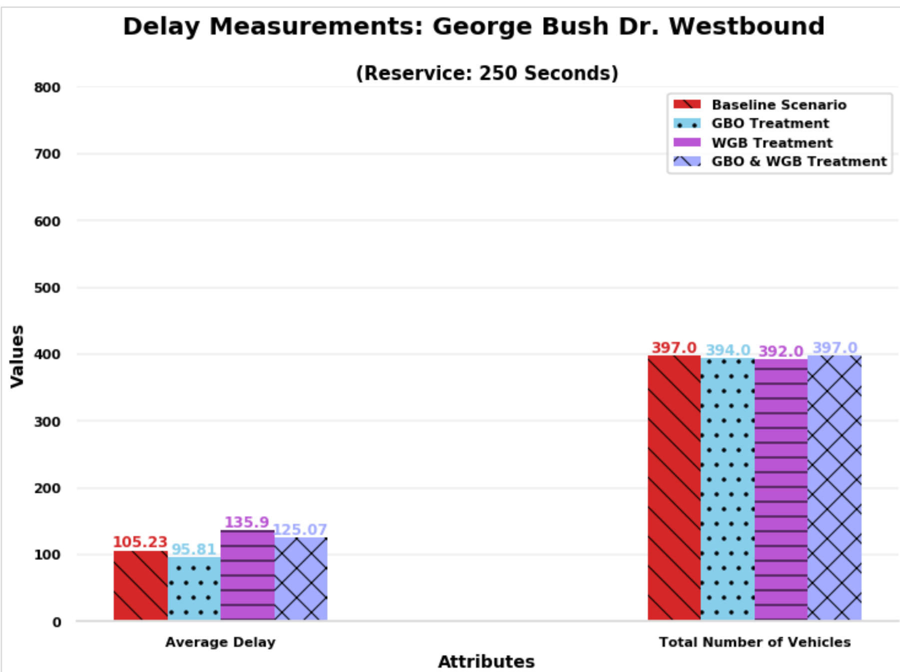

Figure 10. Westbound Route Delay Along George Bush Dr. 250-Second Reservice Settings for Metering

Delay measurement results for Wellborn Rd northbound and southbound approach are shown in Figure 11 to Figure 14. Based on the results, applying WGB treatment and GBO & WGB treatment on the network, would increase the delay on Wellborn Rd approaches. The reason is that WGB treatment would give more green time to the George Bush Dr approach to flush the queue. GBO treatment could slightly decrease the delay results. This indicates that the treatments proposed would harm progression along Wellborn Rd. Essentially the treatments prioritize flushing the queues along George Bush Dr. and increase delay and harm progression along Wellborn.

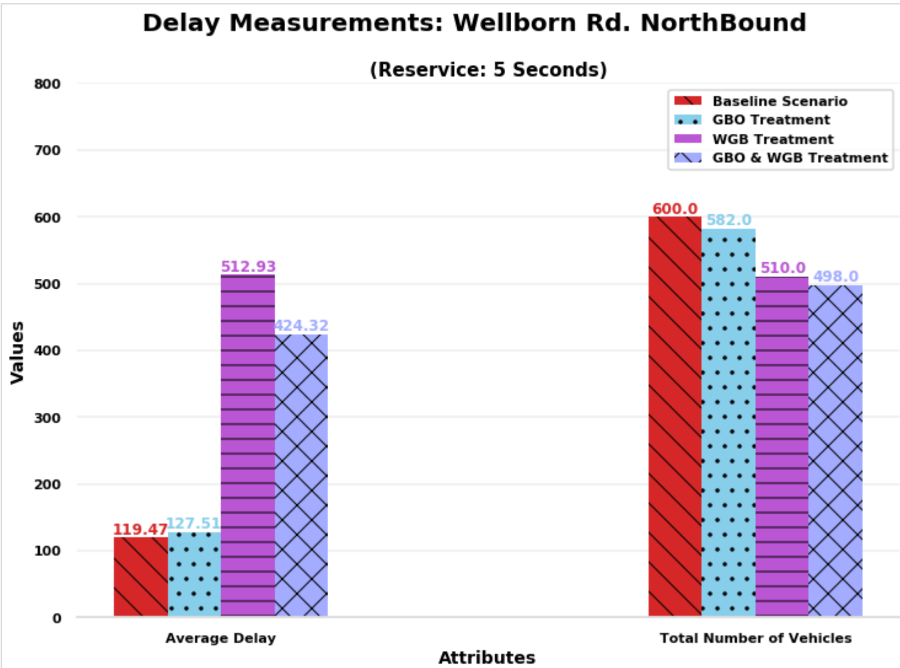

Figure 11. Northbound Route Delay Along Wellborn Rd 5-Second Reservice Settings for Metering

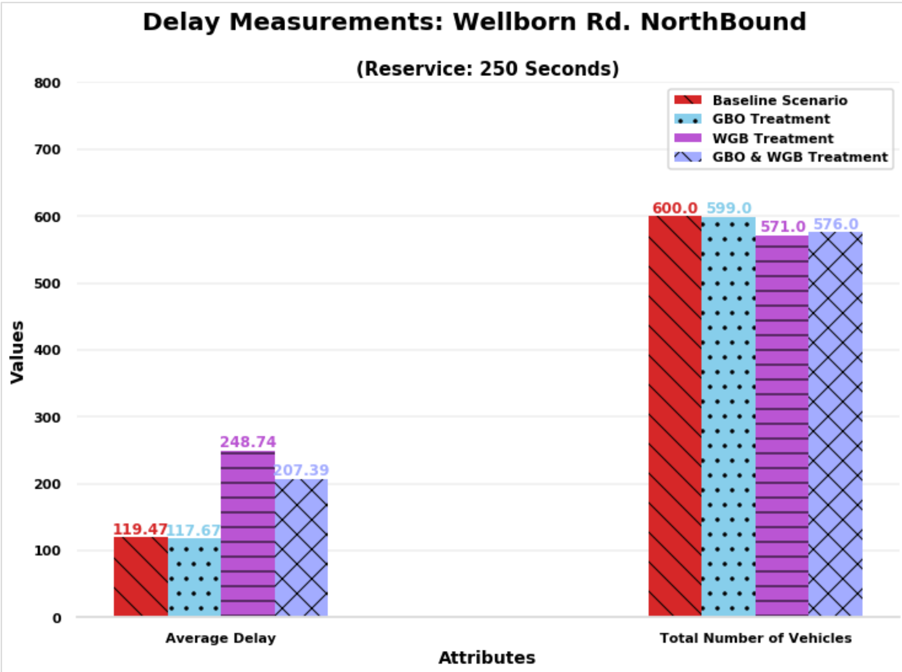

Figure 12. Northbound Route Delay Along Wellborn Rd 250-Second Reservice Settings for Metering

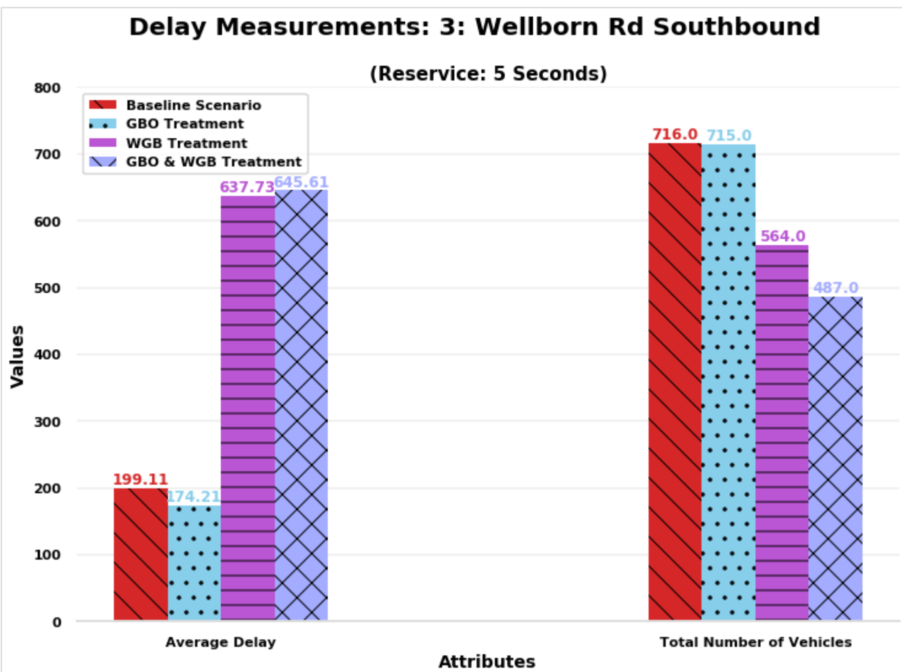

Figure 13. Southbound Route Delay Along Wellborn Rd 5-Second Reservice Settings for Metering

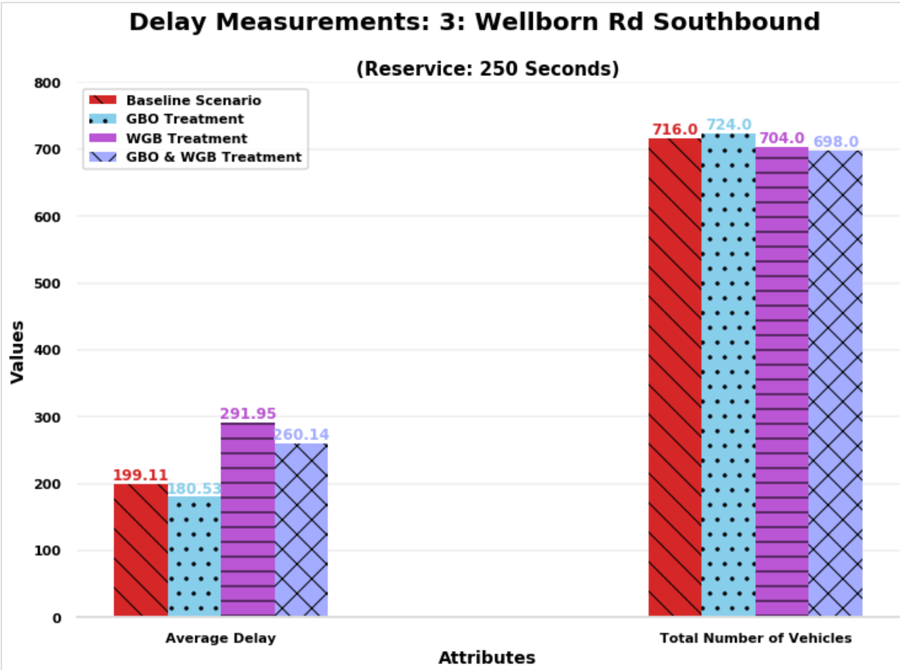

Figure 14. Southbound Route Delay Along Wellborn Rd 250-Second Reservice Settings for Metering

Figure 15 to Figure 24 present the average queue length, average vehicle delay, average stopped delay, and average number of stops at the five main nodes (intersections) in the network while Figure 25 to Figure 32 show the same for several critical movements at the intersection of George Bush Dr and Olsen Blvd and at the intersection of George Bush Dr and Wellborn Rd.

Results in Figure 15 and Figure 16 show the efficiency of WGB treatment and GBO & WGB treatment in reducing the average queue length, average vehicle delay, average stopped delay, and average number of stops, particularly for the 5-second reservice scenario.

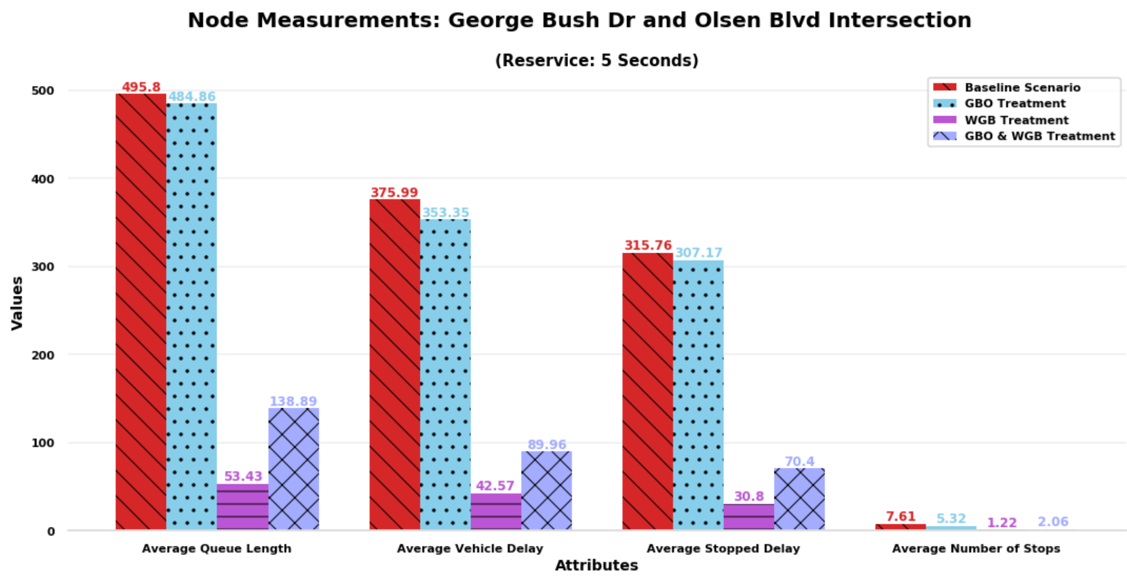

Figure 15. Node measurement results George Bush Dr. – Olsen Blvd 5-second reservice settings for metering

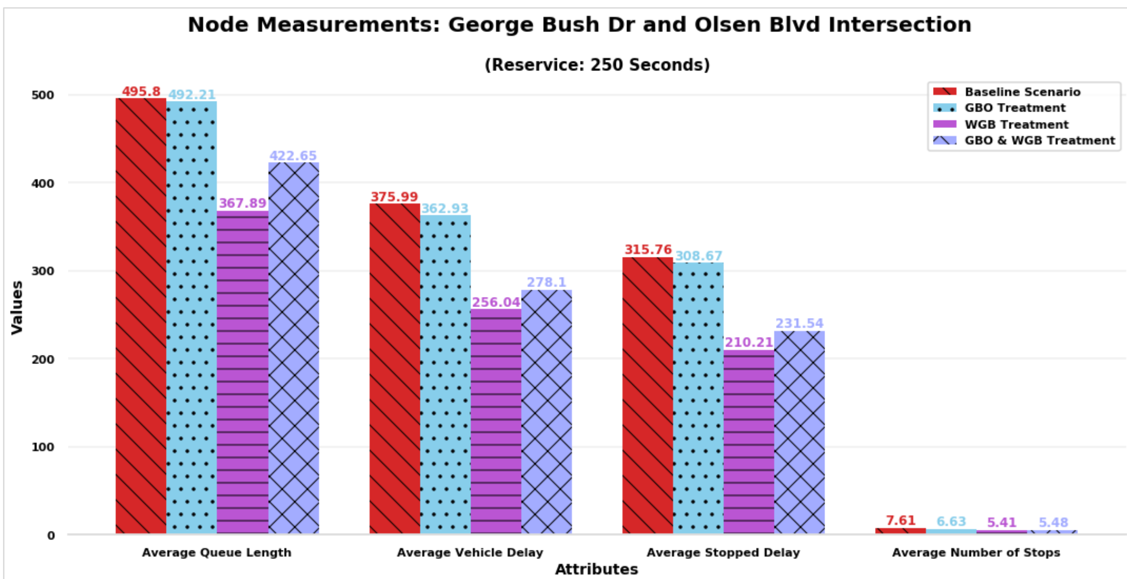

Figure 16. Node measurement results George Bush Dr. – Olsen Blvd 250-second reservice settings for metering

As we expected, the WGB treatment or GBO & WGB treatment have negative impacts on the node measurement results of the George Bush Dr – Wellborn Rd intersection (Figure 17 and Figure 18) and increase all the measurements compared to the Baseline scenario.

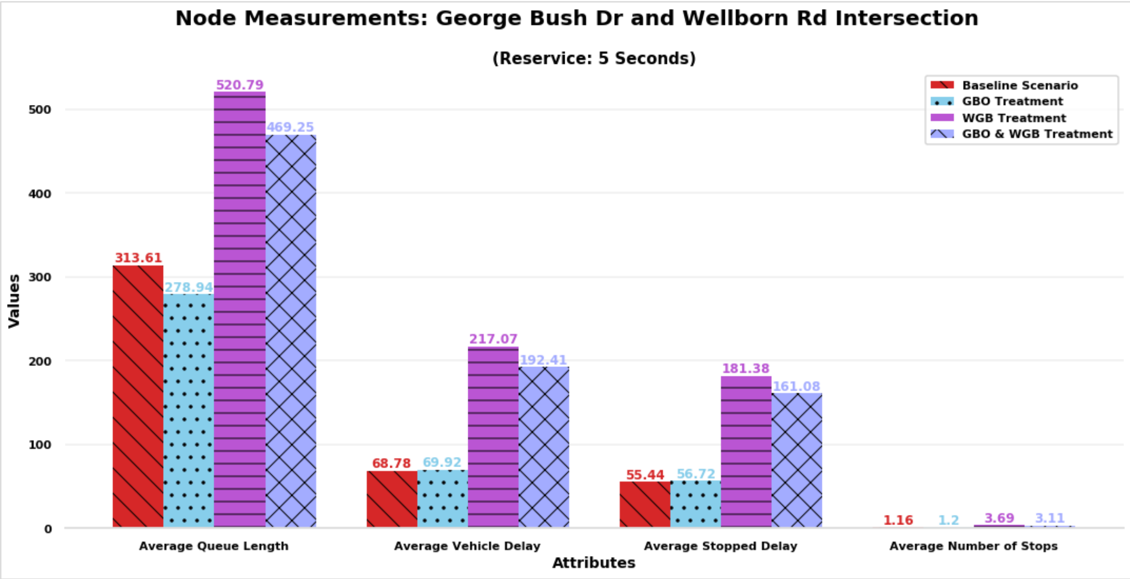

Figure 17. Node measurement results George Bush Dr. – Wellborn Rd 5-second reservice settings for metering

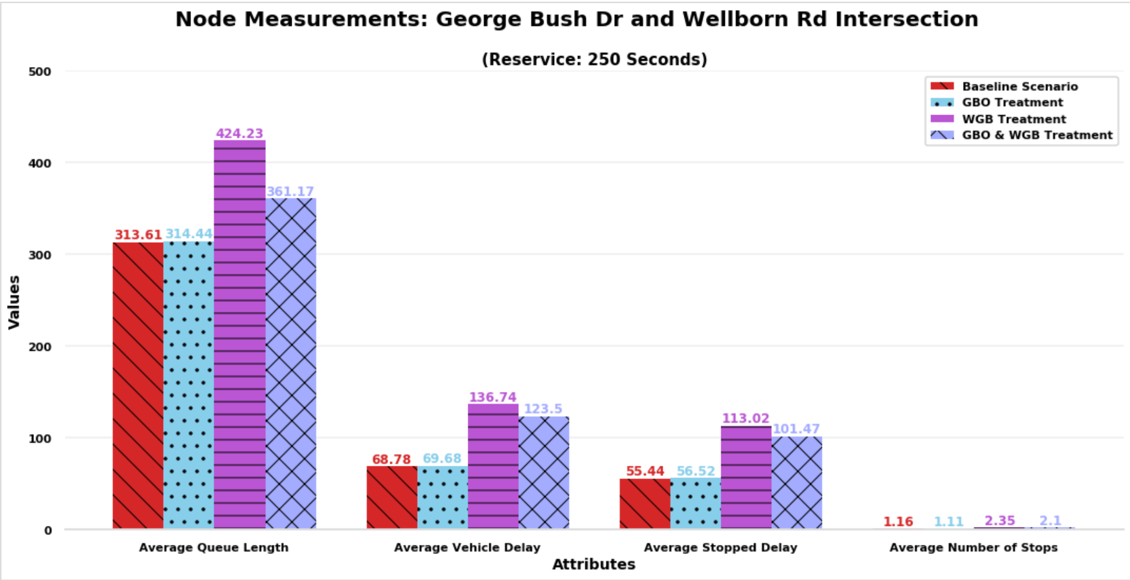

Figure 18. Node measurement results George Bush Dr. – Wellborn Rd 250-second reservice settings for metering

Results in Figure 19 and Figure 20 show that using different treatments does not affect the node measurement results within Wellborn Rd – Holleman Dr intersection.

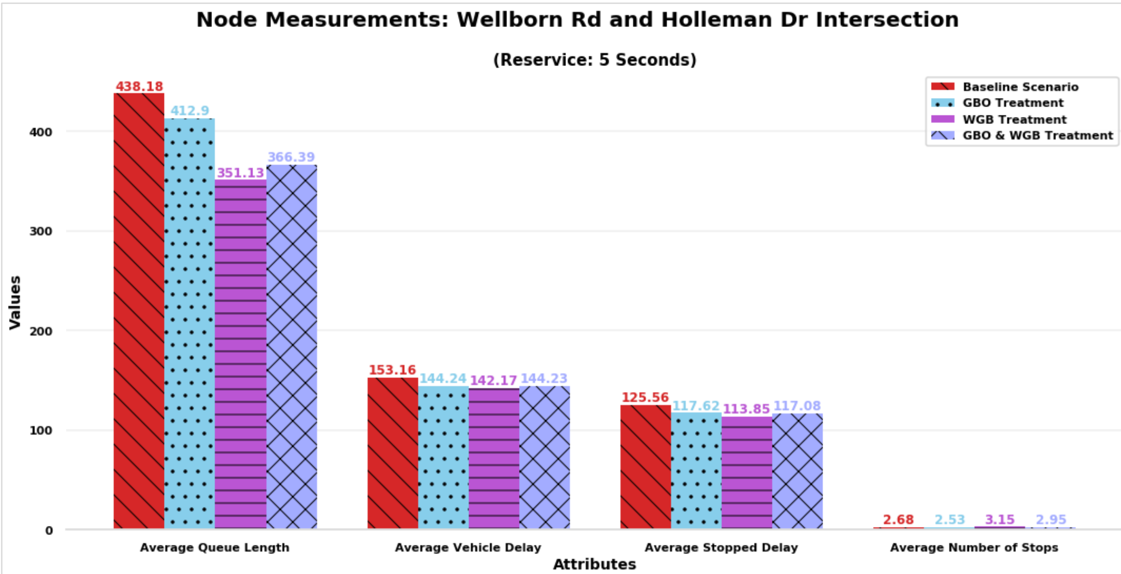

Figure 19. Node measurement results Wellborn Rd – Holleman Dr 5-second reservice settings for metering

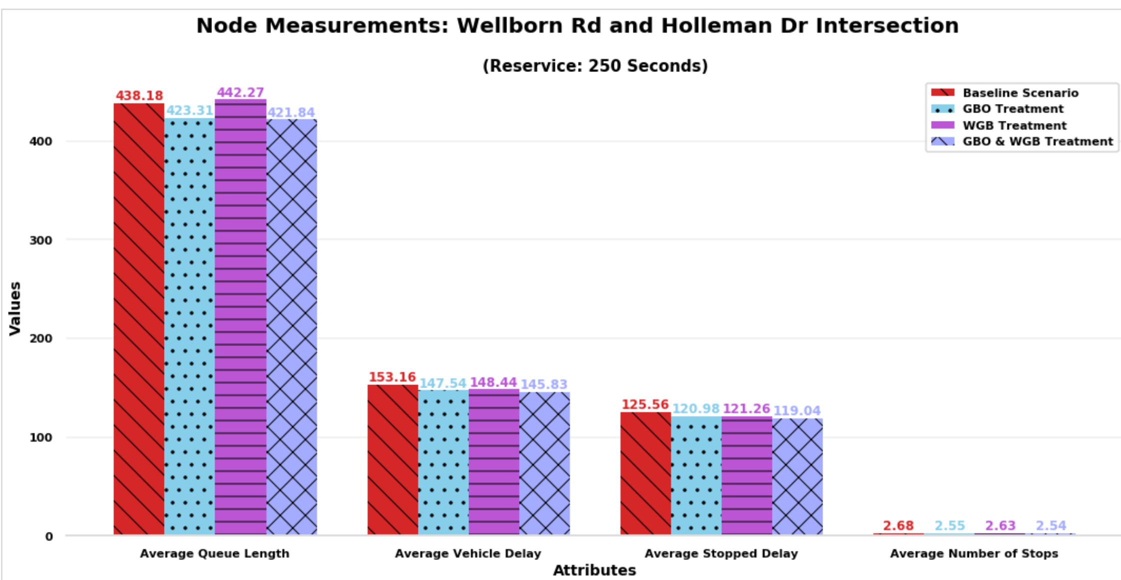

Figure 20. Node measurement results Wellborn Rd – Holleman Dr 250-second reservice settings for metering

Node measurement results for the intersection of Wellborn Rd and Joe Routt Blvd (Figure 21 and Figure 22) reveal that the treatments do not affect the results for the 250-second reservice scenario. In 5-second reservice scenario, the WGB treatment and GBO & WGB treatment affect negatively and increase the queue length, delay, and stops.

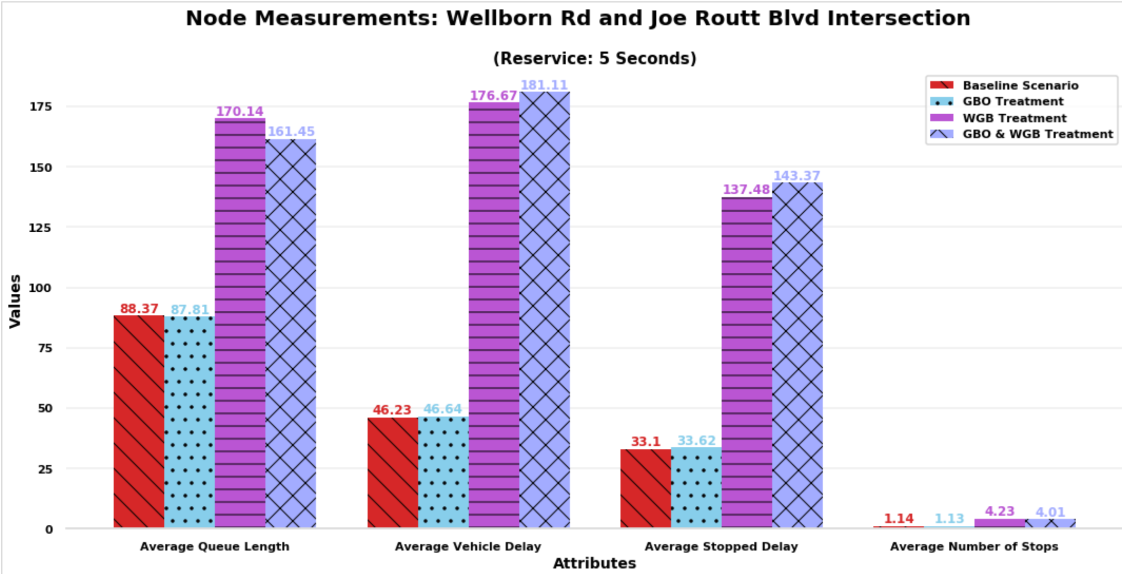

Figure 21. Node measurement results Wellborn Rd – Joe Routt Blvd 5-second reservice settings for metering

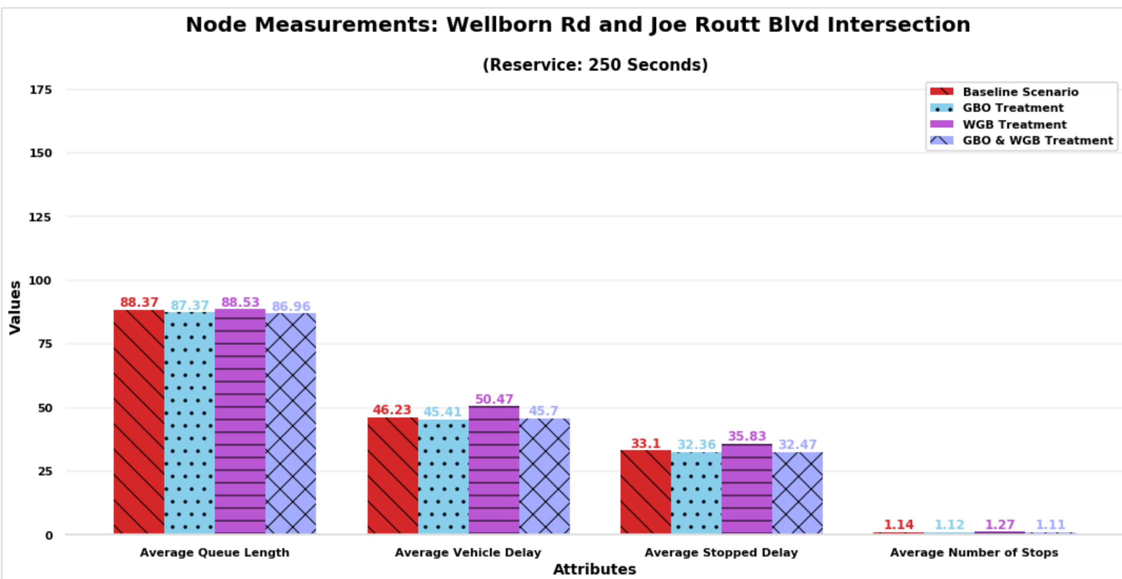

Figure 22. Node measurement results Wellborn Rd – Joe Routt Blvd 250-second reservice settings for metering

Node results for the intersection of George Bush Dr and Houston St in Figure 23 and Figure 24 reveal that treatments have negative impact on their results.

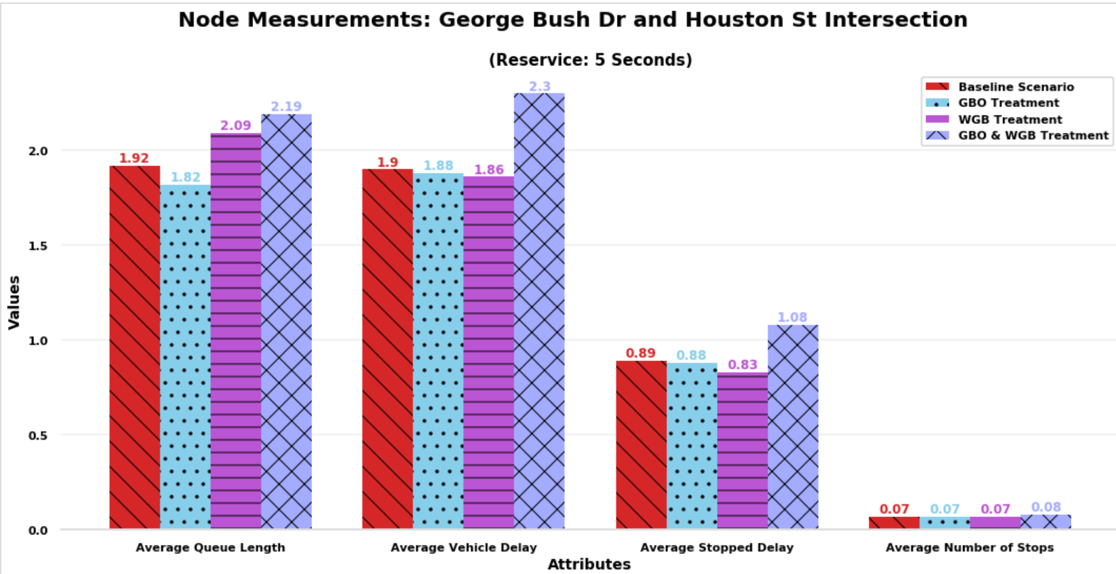

Figure 23. Node measurement results George Bush Dr – Houston St 5-second reservice settings for metering

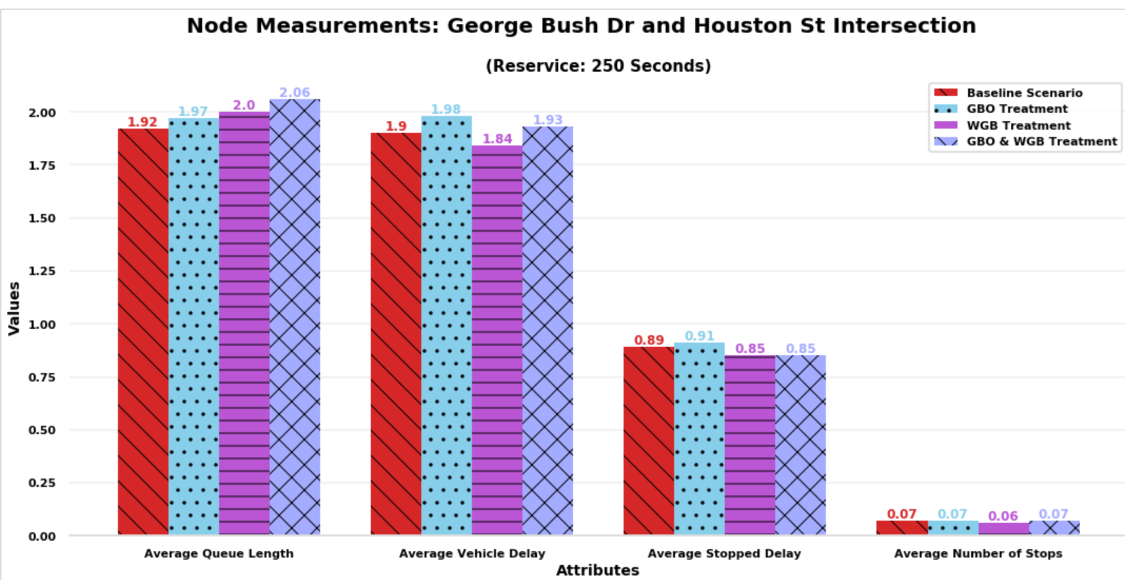

Figure 24. Node measurement results George Bush Dr – Houston St 250-second reservice settings for metering

Node results for eastbound through movement (Figure 25 and Figure 26) and for southbound left turn movement (Figure 27 and Figure 28) within George Bush Dr – Olsen Blvd intersection reveal that WGB treatment and GBO & WGB treatment could reduce the queue length, delay and stops. 5-second reservice shows more significant changes than 250-second reservice.

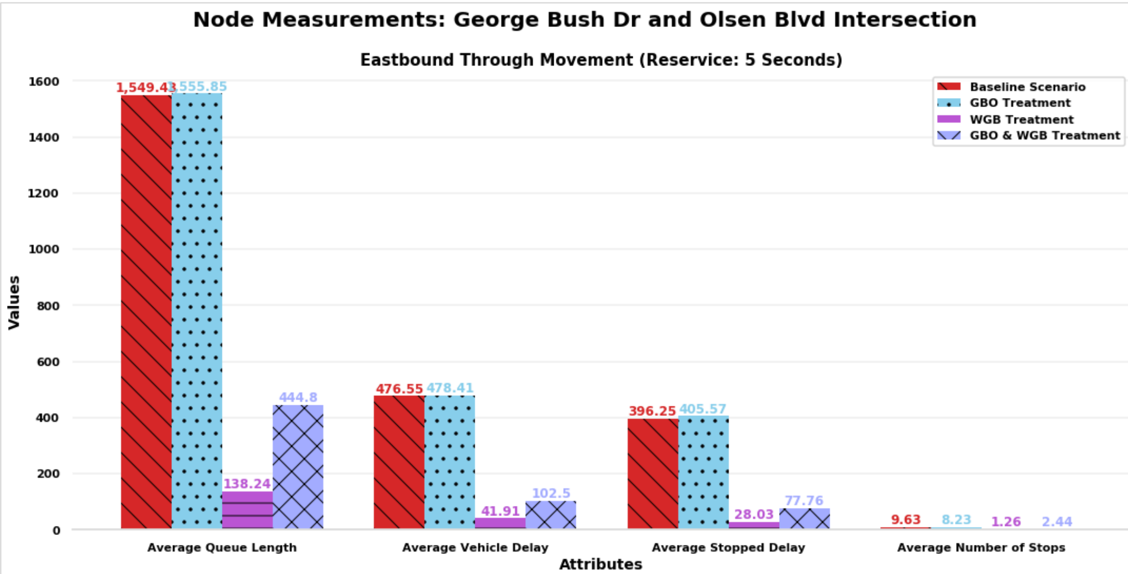

Figure 25. Node measurement results George Bush Dr – Olsen Blvd eastbound through movement 5-second reservice settings for metering

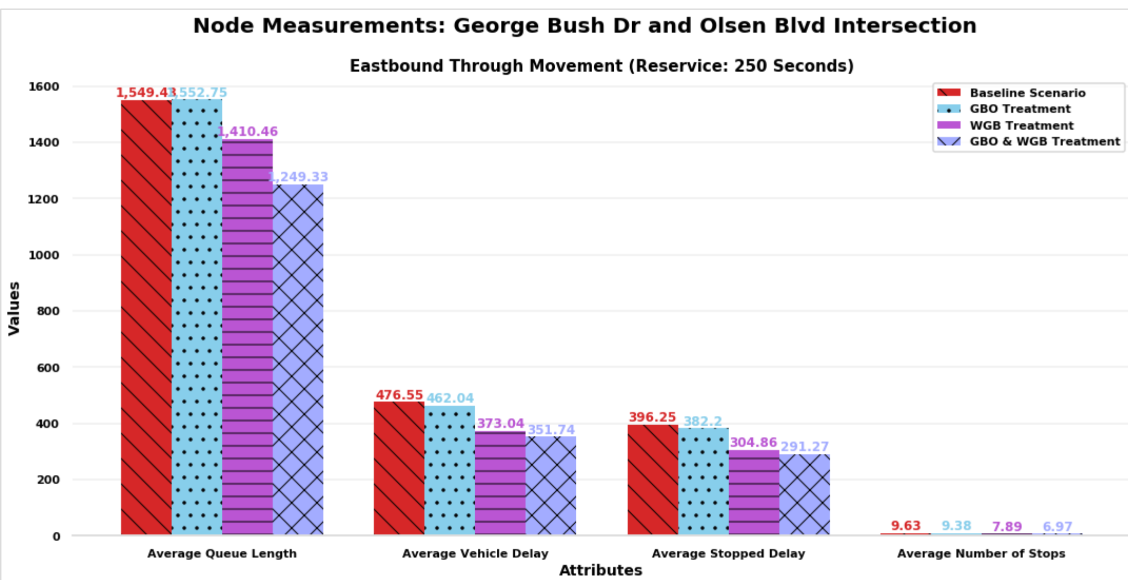

Figure 26. Node measurement results George Bush Dr – Olsen Blvd eastbound through movement 250-second reservice settings for metering

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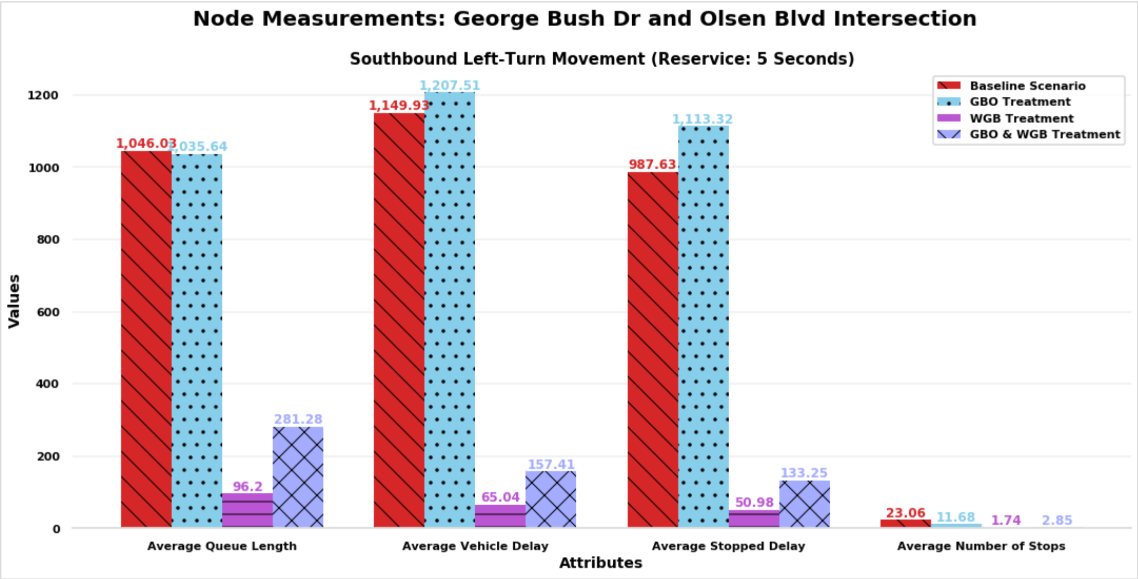

Figure 27. Node measurement results George Bush Dr – Olsen Blvd southbound left turn movement 5-second reservice settings for metering

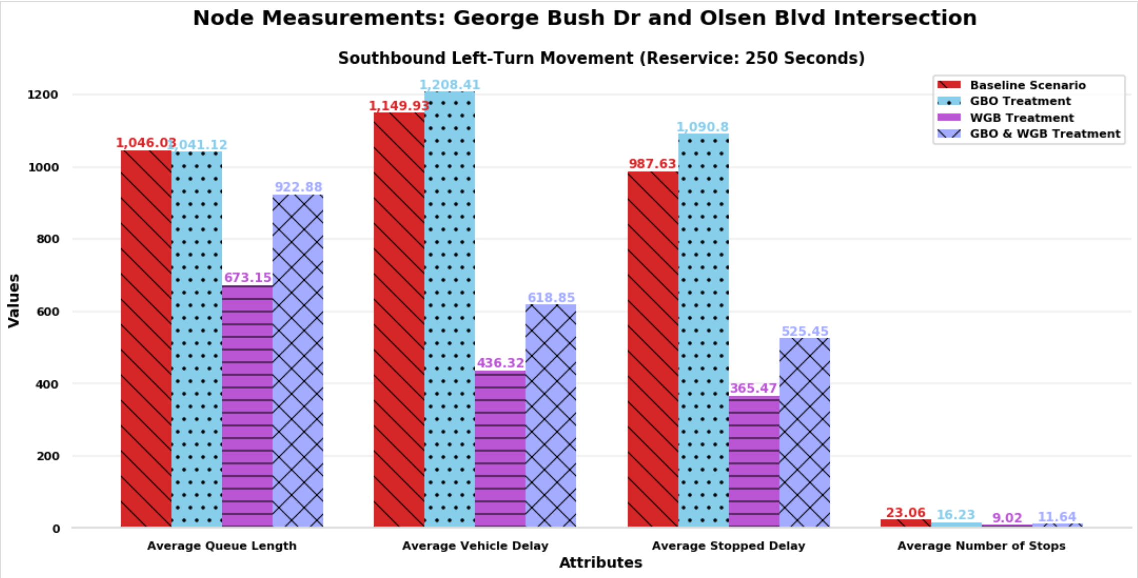

Figure 28. Node measurement results George Bush Dr – Olsen Blvd southbound left turn movement 250-second reservice settings for metering

Node results for eastbound through movement (Figure 29 and Figure 30) and for southbound left turn movement (Figure 31 and Figure 32) within George Bush Dr – Olsen Blvd intersection reveal that WGB treatment and GBO & WGB treatment could reduce the queue length, delay and stops. 5-second reservice shows more significant changes than 250-second reservice.

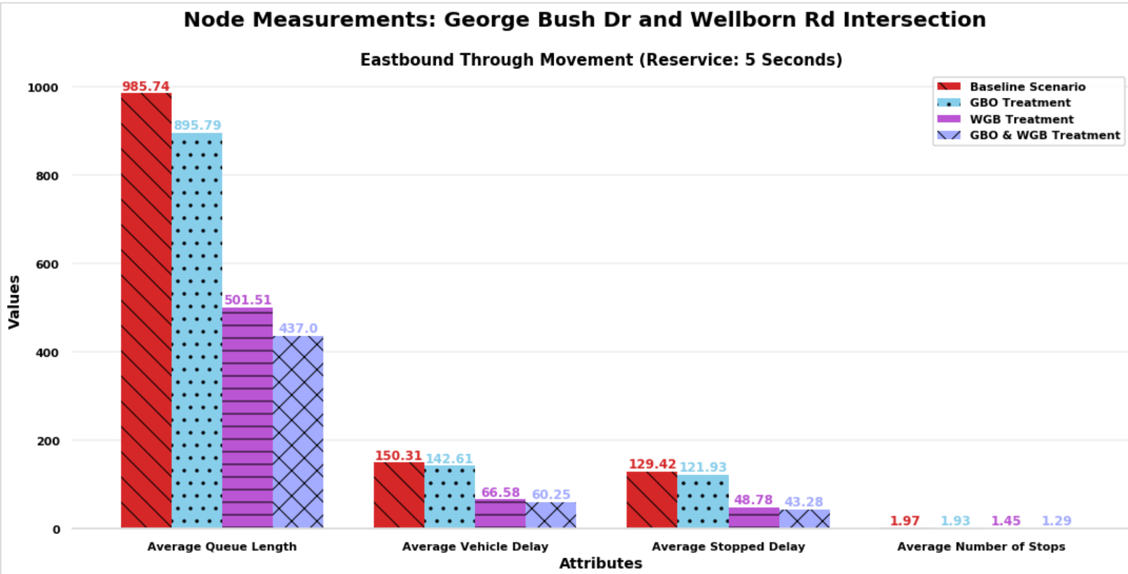

Figure 29. Node measurement results George Bush Dr – Wellborn Rd eastbound through movement 5-second reservice settings for metering

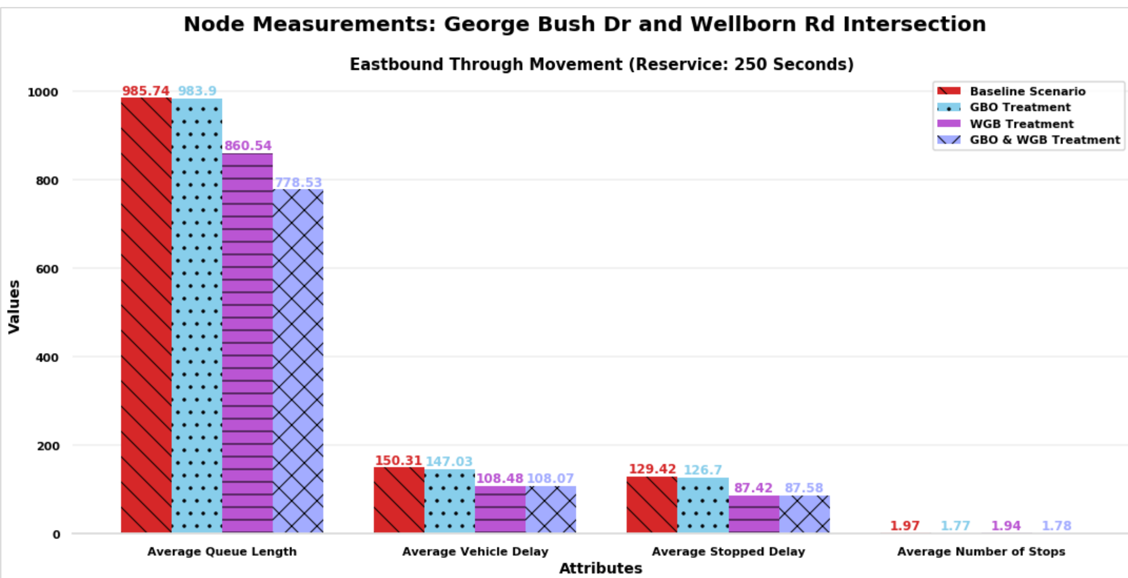

Figure 30. Node measurement results George Bush Dr – Wellborn Rd eastbound through movement 250-second reservice settings for metering

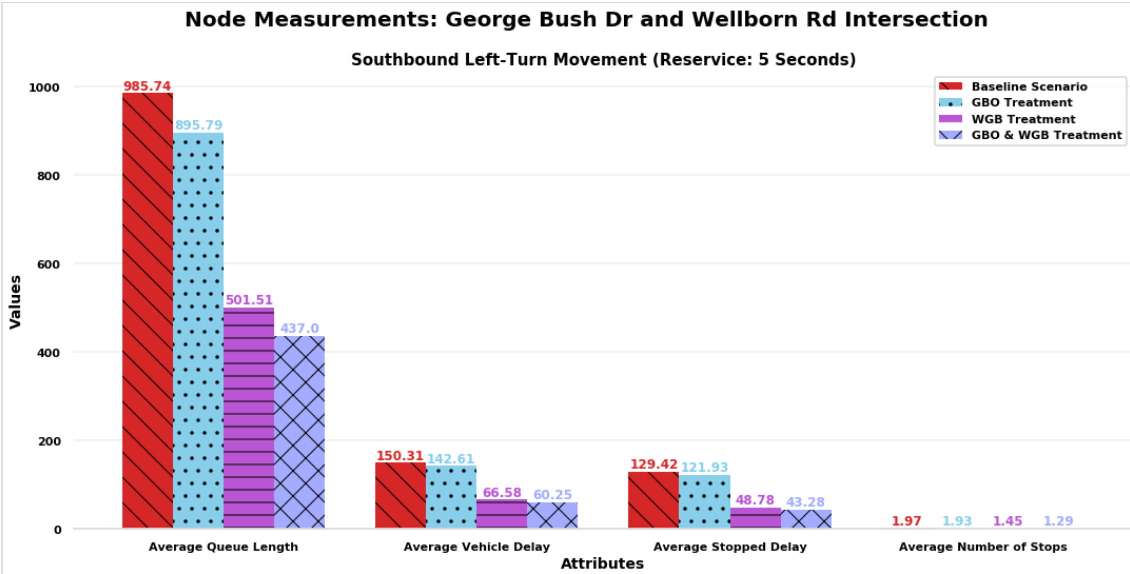

Figure 31. Node measurement results George Bush Dr – Wellborn Rd southbound left turn movement 5-second reservice settings for metering

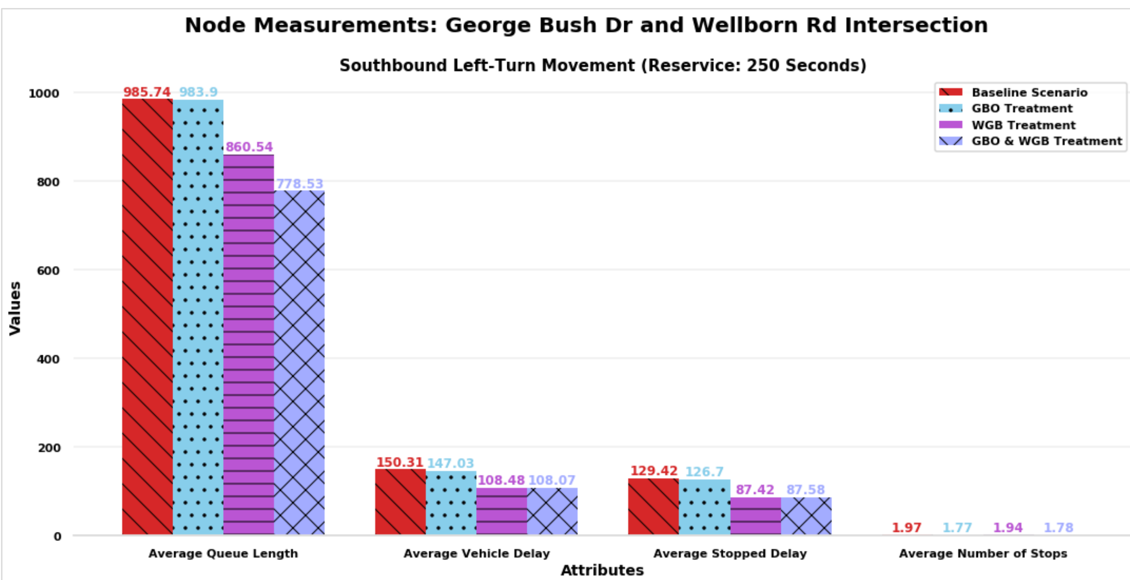

Figure 32. Node measurement results George Bush Dr – Wellborn Rd southbound left turn movement 250-second reservice settings for metering

Figure 33 to Figure 38 show the network performance results. These figures include the total travel time, total delay, and latent delay. Figure 33 and Figure 34 presents the accumulative results for latent delay and total delay. Latent Delay includes the total waiting time of the vehicles before entering the network and the total waiting time of the vehicles do not complete their travel before the end of the simulation. Figure 37 and Figure 38 show the number of active vehicles, arrived vehicles, and latent demand. Active vehicles are the total number of vehicles in the network at the end of the simulation, arrived vehicles are the total number of vehicles that finished their travel at the end of the simulation and left the network, and latent demand is total number of vehicles that could not enter the network from input volume.

In terms of total travel time (Figure 33 and Figure 34), GBO treatment produces lower total travel time in the network totally. In terms of delay (Figure 33, Figure 34, Figure 35, and Figure 36), *WGB treatment* and *GBO & WGB treatment* in 250 reservice value do a better job in reducing the sum of total delay and latent delay in the network, *GBO treatment* does a better job when considering the total delay solely. As we explained in the last paragraph, latent delay is for the vehicles that do not enter the network or the vehicles which do not complete their travel. Hence, relatively high value for the sum of total delay and latent delay for the *GBO treatment* is a critical issue in this study. In terms of total demand (including arrived vehicles and latent demand), Figure 37 and Figure 38 show that WGB treatment and GBO & WGB treatment outperform the GBO treatment.

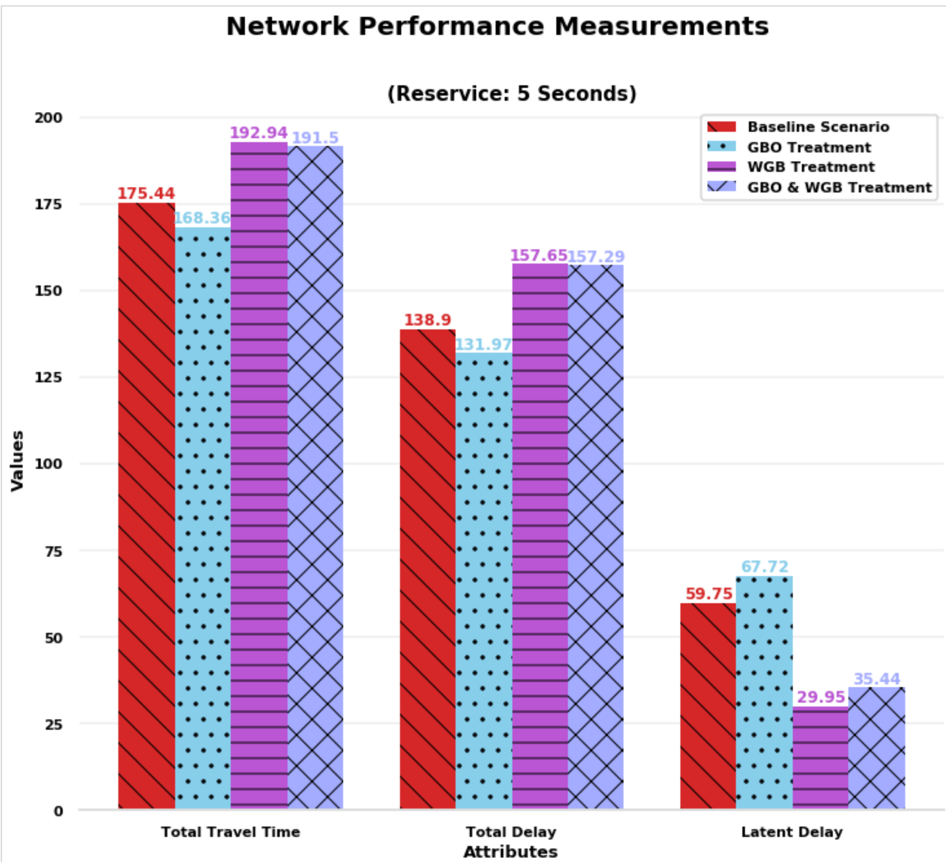

Figure 33. Network performance measurements (total travel time, total delay, and latent delay) 5-Second Reservice Settings for Metering

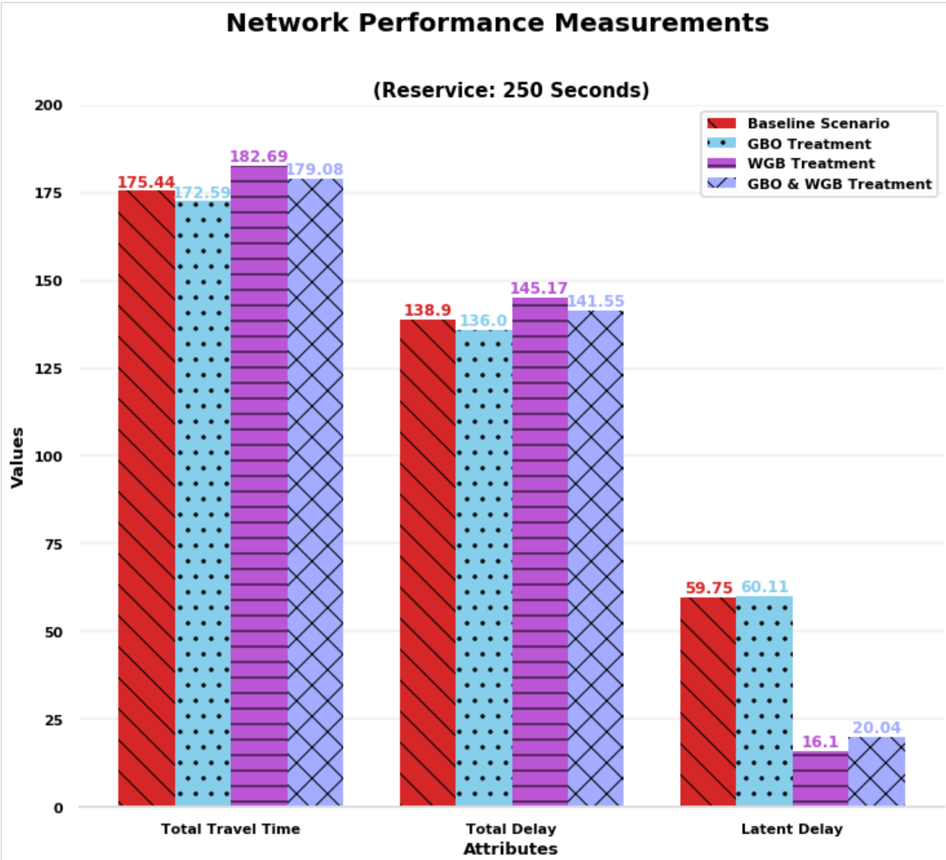

Figure 34. Network performance measurements (total travel time, total delay, and latent delay) 250-Second Reservice Settings for Metering

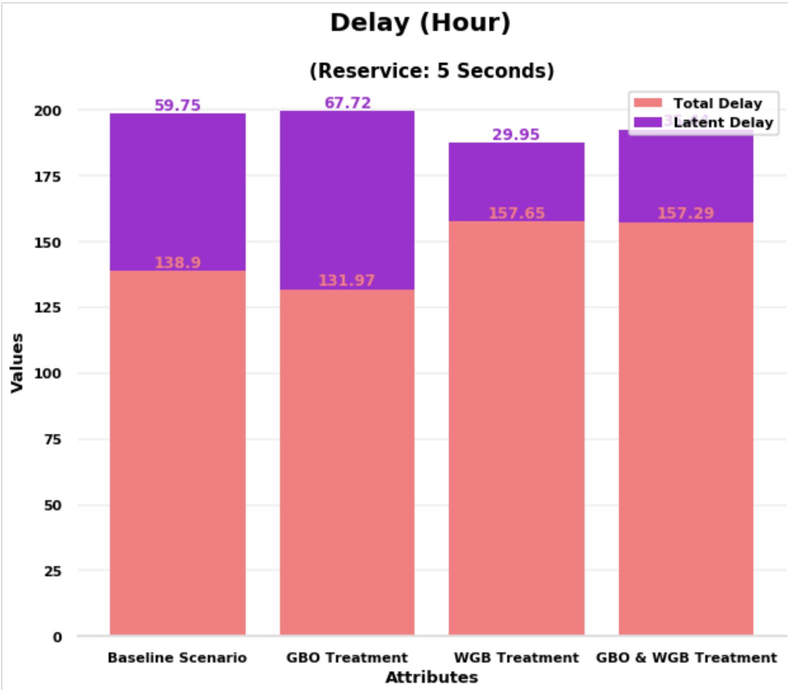

Figure 35. Network performance measurements (total delay and latent delay) *5-Second Reservice Settings for Metering*

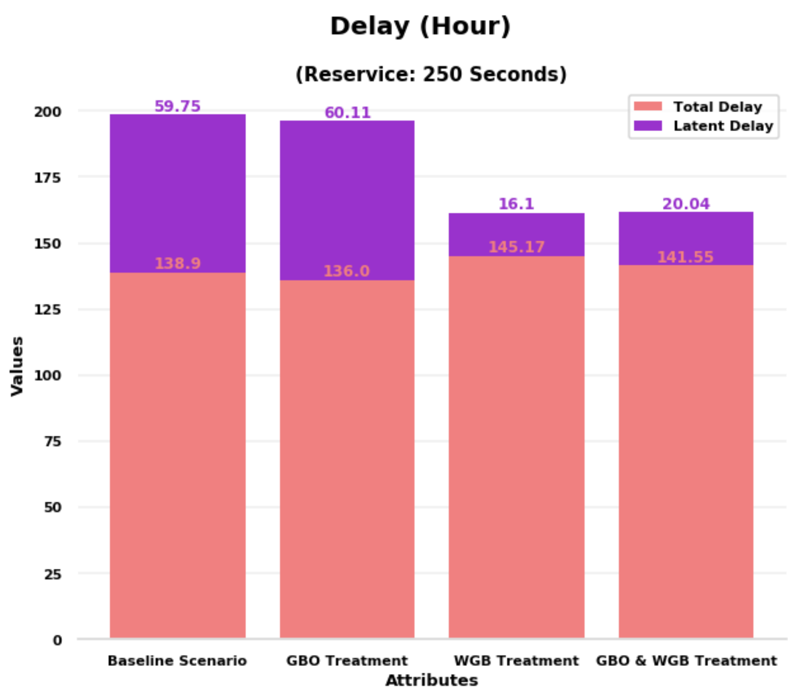

Figure 36. Network performance measurements (total delay and latent delay) *250-Second Reservice Settings for Metering*

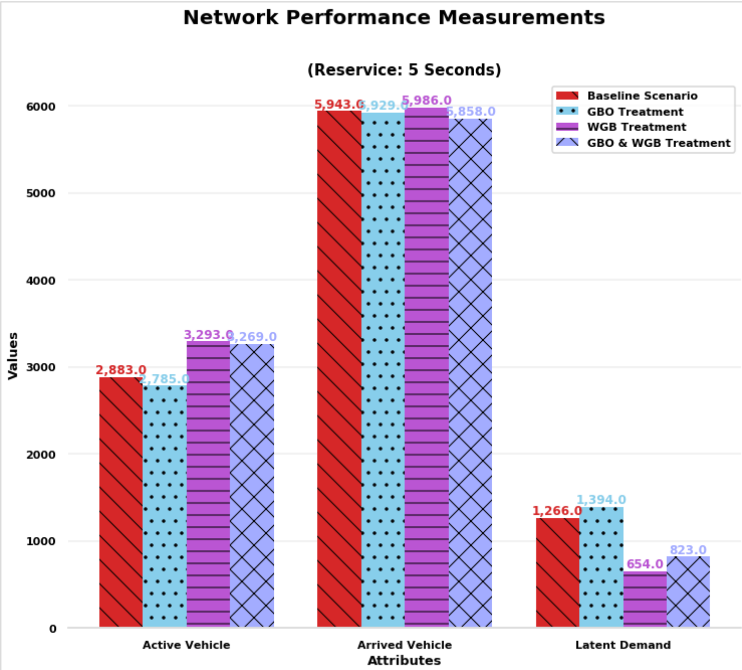

Figure 37. Network performance measurements (active vehicle, arrived vehicle, and latent demand) 5-Second Reservice Settings for Metering

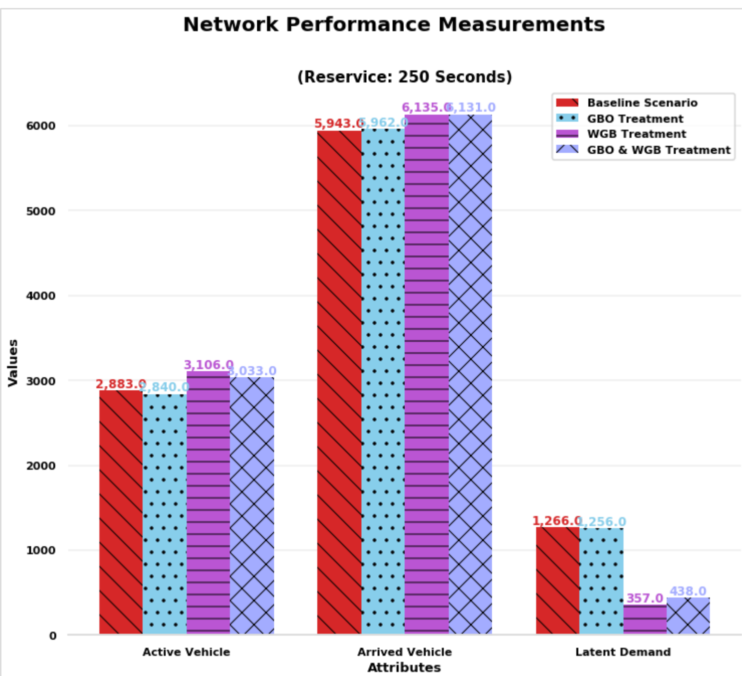

Figure 38. Network performance measurements (active vehicle, arrived vehicle, and latent demand) 250-Second Reservice Settings for Metering

Figure 39 to Figure 48 show the green times usage for each intersection and presents the results for all their signal phases. As the figures present, the treatments only affect the green time usage of the neighboring intersections, including George Bush Dr – Wellborn Rd and George Bush Dr – Olsen Dr. However, they do not have significant impact on the other intersections in the network and their signal phases. Only those phases impacted by the volume in Wellborn Rd and George Bush Dr may be affected which are include phases #2 and #6 of both intersections.

Figure 41, Figure 42, Figure 43, and Figure 44 reveal the green time usage for the George Bush Dr – Wellborn Rd and George Bush Dr – Olsen Dr intersections. At George Bush Dr – Olsen Dr intersection and considering the GBO treatment and preemption reservice 250 seconds, green time usages for the opposite direction (phases #1 and #6) increase to reduce the demand to link with the queue. Hence the green time usage for phase #2 decreases. However, at George Bush Dr – Wellborn Rd intersection and considering the GBO treatment and preemption reservice 250 seconds, green time usages do not change significantly.

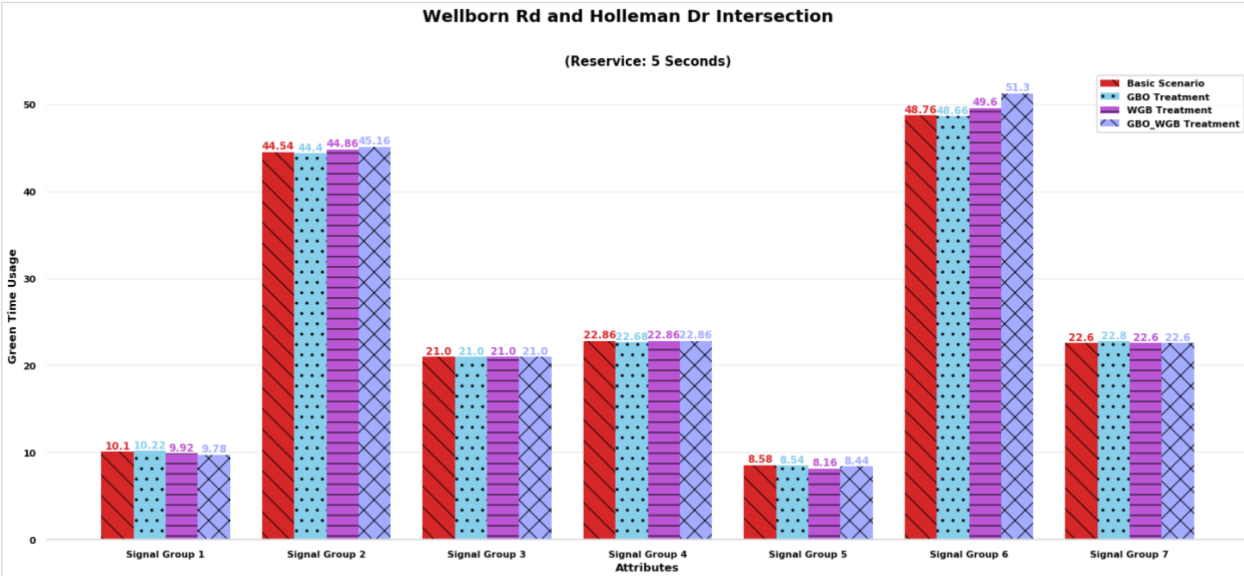

Figure 39. Green Time Usage for Wellborn Rd – Holleman Dr 5-Second Reservice Settings for Metering

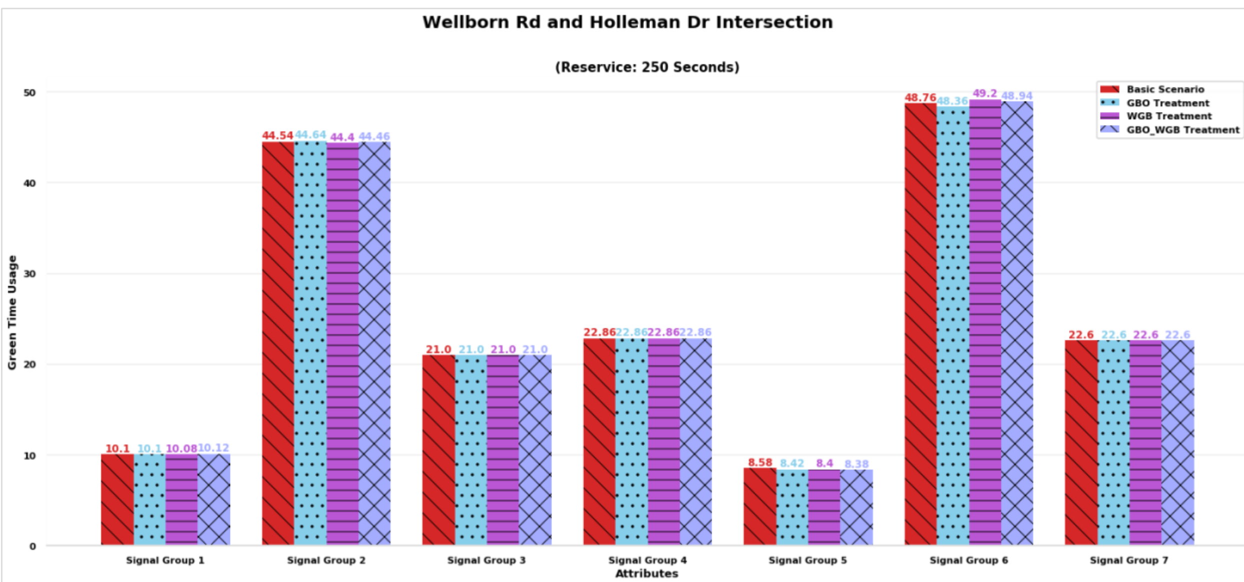

Figure 40. Green Time Usage for Wellborn Rd – Holleman Dr 250-Second Reservice Settings for Metering

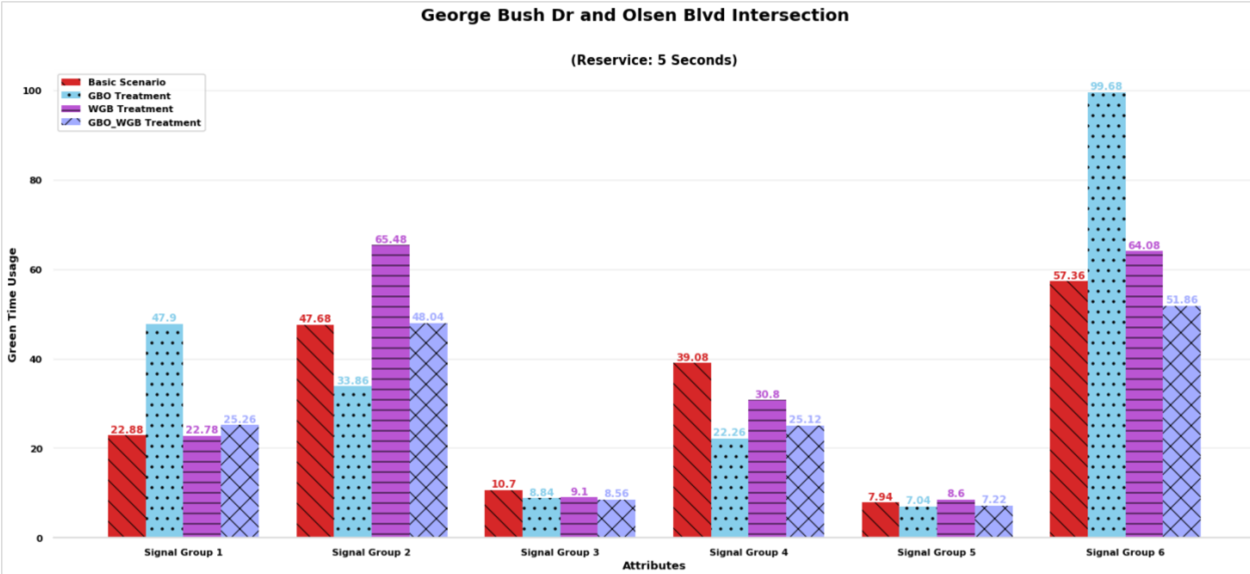

Figure 41. Green Time Usage for George Bush Dr – Olsen Blvd 5-Second Reservice Settings for Metering

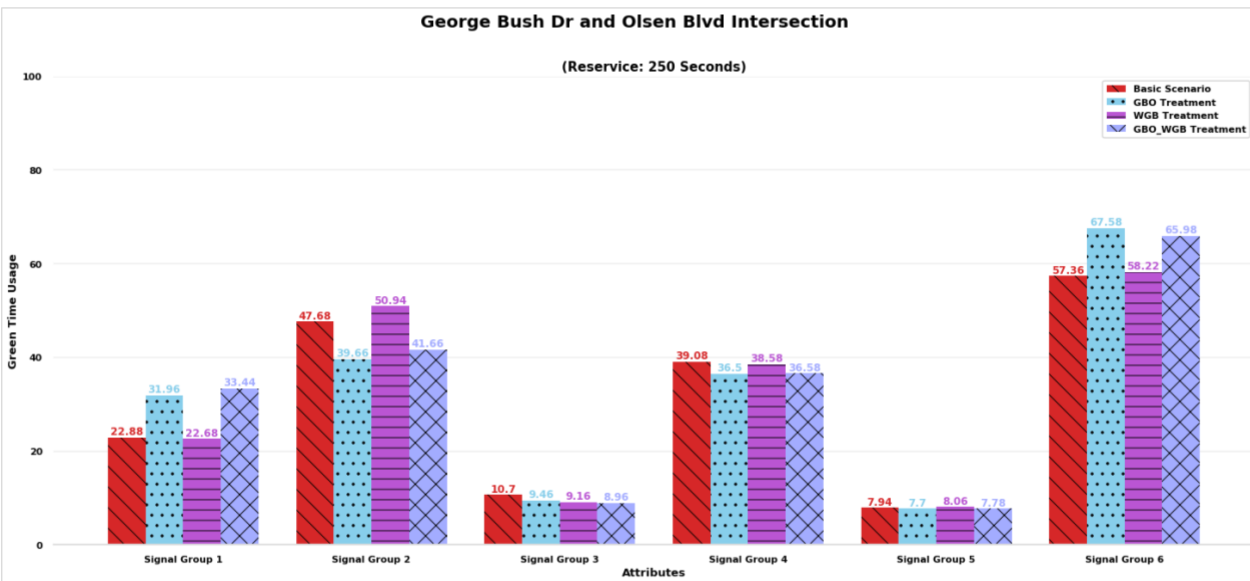

Figure 42. Green Time Usage for George Bush Dr – Olsen Blvd 250-Second Reservice Settings for Metering

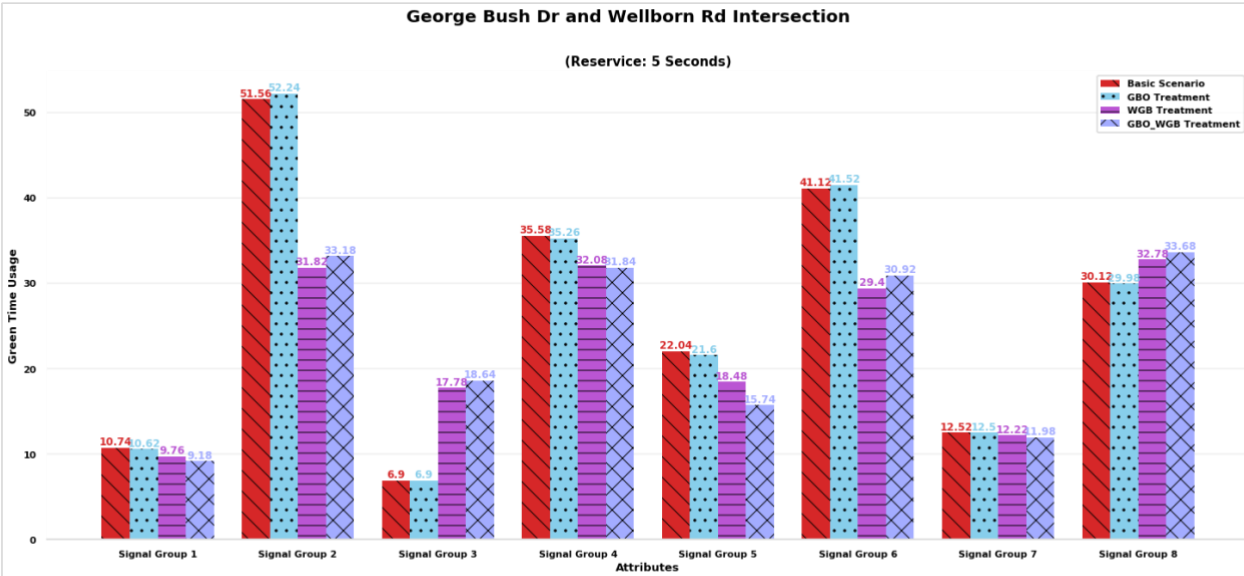

Figure 43. Green Time Usage for George Bush Dr – Wellborn Rd 5-Second Reservice Settings for Metering

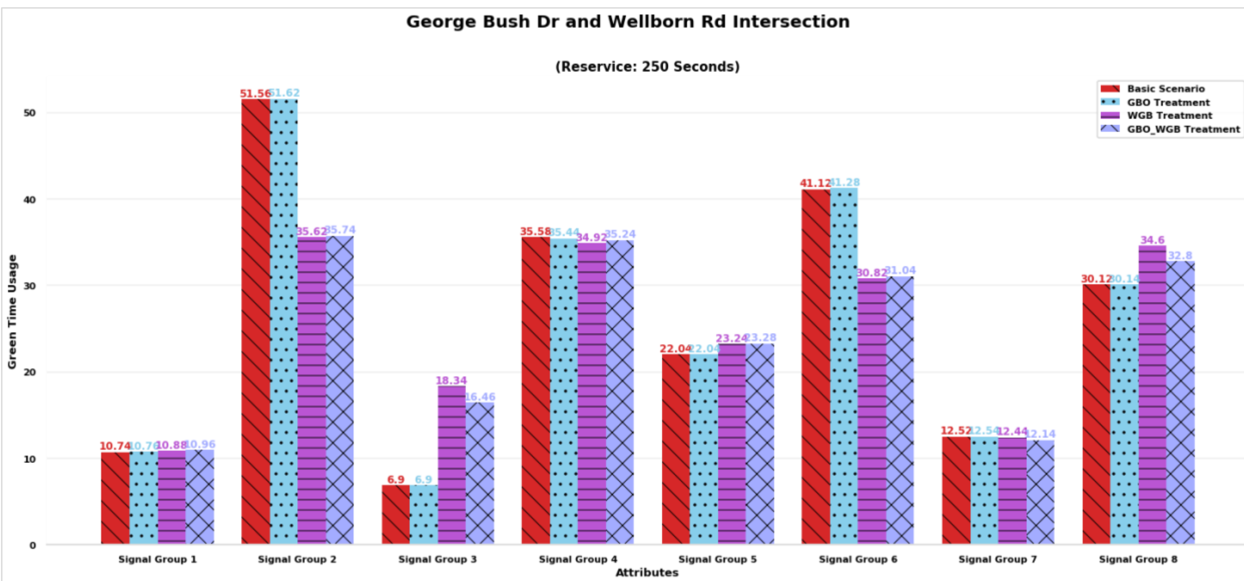

Figure 44. Green Time Usage for George Bush Dr – Wellborn Rd 250-Second Reservice Settings for Metering

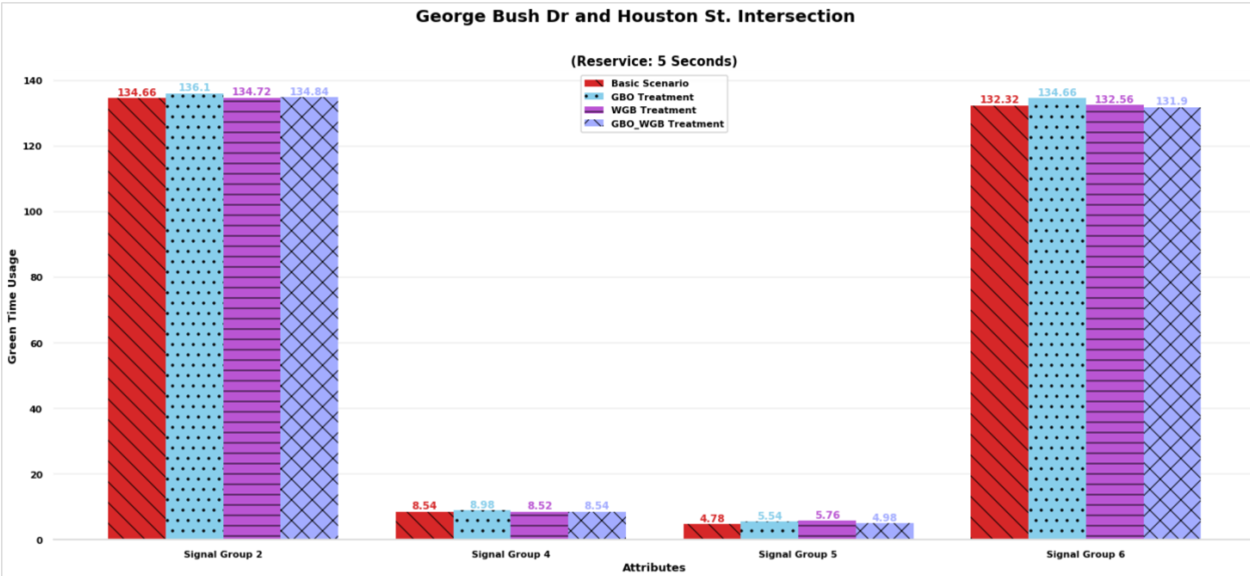

Figure 45. Green Time Usage for George Bush Dr – Houston St 5-Second Reservice Settings for Metering

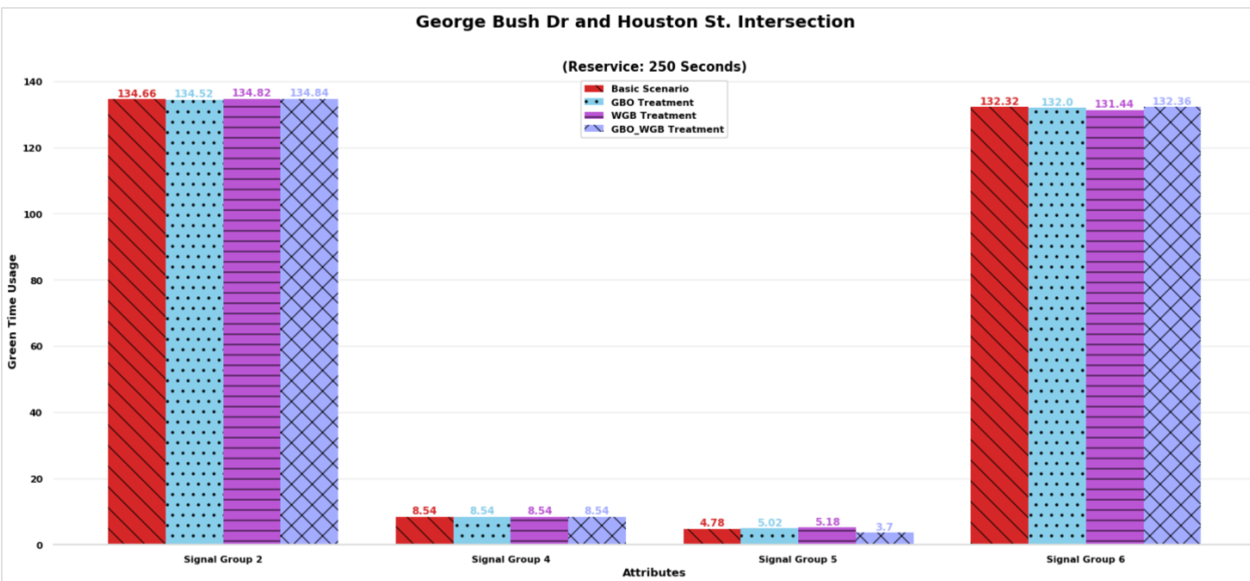

Figure 46. Green Time Usage for George Bush Dr – Houston St 250-Second Reservice Settings for Metering

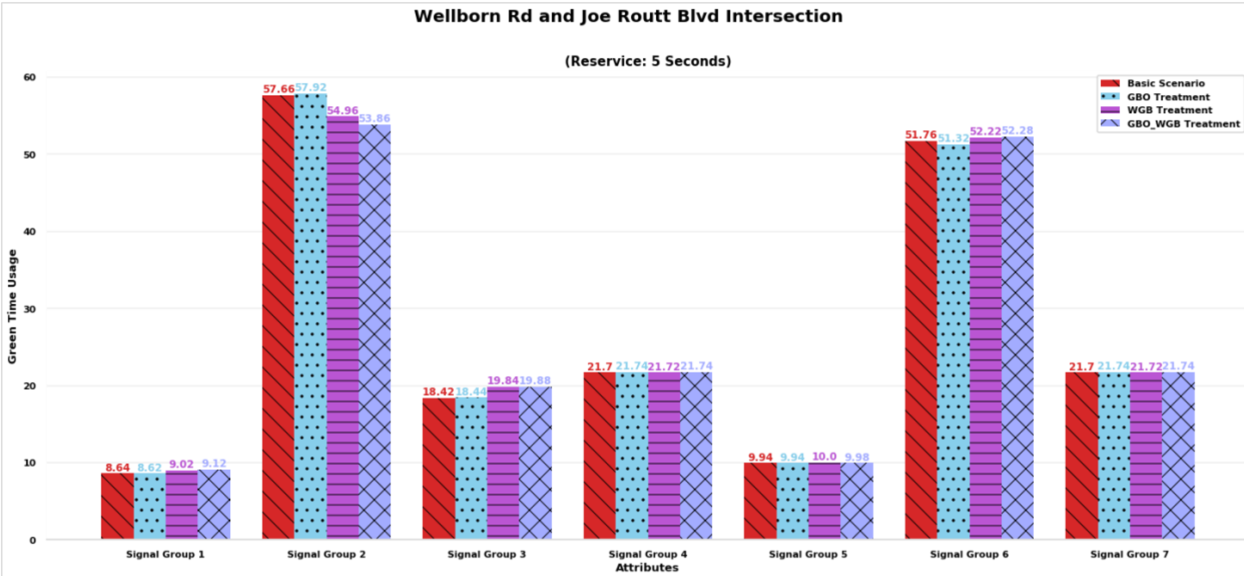

Figure 47. Green Time Usage for Wellborn Rd – Joe Routt Blvd 5-Second Reservice Settings for Metering

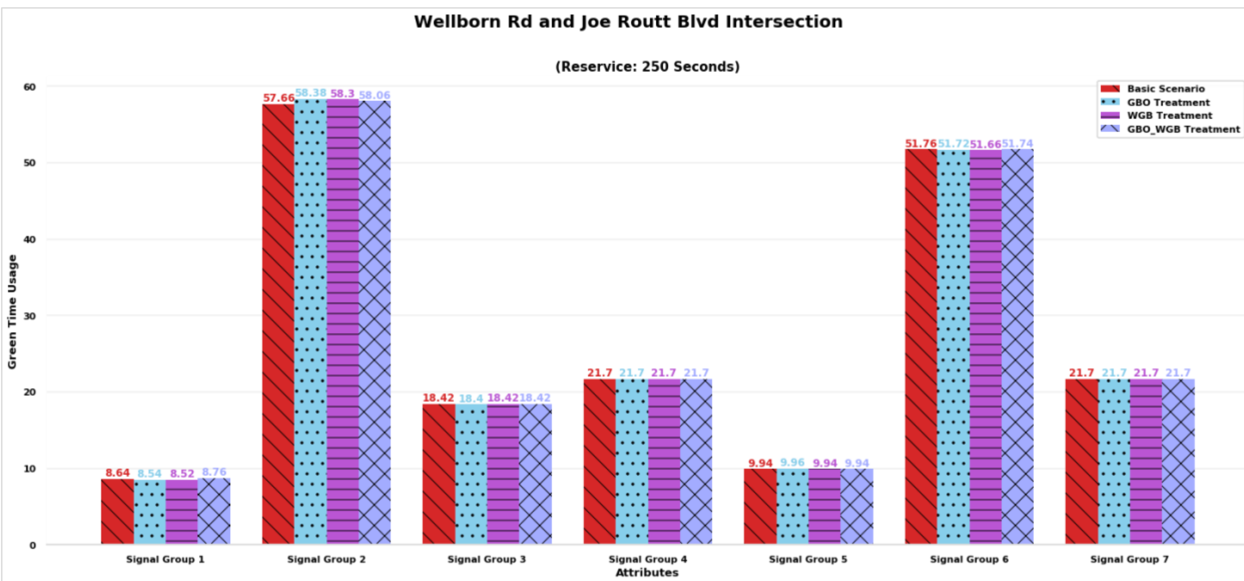

Figure 48. Green Time Usage for Wellborn Rd – Joe Routt Blvd 250-Second Reservice Settings for Metering

The research team also analyzed the controller state in this effort. This set of performance metrics aimed to help the research team understand the frequency and duration of non-standard operations because of the queue management technique employed in the experiment. Figure 49 to Figure 56 show the average total duration and average frequency of the FREE and COORD occurrences of the coordination status during the simulation period. To access the raw data and access the results for other coordination status, please see Appendix C.

Figure 49 and Figure 50 demonstrate the results for the George Bush Dr-Olsen Blvd intersection and for the coordination status 0=Free. It is obvious that WGB treatment does not affect the operations at the George Bush Dr-Olsen Blvd intersection because there is no treatment at the intersection described by these graphs. However, both the GBO treatment and GBO & WGB treatment the average total duration and the frequency for FREE status. For the preemption reservice of 250 seconds, the amount of time in free status is lower, which would cause less time where operations are impacted. Note that the treatment at both intersections lowers the amount of time spend in FREE mode drastically with the 5-second reservice setting. This is because flushing the queue while cutting off demand is able to address the excessive queue better than simply reducing the demand alone.

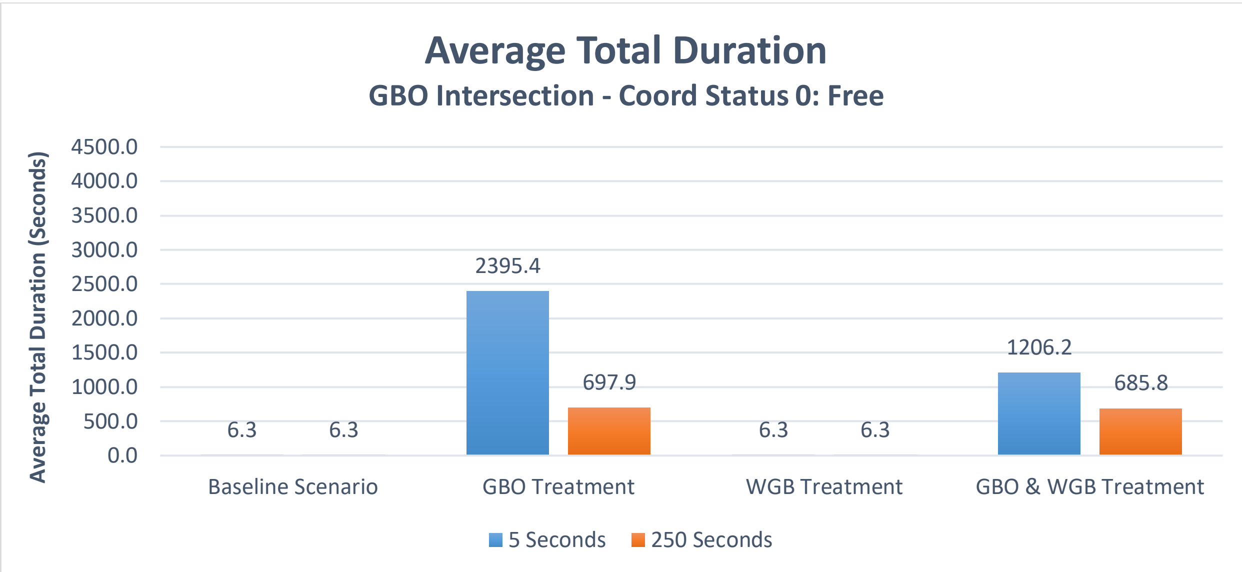

Figure 49 Average Total Duration for the George Bush Dr-Olsen Blvd intersection for the coordination status 0 = FREE

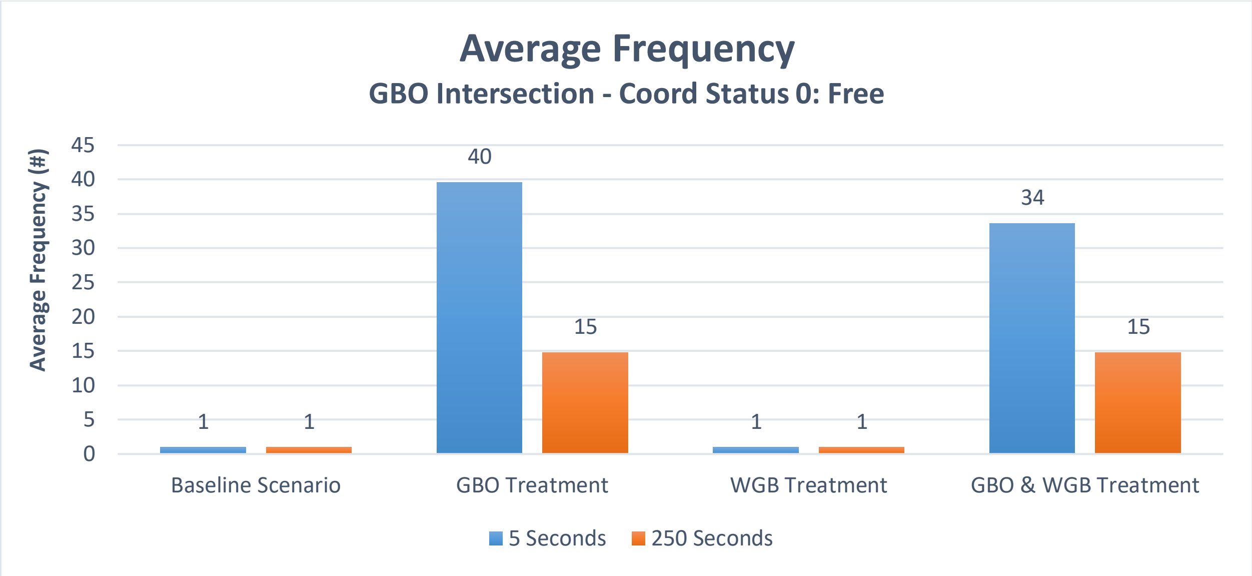

Figure 50 Average Frequency for the George Bush Dr-Olsen Blvd intersection for the coordination status 0 = FREE

Figure 51 and Figure 52 show the results for the Welborn Rd-George Bush Dr intersection for the coordination status 0=Free. Similar to the previous figures, GBO treatment does not have impact on the results at Welborn Rd-George Bush Dr. On the other hand, WGB treatment and GBO & WGB treatment have changes in operations and increase both the total duration and the frequency. Similar to the George Bush Dr-Olsen Blvd intersection results, the effects are lower for the preemption reservice of 250 seconds.

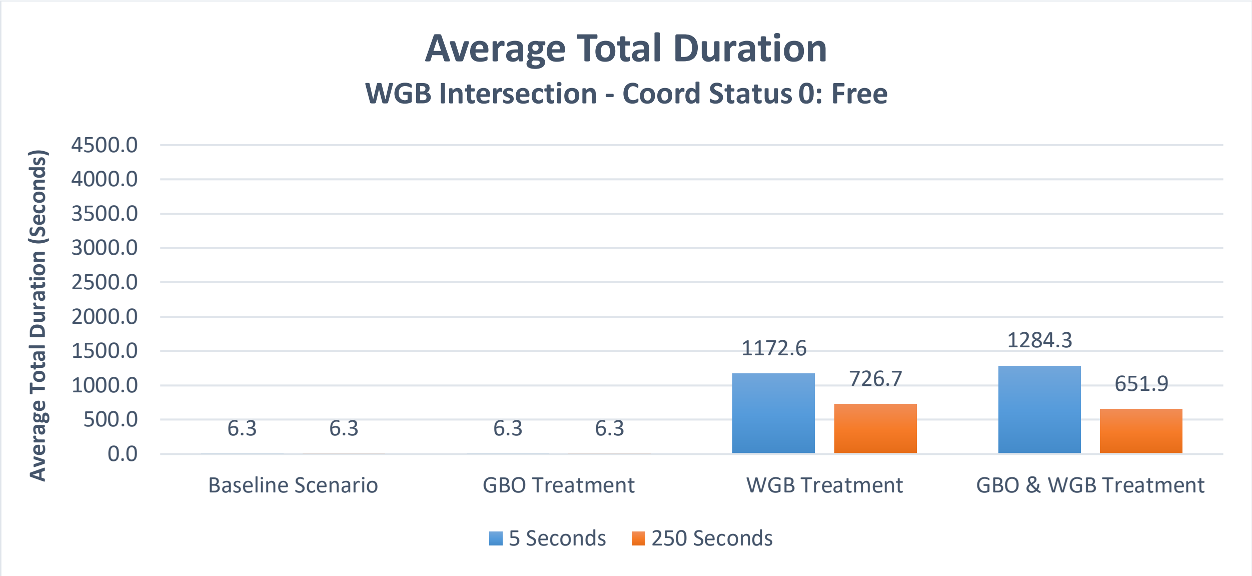

Figure 51 Average Total Duration for the George Bush Dr-Welborn Rd intersection for the coordination status 0 = FREE

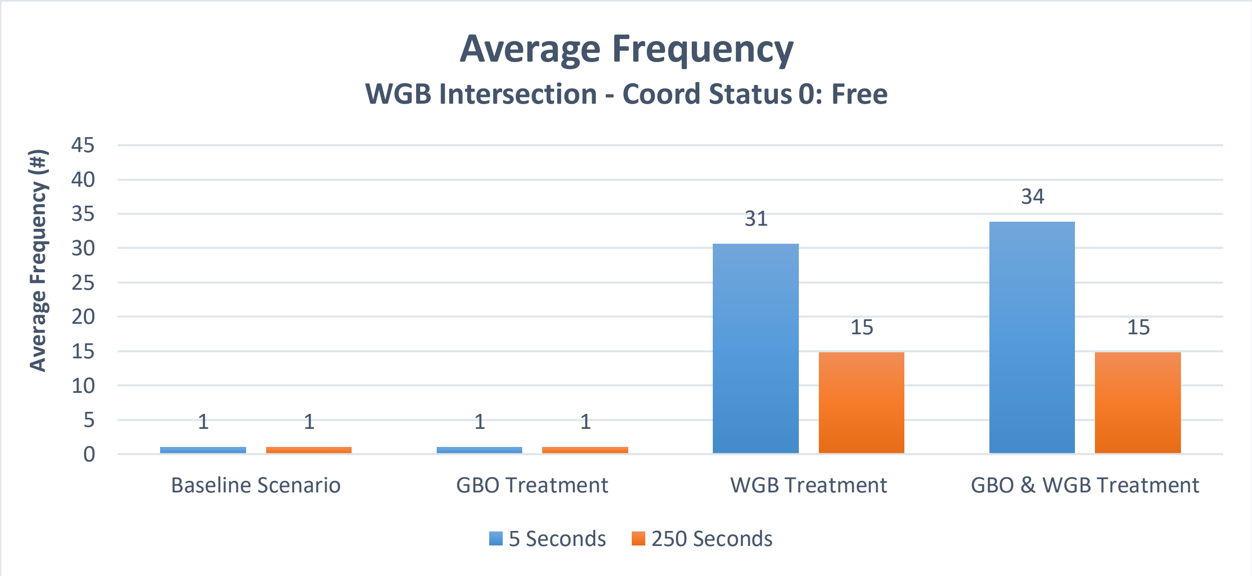

Figure 52 Average Frequency for the George Bush Dr-Welborn Rd intersection for the coordination status 0 = FREE

Average total duration and average frequency for the George Bush Dr-Olsen Blvd and for the coordination status 1= Coord are shown in Figure 53 and Figure 54. Results reveal that although the frequency of COORD status increase for both GBO treatment and GBO & WGB treatment, the total duration are reduced. The reduction is more for preemption reservice 5 seconds meaning that the 5 second reserve setting more drastically reduce the amount of time in normal operations than the 250 second reservice setting.

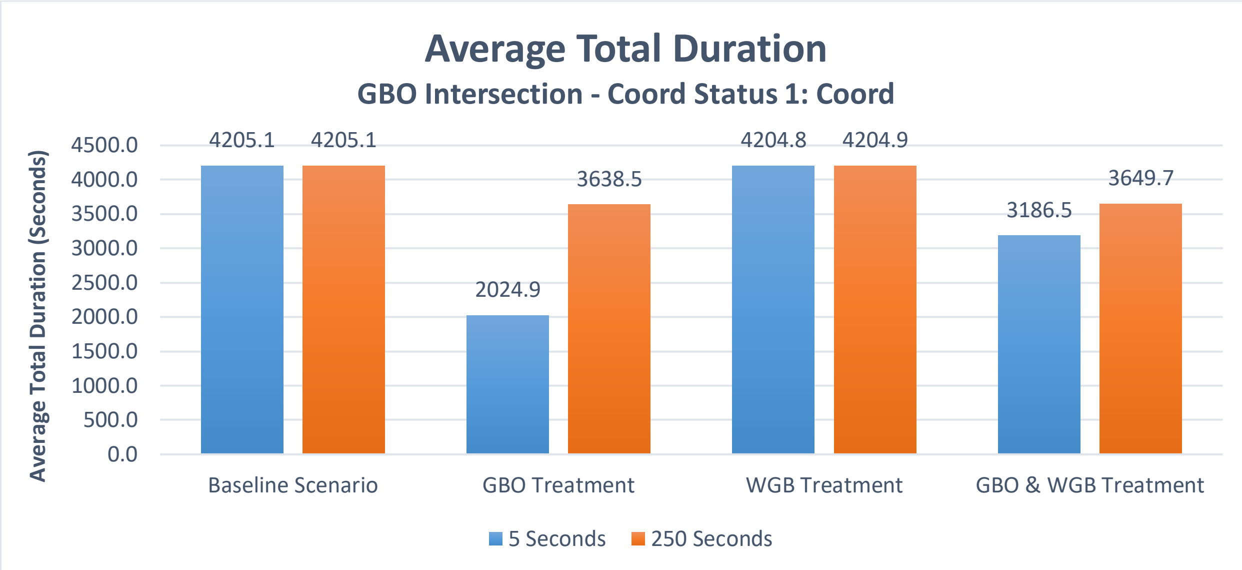

Figure 53 Average Total Duration for the George Bush Dr-Olsen Blvd intersection for the coordination status 1=COORD

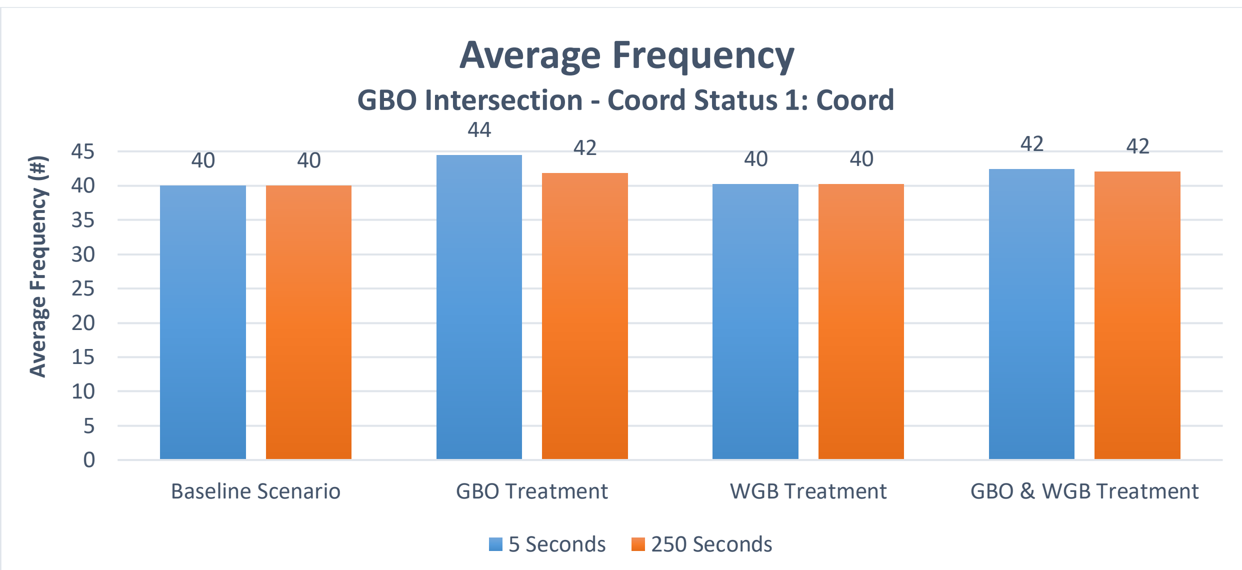

Figure 54 Average Frequency for the George Bush Dr-Olsen Blvd intersection for the coordination status 1=COORD

The same approach is demonstrated for George Bush Dr-Welborn Rd intersection in Figure 55 and Figure 56. Average total duration decreases for both WGB treatment and GBO & WGB treatment. However, the frequency increases for both of the treatments.

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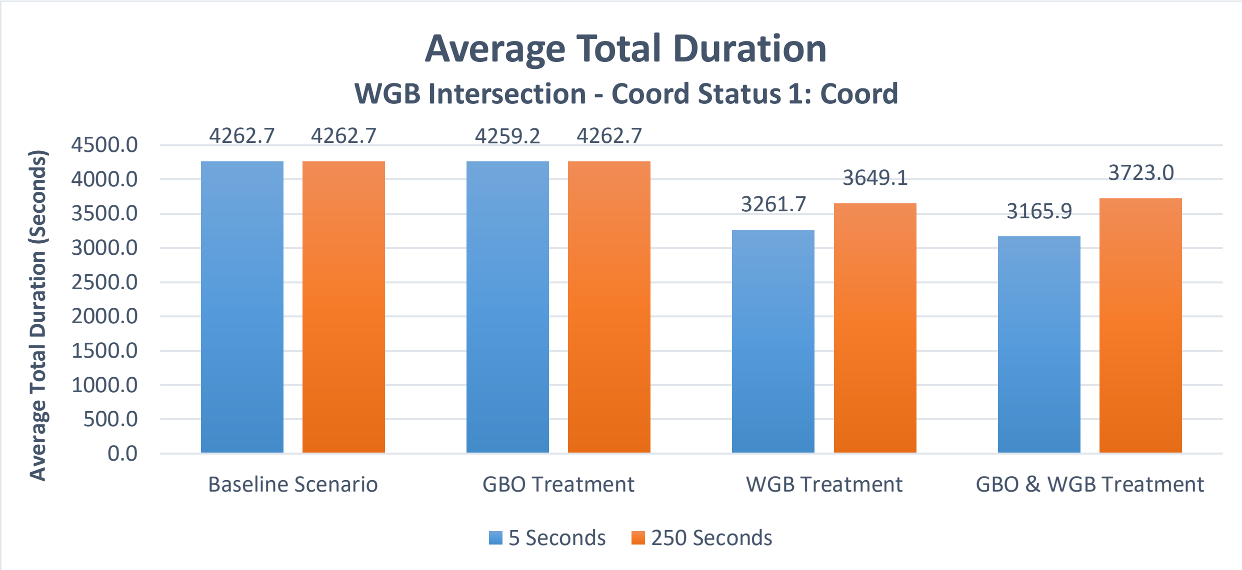

Figure 55 Average Total Duration for the George Bush Dr-Welborn Rd intersection for the coordination status 1=COORD

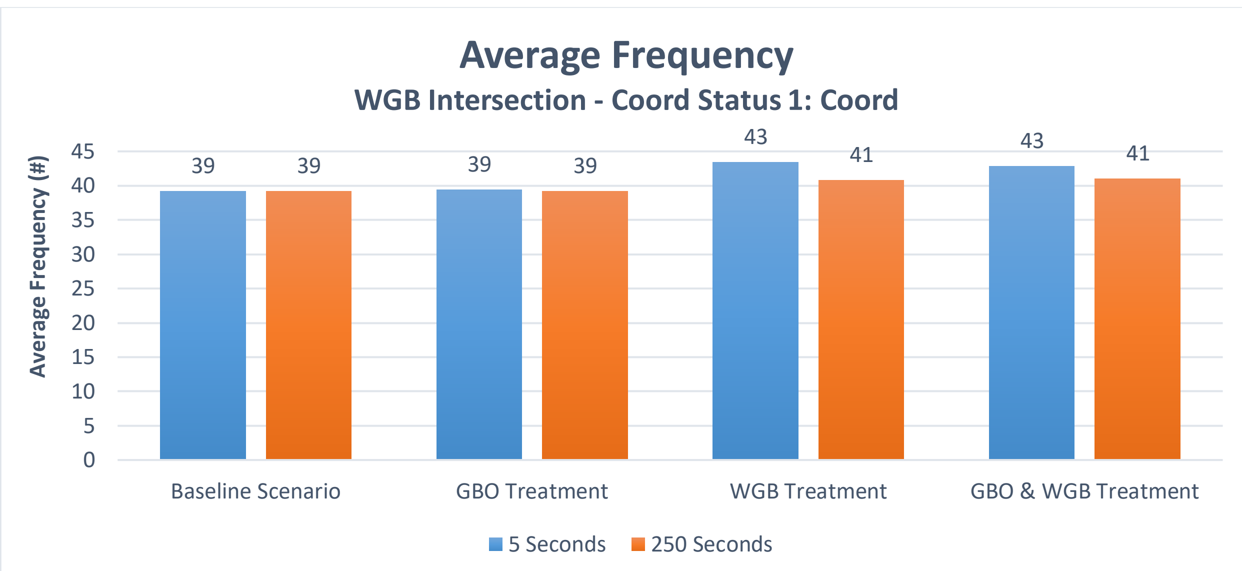

Figure 56 Average Frequency for the George Bush Dr-Welborn Rd intersection for the coordination status 1=COORD

Conclusion

In large cities, traffic congestion is a serious concern. A remedy to this problem is to enhance supply by extending or building additional roads, which would assist to boost capacity. Higher capacity, on the other hand, would increase demand on routes approaching intersections, resulting in delays and bottlenecks. When demand exceeds the capacity of the intersection (oversaturated circumstances), queues may not disperse entirely during the green light. As a result, the queue would spill back and block the downstream intersection (especially in closely spaced intersections). To address these challenges and manage delays and gridlock, traffic management solutions are suggested.

The use of real-time data to regulate each phase timing is introduced in actuated traffic signal control. Phasing time intervals are called or extended in response to real-time demand, specifically the length of the queue at each approach caused by detector actuations.

The city of College Station, Texas has a corridor that suffers from traffic congestion and queue spill-back issue during the PM peak. This corridor includes George Bush Dr, Olsen Blvd, and Wellborn Rd (the last two intersect George Bush Dr. close together).

To resolve this issue, in this report, we first use real volume data, geometry information, and signal timing data to build the network in VISSIM, which includes the three main roads and five main intersections. Then, using VISSIM, a metering plan with different scenarios is built to see how effective each one is to alleviate the queue spill-back issue using real time data, and detector actuation and occupancy. Each scenario is also subjected to a sensitivity analysis (preemption reservice 5 seconds versus 250 seconds).

Considering the results driven from the simulation, *GBO & WGB treatment* with the preemption reservice value of 250 seconds is selected as the best scenario to resolve the issue. Considering the *GBO & WGB treatment*, delay measurements results show a reduction in average delay. Moreover, node measurement results reveal that *GBO & WGB treatment*, in almost all nodes, reduces the average delay, stopped delay, and queue length. Network performance results also show that *GBO & WGB treatment* does a good job on the critical movements in terms of total delay and total travel times. Using the *GBO & WGB treatment* would increase the green time usage for the opposite direction reduce the demand for the critical direction and increase the green time usage for the critical movements to flush the queue and reduce the traffic congestion and queue spill-back issue. However, this treatment is a tradeoff between the movements going eastbound on George Bush Dr. and the traffic on Wellborn Rd. The treatment does increase the delay on Wellborn Rd in both directions by about two minutes on average in favor of reducing the delay for eastbound traffic on George Bush Dr. by greater than two minutes on average, which results in less network delay. This treatment harms coordination but helps ensure that green time allotted to movements in the network are utilized.

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Appendix A

Peak period determination

To determine the peak period, consecutive 15-minute volumes are aggregated over each one-hour period (e.g., 1:15 to 2:15, 1:30 to 2:30, 1:45 to 2:45, etc.) over all intersections (Table 1). We then determine the peak periods considering the ones (during the morning and afternoon, separately) which contain the most volume. Table 2 shows the 15-minute volume for all turning movements and for each intersection separately. In the column titled "Total Volumes (All Intersections) (veh/hr)," 15-minute volumes across all intersections are aggregated. Then the volume for one hour is calculated by aggregating the "Total Volume" across four consecutive 15-minute volume data (e.g., 0:00 to 1:00, 0:15 to 1:15, 0:30 to 1:30, etc.). The one-hour periods with the highest aggregated volume for morning and afternoon, separately, are considered for AM and PM peak hours, respectively. Finally, the 8:45 – 9:45 time period is considered for the AM peak, and the 16:45 – 17:45 is considered for the PM peak.

Table 2. Peak Period Determination

Timestamp	15-minute Volume				Total Volumes (All Intersections) (veh/hr)	Total Volume (one hour) (veh/hr)
	HGB	WGB	OGB	WJ		
4/13/2021 0:00	240	1016	116	600	1972	6336
4/13/2021 0:15	260	888	76	592	1816	5508
4/13/2021 0:30	232	788	60	456	1536	4456
4/13/2021 0:45	116	524	48	324	1012	3784
4/13/2021 1:00	152	552	44	396	1144	3568
4/13/2021 1:15	104	416	12	232	764	3168
4/13/2021 1:30	120	480	24	240	864	2860
4/13/2021 1:45	72	400	56	268	796	2452
4/13/2021 2:00	96	412	40	196	744	2104
4/13/2021 2:15	60	252	16	128	456	1684
4/13/2021 2:30	52	232	24	148	456	1544
4/13/2021 2:45	40	248	16	144	448	1376
4/13/2021 3:00	36	164	12	112	324	1192
4/13/2021 3:15	48	156	8	104	316	1100
4/13/2021 3:30	40	112	20	116	288	996
4/13/2021 3:45	60	108	24	72	264	1008
4/13/2021 4:00	44	124	16	48	232	1180
4/13/2021 4:15	36	96	4	76	212	1700
4/13/2021 4:30	44	132	0	124	300	2244
4/13/2021 4:45	64	244	4	124	436	2940
4/13/2021 5:00	148	388	44	172	752	4236

4/13/2021 5:15	140	388	32	196	756	4868
4/13/2021 5:30	172	472	96	256	996	5648
4/13/2021 5:45	300	788	124	520	1732	7236
4/13/2021 6:00	232	716	132	304	1384	8644
4/13/2021 6:15	204	760	140	432	1536	10708
4/13/2021 6:30	356	1100	184	944	2584	13896
4/13/2021 6:45	432	1444	232	1032	3140	17612
4/13/2021 7:00	560	1724	224	940	3448	21972
4/13/2021 7:15	796	2296	284	1348	4724	24216
4/13/2021 7:30	1156	2976	436	1732	6300	24400
4/13/2021 7:45	1392	3536	536	2036	7500	23100
4/13/2021 8:00	1128	2664	368	1532	5692	21240
4/13/2021 8:15	1028	2356	360	1164	4908	21580
4/13/2021 8:30	904	2428	392	1276	5000	23872
4/13/2021 8:45	**1132**	**2632**	**400**	**1476**	**5640**	**25672**
4/13/2021 9:00	**1048**	**2980**	**516**	**1488**	**6032**	**25140**
4/13/2021 9:15	**1356**	**3440**	**624**	**1780**	**7200**	**23736**
4/13/2021 9:30	**1284**	**3260**	**616**	**1640**	**6800**	**21320**
4/13/2021 9:45	928	2536	376	1268	5108	20000
4/13/2021 10:00	916	2208	300	1204	4628	21456
4/13/2021 10:15	972	2280	316	1216	4784	25088
4/13/2021 10:30	1032	2644	400	1404	5480	28180
4/13/2021 10:45	1192	3184	520	1668	6564	29000
4/13/2021 11:00	1512	3868	716	2164	8260	28684
4/13/2021 11:15	1472	3724	652	2028	7876	27212
4/13/2021 11:30	1176	3012	368	1744	6300	26360
4/13/2021 11:45	1240	3036	412	1560	6248	27588
4/13/2021 12:00	1428	3240	420	1700	6788	30324
4/13/2021 12:15	1308	3440	416	1860	7024	33316
4/13/2021 12:30	1536	3492	504	1996	7528	35608
4/13/2021 12:45	1700	4276	652	2356	8984	35620
4/13/2021 13:00	1876	4492	672	2740	9780	33592
4/13/2021 13:15	1872	4260	748	2436	9316	30656
4/13/2021 13:30	1564	3708	416	1852	7540	28216
4/13/2021 13:45	1424	3248	464	1820	6956	28608
4/13/2021 14:00	1168	3364	496	1816	6844	31616
4/13/2021 14:15	1216	3272	548	1840	6876	34000
4/13/2021 14:30	1528	3764	624	2016	7932	34452
4/13/2021 14:45	1876	4632	884	2572	9964	34304
4/13/2021 15:00	1672	4320	692	2544	9228	31676
4/13/2021 15:15	1228	3576	492	2032	7328	29536

4/13/2021 15:30	1496	3764	532	1992	7784	29900
4/13/2021 15:45	1300	3632	380	2024	7336	31108
4/13/2021 16:00	1320	3496	476	1796	7088	33240
4/13/2021 16:15	1308	3764	560	2060	7692	36512
4/13/2021 16:30	1620	4200	752	2420	8992	38516
4/13/2021 16:45	**1816**	**4544**	**644**	**2464**	**9468**	**38856**
4/13/2021 17:00	**2008**	**4760**	**740**	**2852**	**10360**	**38276**
4/13/2021 17:15	**1872**	**4732**	**648**	**2444**	**9696**	**36256**
4/13/2021 17:30	**1716**	**4468**	**564**	**2584**	**9332**	**35252**
4/13/2021 17:45	1656	4384	628	2220	8888	34368
4/13/2021 18:00	1616	4064	596	2064	8340	33364
4/13/2021 18:15	1680	4256	728	2028	8692	32808
4/13/2021 18:30	1568	4048	528	2304	8448	31212
4/13/2021 18:45	1564	3808	500	2012	7884	29488
4/13/2021 19:00	1528	3924	432	1900	7784	29392
4/13/2021 19:15	1380	3460	452	1804	7096	28904
4/13/2021 19:30	1380	3124	496	1724	6724	29652
4/13/2021 19:45	1524	3916	468	1880	7788	31012
4/13/2021 20:00	1396	3144	540	2216	7296	31248
4/13/2021 20:15	1552	3220	564	2508	7844	30000
4/13/2021 20:30	1420	3400	760	2504	8084	27616
4/13/2021 20:45	1512	3480	740	2292	8024	23988
4/13/2021 21:00	1044	2584	480	1940	6048	20536
4/13/2021 21:15	1056	2256	336	1812	5460	19340
4/13/2021 21:30	860	2008	320	1268	4456	18756
4/13/2021 21:45	884	2000	312	1376	4572	19600
4/13/2021 22:00	784	2112	288	1668	4852	19416
4/13/2021 22:15	876	2016	520	1464	4876	18176
4/13/2021 22:30	1020	2072	584	1624	5300	16272
4/13/2021 22:45	856	1900	376	1256	4388	13892
4/13/2021 23:00	692	1648	196	1076	3612	12200
4/13/2021 23:15	544	1280	244	904	2972	11048
4/13/2021 23:30	476	1336	140	968	2920	10384
4/13/2021 23:45	516	1196	128	856	2696	9420
4/14/2021 0:00	424	1040	124	872	2460	-
4/14/2021 0:15	372	1032	100	804	2308	-
4/14/2021 0:30	288	888	52	728	1956	-

Appendix B

Relative Traffic Flow

Based on the values of the turning movements presented in the excel files and for PM and AM peak separately, relative traffic flow for each static vehicle route is defined. To calculate each relative flow rate, the volume of each movement is divided into the total volume of the static vehicle route. As an example, Figure 57 shows the route number 1-1 (Wellborn Rd. northbound - Holleman Dr. westbound) and the relative flow rate for this route. Since the volume differences between 15-minute intervals are too small, the average relative flow rate across four intervals (in one hour of peak hour) is determined (Table 3).

Figure 57 Relative Flow Rate for Wellborn Rd Northbound - Holleman Dr Westbound

Table 3 Relative flow rate

Number	Intersection(s) Included	Start	End	Relative Flow Rate
1-1	WHO	Wellborn Rd. northbound	Holleman Dr. westbound	0.14
1-2	WHO	Wellborn Rd. northbound	Wellborn Rd. northbound	0.78e
1-3	WHO	Wellborn Rd. northbound	Holleman Dr. eastbound	0.08
2-1	WHO	Wellborn Rd. southbound	Holleman Dr. eastbound	0.05
2-2	WHO	Wellborn Rd. southbound	Wellborn Rd. southbound	0.82
2-3	WHO	Wellborn Rd. southbound	Holleman Dr. westbound	0.13

3-1	WHO	Holleman Dr. eastbound	Wellborn Rd. northbound	0.28
3-2	WHO	Holleman Dr. eastbound	Holleman Dr. eastbound	0.52
3-3	WHO	Holleman Dr. eastbound	Wellborn Rd. southbound	0.20
4-1	WHO	Holleman Dr. westbound	Wellborn Rd. southbound	0.15
4-2	WHO	Holleman Dr. westbound	Holleman Dr. westbound	0.64
4-3	WHO	Holleman Dr. westbound	Wellborn Rd. northbound	0.21
5-1	WGB, GBO	Wellborn Rd. northbound	George Bush Dr. westbound	0.10
5-2	WGB	Wellborn Rd. northbound	Wellborn Rd. northbound	0.70
5-3	WGB	Wellborn Rd. northbound	George Bush Dr. eastbound	0.10
5-4	WGB, GBO	Wellborn Rd. northbound	Olsen Blvd. northbound	0.10
6-1	WGB	Wellborn Rd. northbound	George Bush Dr. eastbound	0.22
6-2	WGB	Wellborn Rd. southbound	Wellborn Rd. southbound	0.68
6-3	WGB, GBO	Wellborn Rd. southbound	George Bush Dr. westbound	0.06
6-4	WGB	Wellborn Rd. southbound	Marion Pugh Dr. southbound	0.01
6-5	WGB, GBO	Wellborn Rd. southbound	Olsen Blvd. southbound	0.01
6-6	WGB, GBO	Wellborn Rd. southbound	Olsen Blvd. northbound	0.02
7-1	WJ	Wellborn Rd. northbound	Joe Routt Blvd. westbound	0.05
7-2	WJ	Wellborn Rd. northbound	Wellborn Rd. northbound	0.90
7-3	WJ	Wellborn Rd. northbound	Joe Routt Blvd. eastbound	0.05
8-1	WJ	Wellborn Rd. southbound	Joe Routt Blvd. eastbound	0.05
8-2	WJ	Wellborn Rd. southbound	Wellborn Rd. southbound	0.90
8-3	WJ	Wellborn Rd. southbound	Joe Routt Blvd. westbound	0.05
9-1	WJ	Joe Routt Blvd. eastbound	Wellborn Rd. northbound	0.05
9-2	WJ	Joe Routt Blvd. eastbound	Joe Routt Blvd. eastbound	0.10
9-3	WJ	Joe Routt Blvd. eastbound	Wellborn Rd. southbound	0.40
10-1	WJ	Joe Routt Blvd. westbound	Wellborn Rd. southbound	0.33
10-2	WJ	Joe Routt Blvd. westbound	Joe Routt Blvd. eastbound	0.33
10-3	WJ	Joe Routt Blvd. westbound	Wellborn Rd. northbound	0.33
11-1	GBO	George Bush Dr. eastbound	Olsen Blvd. northbound	0.10
11-2	GBO, WGB	George Bush Dr. eastbound	George Bush Dr. eastbound	0.68
11-3	GBO	George Bush Dr. eastbound	Olsen Blvd. southbound	0.02
11-4	GBO	George Bush Dr. eastbound	Marion Pugh Dr. southbound	0.04
11-5	GBO, WGB	George Bush Dr. eastbound	Wellborn Rd. southbound	0.08
11-6	GBO, WGB	George Bush Dr. eastbound	Wellborn Rd. northbound	0.08
13-1	GBH	George Bush Dr. eastbound	Houston St. northbound	0.02
13-2	GBH	George Bush Dr. eastbound	George Bush Dr. eastbound	0.98
14-1	WGB	George Bush Dr. eastbound	Wellborn Rd. southbound	0.15
14-2	WGB, GBO	George Bush Dr. westbound	George Bush Dr. westbound	0.50
14-3	WGB	George Bush Dr. westbound	Wellborn Rd. northbound	0.15
14-4	WGB, GBO	George Bush Dr. westbound	Olsen Blvd. southbound	0.05
14-5	WGB	George Bush Dr. westbound	Marion Pugh Dr. southbound	0.05
14-6	WGB	George Bush Dr. westbound	Olsen Blvd. northbound	0.10
16-1	GBH	George Bush Dr. westbound	George Bush Dr. westbound	0.98

16-2	GBH	George Bush Dr. westbound	Houston St. northbound	0.02
17-1	GBH	Houston St. southbound	George Bush Dr. eastbound	0.50
17-2	GBH	Houston St. southbound	George Bush Dr. westbound	0.50
18-1	GBO	Olsen Blvd. northbound	George Bush Dr. westbound	0.33
18-2	GBO	Olsen Blvd. northbound	Olsen Blvd. northbound	0.33
18-3	GBO	Olsen Blvd. northbound	George Bush Dr. eastbound	0.33
19-1	GBO	Olsen Blvd. southbound	Marion Pugh Dr. southbound	0.05
19-2	GBO	Olsen Blvd. southbound	Olsen Blvd. southbound	0.05
19-3	GBO	Olsen Blvd. southbound	George Bush Dr. westbound	0.10
19-4	GBO, WGB	Olsen Blvd. southbound	Wellborn Rd. southbound	0.08
19-5	GBO, WGB	Olsen Blvd. southbound	George Bush Dr. westbound	0.64
19-6	GBO, WGB	Olsen Blvd. southbound	Wellborn Rd. northbound	0.08
21-1	WGB	Marion Pugh Dr. northbound	Wellborn Rd. southbound	0.10
21-2	WGB	Marion Pugh Dr. northbound	George Bush Dr. eastbound	0.35
21-3	WGB	Marion Pugh Dr. northbound	Wellborn Rd. northbound	0.10
21-4	GBO	Marion Pugh Dr. northbound	George Bush Dr. westbound	0.35
21-5	GBO	Marion Pugh Dr. northbound	Olsen Blvd. northbound	0.10

Appendix C

Coordination Status Results

Table 4 and Table 5 show the results of the total duration and frequency of each coordination status, treatment, and reservice time for George Bush Dr-Olsen Blvd intersection and George Bush Dr-Welborn Rd intersection, respectively.

Table 4 Total Duration and Frequency of Different Coordination status for George Bush Dr-Olsen Blvd intersection

Intersection	Treatment	Reservice Time	Run #	Coord Status	Total Duration (Seconds)	Frequency
GBO	Baseline	-	1	0: FREE	6.3	1
				1: COORD	4205.1	40
				4: DWELL	119.8	6
				5: SYNC	132.6	34
				6: PICK-UP	36.2	1
GBO	Baseline	-	2	0: FREE	6.3	1
				1: COORD	4205.1	40
				4: DWELL	119.8	6
				5: SYNC	132.6	34
				6: PICK-UP	36.2	1
GBO	Baseline	-	3	0: FREE	6.3	1
				1: COORD	4205.1	40
				4: DWELL	119.8	6
				5: SYNC	132.6	34
				6: PICK-UP	36.2	1
GBO	Baseline	-	4	0: FREE	6.3	1
				1: COORD	4205.1	40
				4: DWELL	119.8	6
				5: SYNC	132.6	34
				6: PICK-UP	36.2	1
GBO	Baseline	-	5	0: FREE	6.3	1
				1: COORD	4205.1	40
				4: DWELL	119.8	6
				5: SYNC	132.6	34
				6: PICK-UP	36.2	1
GBO	GBO	5 Seconds	1	0: FREE	2260.9	37
				1: COORD	2158.3	43
				4: DWELL	20.5	2
				5: SYNC	24.1	7

				6: PICK-UP	36.2	1
GBO	GBO	5 Seconds	2	0: FREE	2386.9	39
				1: COORD	2031.8	44
				4: DWELL	20	1
				5: SYNC	25.1	8
				6: PICK-UP	36.2	1
GBO	GBO	5 Seconds	3	0: FREE	2449	39
				1: COORD	1966.8	44
				4: DWELL	20	1
				5: SYNC	28	8
				6: PICK-UP	36.2	1
GBO	GBO	5 Seconds	4	0: FREE	2387.4	45
				1: COORD	2036	49
				4: DWELL	15.5	1
				5: SYNC	24.9	8
				6: PICK-UP	36.2	1
GBO	GBO	5 Seconds	5	0: FREE	2492.7	38
				1: COORD	1931.7	42
				4: DWELL	20	1
				5: SYNC	19.4	5
				6: PICK-UP	36.2	1
GBO	WGB	5 Seconds	1	0: FREE	6.3	1
				1: COORD	4205.1	40
				4: DWELL	119.8	6
				5: SYNC	132.6	34
				6: PICK-UP	36.2	1
GBO	WGB	5 Seconds	2	0: FREE	6.3	1
				1: COORD	4205.1	40
				4: DWELL	119.8	6
				5: SYNC	132.6	34
				6: PICK-UP	36.2	1
GBO	WGB	5 Seconds	3	0: FREE	6.3	1
				1: COORD	4205.1	40
				4: DWELL	119.8	6
				5: SYNC	132.6	34
				6: PICK-UP	36.2	1
GBO	WGB	5 Seconds	4	0: FREE	6.3	1
				1: COORD	4203.7	41
				4: DWELL	121.2	7
				5: SYNC	132.6	34
				6: PICK-UP	36.2	1
GBO	WGB	5 Seconds	5	0: FREE	6.3	1
				1: COORD	4205.1	40

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				4: DWELL	119.8	6
				5: SYNC	132.6	34
				6: PICK-UP	36.2	1
GBO	GBO & WGB	5 Seconds	1	0: FREE	983.9	31
				1: COORD	3397.6	43
				4: DWELL	20.5	2
				5: SYNC	61.8	16
				6: PICK-UP	36.2	1
GBO	GBO & WGB	5 Seconds	2	0: FREE	955.9	30
				1: COORD	3424.4	40
				4: DWELL	20	1
				5: SYNC	63.5	18
				6: PICK-UP	36.2	1
GBO	GBO & WGB	5 Seconds	3	0: FREE	1428.5	37
				1: COORD	2973.7	44
				4: DWELL	20.5	2
				5: SYNC	41.1	13
				6: PICK-UP	36.2	1
GBO	GBO & WGB	5 Seconds	4	0: FREE	1261	35
				1: COORD	3131.1	43
				4: DWELL	20	1
				5: SYNC	51.7	15
				6: PICK-UP	36.2	1
GBO	GBO & WGB	5 Seconds	5	0: FREE	1401.7	35
				1: COORD	3005.9	42
				4: DWELL	20	1
				5: SYNC	36.2	11
				6: PICK-UP	36.2	1
GBO	GBO	250 Seconds	1	0: FREE	804.4	14
				1: COORD	3534.6	40
				4: DWELL	20.5	2
				5: SYNC	104.3	27
				6: PICK-UP	36.2	1
GBO	GBO	250 Seconds	2	0: FREE	645.4	15
				1: COORD	3692.2	43
				4: DWELL	20	1
				5: SYNC	106.2	28
				6: PICK-UP	36.2	1
GBO	GBO	250 Seconds	3	0: FREE	748.1	15
				1: COORD	3590	42
				4: DWELL	20.5	2
				5: SYNC	105.2	27
				6: PICK-UP	36.2	1

GBO	GBO	250 Seconds	4	0: FREE	641.6	15
				1: COORD	3693.1	43
				4: DWELL	20	1
				5: SYNC	109.1	28
				6: PICK-UP	36.2	1
GBO	GBO	250 Seconds	5	0: FREE	650	15
				1: COORD	3682.7	41
				4: DWELL	20	1
				5: SYNC	111.1	29
				6: PICK-UP	36.2	1
GBO	WGB	250 Seconds	1	0: FREE	6.3	1
				1: COORD	4205.1	40
				4: DWELL	119.8	6
				5: SYNC	132.6	34
				6: PICK-UP	36.2	1
GBO	WGB	250 Seconds	2	0: FREE	6.3	1
				1: COORD	4205.1	40
				4: DWELL	119.8	6
				5: SYNC	132.6	34
				6: PICK-UP	36.2	1
GBO	WGB	250 Seconds	3	0: FREE	6.3	1
				1: COORD	4205.1	40
				4: DWELL	119.8	6
				5: SYNC	132.6	34
				6: PICK-UP	36.2	1
GBO	WGB	250 Seconds	4	0: FREE	6.3	1
				1: COORD	4204	41
				4: DWELL	120.9	7
				5: SYNC	132.6	34
				6: PICK-UP	36.2	1
GBO	WGB	250 Seconds	5	0: FREE	6.3	1
				1: COORD	4205.1	40
				4: DWELL	119.8	6
				5: SYNC	132.6	34
				6: PICK-UP	36.2	1
GBO	GBO & WGB	250 Seconds	1	0: FREE	783.8	14
				1: COORD	3554.4	40
				4: DWELL	20.5	2
				5: SYNC	105.1	27
				6: PICK-UP	36.2	1
GBO	GBO & WGB	250 Seconds	2	0: FREE	687.1	15
				1: COORD	3652.5	41
				4: DWELL	20	1

				5: SYNC	104.2	28
				6: PICK-UP	36.2	1
GBO	GBO & WGB	250 Seconds	3	0: FREE	603.8	15
				1: COORD	3730.3	44
				4: DWELL	20.5	2
				5: SYNC	109.2	28
				6: PICK-UP	36.2	1
GBO	GBO & WGB	250 Seconds	4	0: FREE	723.2	15
				1: COORD	3608.6	42
				4: DWELL	20	1
				5: SYNC	112	29
				6: PICK-UP	36.2	1
GBO	GBO & WGB	250 Seconds	5	0: FREE	630.9	15
				1: COORD	3702.9	43
				4: DWELL	20	1
				5: SYNC	110	29
				6: PICK-UP	36.2	1

Table 5 Total Duration and Frequency of Different Coordination status for George Bush Dr-Welborn Rd intersection

Intersection	Treatment	Reservice Time	Run #	Coord Status	Total Duration (Seconds)	Frequency
WGB	Baseline	-	1	0: FREE	6.3	1
				1: COORD	4263.3	39
				4: DWELL	97.8	5
				5: SYNC	132.6	34
				6: PICK-UP	0	0
WGB	Baseline	-	2	0: FREE	6.3	1
				1: COORD	4262.8	39
				4: DWELL	98.3	5
				5: SYNC	132.6	34
				6: PICK-UP	0	0
WGB	Baseline	-	3	0: FREE	6.3	1
				1: COORD	4263.3	39
				4: DWELL	97.8	5
				5: SYNC	132.6	34
				6: PICK-UP	0	0
WGB	Baseline	-	4	0: FREE	6.3	1
				1: COORD	4260.7	40
				4: DWELL	100.4	6

				5: SYNC	132.6	34
				6: PICK-UP	0	0
WGB	Baseline	-	5	0: FREE	6.3	1
				1: COORD	4263.3	39
				4: DWELL	97.8	5
				5: SYNC	132.6	34
				6: PICK-UP	0	0
WGB	GBO	5 Seconds	1	0: FREE	6.3	1
				1: COORD	4263.3	39
				4: DWELL	97.8	5
				5: SYNC	132.6	34
				6: PICK-UP	0	0
WGB	GBO	5 Seconds	2	0: FREE	6.3	1
				1: COORD	4260.7	40
				4: DWELL	100.4	6
				5: SYNC	132.6	34
				6: PICK-UP	0	0
WGB	GBO	5 Seconds	3	0: FREE	6.3	1
				1: COORD	4263.3	39
				4: DWELL	97.8	5
				5: SYNC	132.6	34
				6: PICK-UP	0	0
WGB	GBO	5 Seconds	4	0: FREE	6.3	1
				1: COORD	4245.4	40
				4: DWELL	115.7	6
				5: SYNC	132.6	34
				6: PICK-UP	0	0
WGB	GBO	5 Seconds	5	0: FREE	6.3	1
				1: COORD	4263.3	39
				4: DWELL	97.8	5
				5: SYNC	132.6	34
				6: PICK-UP	0	0
WGB	WGB	5 Seconds	1	0: FREE	896.2	23
				1: COORD	3520.7	39
				4: DWELL	20	1
				5: SYNC	63.1	17
				6: PICK-UP	0	0
WGB	WGB	5 Seconds	2	0: FREE	1228.9	34
				1: COORD	3234.5	42
				4: DWELL	4	1
				5: SYNC	32.6	10
				6: PICK-UP	0	0
WGB	WGB	5 Seconds	3	0: FREE	1273.3	33

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				1: COORD	3156	47
				4: DWELL	20	1
				5: SYNC	50.7	13
				6: PICK-UP	0	0
WGB	WGB	5 Seconds	4	0: FREE	1145.1	28
				1: COORD	3275.7	43
				4: DWELL	20	1
				5: SYNC	59.2	16
				6: PICK-UP	0	0
WGB	WGB	5 Seconds	5	0: FREE	1319.3	35
				1: COORD	3121.7	46
				4: DWELL	20	1
				5: SYNC	39	10
				6: PICK-UP	0	0
WGB	GBO & WGB	5 Seconds	1	0: FREE	1094.7	32
				1: COORD	3346.3	43
				4: DWELL	20	1
				5: SYNC	39	10
				6: PICK-UP	0	0
WGB	GBO & WGB	5 Seconds	2	0: FREE	1081.1	29
				1: COORD	3372	39
				4: DWELL	4	1
				5: SYNC	42.9	11
				6: PICK-UP	0	0
WGB	GBO & WGB	5 Seconds	3	0: FREE	1505.8	37
				1: COORD	2950.1	44
				4: DWELL	20	1
				5: SYNC	24.1	7
				6: PICK-UP	0	0
WGB	GBO & WGB	5 Seconds	4	0: FREE	1291.4	34
				1: COORD	3153.5	44
				4: DWELL	20	1
				5: SYNC	35.1	9
				6: PICK-UP	0	0
WGB	GBO & WGB	5 Seconds	5	0: FREE	1448.4	37
				1: COORD	3007.5	44
				4: DWELL	20	1
				5: SYNC	24.1	7
				6: PICK-UP	0	0
WGB	GBO	250 Seconds	1	0: FREE	6.3	1
				1: COORD	4263.3	39
				4: DWELL	97.8	5
				5: SYNC	132.6	34

				6: PICK-UP	0	0
WGB	GBO	250 Seconds	2	0: FREE	6.3	1
				1: COORD	4262.8	39
				4: DWELL	98.3	5
				5: SYNC	132.6	34
				6: PICK-UP	0	0
WGB	GBO	250 Seconds	3	0: FREE	6.3	1
				1: COORD	4263.3	39
				4: DWELL	97.8	5
				5: SYNC	132.6	34
				6: PICK-UP	0	0
WGB	GBO	250 Seconds	4	0: FREE	6.3	1
				1: COORD	4260.7	40
				4: DWELL	100.4	6
				5: SYNC	132.6	34
				6: PICK-UP	0	0
WGB	GBO	250 Seconds	5	0: FREE	6.3	1
				1: COORD	4263.3	39
				4: DWELL	97.8	5
				5: SYNC	132.6	34
				6: PICK-UP	0	0
WGB	WGB	250 Seconds	1	0: FREE	626.6	15
				1: COORD	3743.9	43
				4: DWELL	20	1
				5: SYNC	109.5	29
				6: PICK-UP	0	0
WGB	WGB	250 Seconds	2	0: FREE	742.3	15
				1: COORD	3641.4	38
				4: DWELL	20	1
				5: SYNC	96.3	27
				6: PICK-UP	0	0
WGB	WGB	250 Seconds	3	0: FREE	820.8	15
				1: COORD	3555.4	41
				4: DWELL	20	1
				5: SYNC	103.8	28
				6: PICK-UP	0	0
WGB	WGB	250 Seconds	4	0: FREE	750.7	14
				1: COORD	3625.8	41
				4: DWELL	20	1
				5: SYNC	103.5	27
				6: PICK-UP	0	0
WGB	WGB	250 Seconds	5	0: FREE	693.2	15
				1: COORD	3679.1	41

				4: DWELL	20	1
				5: SYNC	107.7	29
				6: PICK-UP	0	0
WGB	GBO & WGB	250 Seconds	1	0: FREE	675.6	14
				1: COORD	3705.4	38
				4: DWELL	20	1
				5: SYNC	99	27
				6: PICK-UP	0	0
WGB	GBO & WGB	250 Seconds	2	0: FREE	642.2	15
				1: COORD	3733.2	40
				4: DWELL	20	1
				5: SYNC	104.6	28
				6: PICK-UP	0	0
WGB	GBO & WGB	250 Seconds	3	0: FREE	623.5	15
				1: COORD	3750.9	42
				4: DWELL	20	1
				5: SYNC	105.6	28
				6: PICK-UP	0	0
WGB	GBO & WGB	250 Seconds	4	0: FREE	725.7	15
				1: COORD	3646.9	43
				4: DWELL	20	1
				5: SYNC	107.4	28
				6: PICK-UP	0	0
WGB	GBO & WGB	250 Seconds	5	0: FREE	592.7	15
				1: COORD	3778.7	42
				4: DWELL	20	1
				5: SYNC	108.6	29
				6: PICK-UP	0	0

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The National Institute for Congestion Reduction (NICR) will emerge as a national leader in providing multimodal congestion reduction strategies through real-world deployments that leverage advances in technology, big data science and innovative transportation options to optimize the efficiency and reliability of the transportation system for all users. Our efficient and effective delivery of an integrated research, education, workforce development and technology transfer program will be a model for the nation.

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