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Modeling Clemson Football Traffic: New Techniques for Small Communities

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MODELING CLEMSON FOOTBALL TRAFFIC: NEW TECHNIQUES FOR SMALL COMMUNITIES

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ABSTRACT

Many communities host planned special events that generate several times the communties' AADT around the event period (e.g. pro and college football games). Larger metropolises benefit from ITS to collect data from, model, plan for, and analyze potential solutions to event-caused congestion. The smaller communities, which do not have the resources for traffic management centers, could benefit from more cost-appropriate methodologies. This thesis presents a cost-effective methodology for traffic data collection before and after these events. Modelers can then use this data in a microsimulation package, such as VISSIM, to model how the transportation network performs during this period, to model treatments, and to obtain MOEs useful for making planning decisions. Furthermore, because these events cause networks to be severely over-saturated, collected data can underestimate the level of demand, as it is restricted by capacity. This thesis also presents a methodology to account for this as well. Researchers collected traffic data with these methods from games in 2014-16, developed models for base and treatment scenarios, and proposed changes to the traffic plan starting in 2015. In addition to the methodology, travel-time results from these models are provided as measures of effectiveness. The author's uses his experience with this project to demonstrate that these methods can be used to microsimulate a severely-oversaturated network and predict treatment effectiveness.

DEDICATION

This thesis is dedicated first to my parents, Theodore and Marie Fry, Grandmère Lariviere, and our friends who prayed for me to get through this phase of my life.

This thesis is also dedicated to the Clemson Student Chapter of the Institute of Transportation Engineers, who were the bedrock of this work. Keep winning Traffic Bowls, and …

…GO TIGERS!

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Next, I want to thank to groups who funded and assisted Dr. Sarasua and I for three years. First, thanks to the CU Athletic Department and AD Dan Radakovich for funding the project and my thesis and to Jon Allen for coordinating with TSL on Game Days. We hope that we have been helpful to you, and we hope you will continue to benefit from TSL's work. Second, thanks to Laura Matney, Gowtham Cherukumalli, Sarath Gorthy, Leonildo Cassule, and Nassim Benaissa for your research contributions and for taking on a lot of the extra work associated with this project. Third, thanks to all the students and volunteers who helped on the Traffic Study and provided much experience and many lessons for the Transportations System Laboratory and me as well. You guys and gals were (and still are) essential to data collection. The total list is too long for this section. I also want to thank Adam Gibson, who paved the way for this thesis and inspired it with his own. Finally, thanks to all members of the Clemson Student Chapter of ITE, who provided the backbone for TSL's efforts and were always available whenever Dr. Sarasua or I asked for your assistance. Also thanks to all of you for your comradery as Gowtham, Laura, and I leaned upon you for support during the trying times of our theses.

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CHAPTER 1: INTRODUCTION

Every year Clemson University, SC, hosts seven football games that generate large volumes of traffic from visitors outside the area. During the study period, the City of Clemson's transportation network supported a student body of 20,000-21,000 students, *(1)* and a town of 15,000-16,000 residents. *(2)* Because stadium capacity is much larger than 37,000, the network's load surges to several times the AADT's of most links on Game Days. Since these volumes are generated by an event presented by the University's Athletics Department, CU Athletics is the lead stakeholder responsible for event traffic management.

In 2003, the SC Highway Patrol (one of the stakeholders who help CU Athletics mange traffic) estimated that an attendance of 65,000 fans could be accommodated with the 2003 network plan. *(3)* Even by 2003, stadium capacity had grown to over 80,000, pushing demand for the network above the SCHP's stated comfort level of 65,000. Back then, this occurred for only the most popular games; now, it occurs regularly during the season.

The current demand for Clemson Football Tickets is at an all-time high. Games against Troy and Georgia Tech had the lowest attendance during the 2016 and 2015 seasons at 78,532 *(4)* and 82,941 *(5)* respectively. Severe over-saturation of the traffic network due to the home football games is an on-going problem that CU Athletics is trying to address. To seek treatments for this problem, CU Athletics commissioned the Clemson Football Traffic Improvement Study. The CU Transportation Systems Laboratory (TSL) in the

Glenn Department of Civil Engineering has carried out this project over the past three years, and their work has served as the basis for several theses and papers, including this one. This thesis, in particular, lays out methods of data collection and analysis that are both predictive and cost-effective for small communities. As a small college town, Clemson does not have the resources for a traffic management center to conduct this type of research. Therefore, methods are desired which do not overburden the stakeholders but can still treat the congestion's causes.

Objectives

This thesis's objectives are as follows:

1. To demonstrate how large quantities of data required for a microscopic simulation (microsimulation) can be collected in a cost-effective manner
2. To develop an efficient method to measure queue growth caused by severe saturation for use in modeling
3. To identify challenges in creating and calibrating a severely oversaturated model and how Bluetooth data can benefit calibration
4. To develop transferable (and scalable) methods that could assist in special event traffic planning.

Research for this thesis discovered several cases where researchers used large data collection efforts to address congestion caused by events such as football games and found other cases where researchers modeled in VISSIM and TransModeler how special event traffic would react to treatment. These case studies are discussed in Chapter 2. The author did not find any research combining the following: 1) a cost-effective data collection campaign, 2) collection of queue length data to address severe saturation, and 3) use of a microscopic car-following model to analyze non-recurring traffic from special events. To address Clemson's Game Day traffic problem, the author combined these techniques.

Organization

This thesis is divided into seven chapters. This First Chapter is the Introduction and describes the overall mission of the Clemson Football Traffic Improvement Study, why the Study began, the objectives of this thesis, and briefly summarizes how the author and TSL carried them out. The Second Chapter gives a Review of the Literature the research discovered on collecting data for networks over-saturated due to special events and modeling treatments for these networks. Then in Chapter 3, some Background is given on the Clemson Football Traffic Improvement Study and similar historical efforts. Next, Chapter 4, Data Collection, describes the process TSL used to collect the data required for this thesis and how to process it to be useful in VISSIM. Chapter 5, Modeling, explains how the author used the data to create VISSIM models for a base condition and three treatment scenarios as well as challenges TSL encountered and how TSL overcame them. Chapter 6, Modeling Results, summarizes travel-times evaluated by VISSIM for each scenario and interprets them within the context of football traffic management. Finally the Seventh Chapter presents this thesis' Conclusions, recapping the project's overall success and lessons learned.

At the end, this thesis includes a References chapter to help readers find the literature in Chapter 2 and additional sources for some foundational concepts supporting this thesis and TSL's work. This thesis also includes a Glossary to clearly define how special terms are used in this thesis. Lastly this thesis has an Appendix. Here, the reader can find the timing plans and network geometry where treatments were tested and travel-time results and hypothesis tests.

CHAPTER 2: LITERATURE REVIEW

Data Collection

Murphy, R. P., 2009 *(6)*. Murphy's group RPM Transportation Consultants LLC led a data collection effort, analysis, and parking and traffic plan development for the Iroquois Steeplechase in Nashville. This effort is similar in scope to the Clemson Football Traffic Study, but is for a far bigger metropolitan influence area. He also had recommendations for future events based on his study. Murphy's group collected turning counts, vehicle occupancies, parking utilization, and transit rider counts. His group did not use their data to construct simulation models of the event, but instead exercised good engineering judgement based upon analysis of their collected data.

Eck, R. W., and D. A. Montag, 2003 *(7)*. Eck, et. al., examined how local fairs generate traffic in small communities. They collected traffic and survey data from four fairs in West Virginia. Their traffic data consisted of automated and manual traffic counts at each site. In addition, they obtained attendance data from the event organizers. Results indicated possible trip generation rates and occupancies as well as possible daily volume factors. None of these efforts were obtained through traffic modeling output; in fact, they would be useful inputs to a TDM. The scope varies slightly from the Clemson Study in that it is macroscopic in modeling scale rather than microscopic, but the rural nature of the events is similar.

Zhang, Z., M. Ni, Q. He, and J. Gao, 2016 *(8)*. Zhang, et. al., Surveyed inductive loop and Twitter API data to examine relationship between social media and more traditional traffic data in identifying incidents and monitoring special event traffic for Flushing Meadows, NY, and Northern VA in 2014. This study did not produce the traditional traffic data such as volumes, queues, and signal timings, which was TSL's focus.

Parr, S. A., 2014 *(9)*. Parr's team collected their data from LSU's 2012 football season and the 2012 Sun Life Stadium's Winter Events season. Of all identified literature, Parr's research was the most like TSL's with respect to data collection methodology. He used pole-mounted sports cameras at each intersection and processed the videos for volumes using video-bookmarking. This differed with TSL's use of JAMAR count boards. While their method allowed for more precise counting, TSL's method allowed entire intersections to be fully counted just as in the field. Parr's team processed operational data in the same manner as TSL. With these data, he developed an officer control logit model in VISSIM's VAP and compared its performance with cabinet-control.

Lassacher, S., D. Veneziano, S. Albert, L. Haden, and Z. Ye, 2009, 2011 *(10, 11)*. While Parr's work best matches with TSL in terms of video data collection, Lassacher's, et. al., efforts best align with the conditions of Clemson Football Traffic, particularly in its rural nature and the demand surge produced. Their data came from MT State Football games from 2006-07. Although the scale of demand for MT State games is much lower than for Clemson, the research goals and challenges were similar. They used trailer-mounted Autoscope cameras to collect video data, seed-car drivers to collect travel-times, pavement sensors to collect intersection counts and speeds, and real-time JAMAR board personnel to collect data at specific intersections. Their work primarily centered around qualitative observation and field-testing, but they did simulate one intersection in Synchro. For this one case, queues were observed from the video and not through walking volunteers.

Long, G., 2002 *(12).* Long studied spacing between vehicles and developed a queue length estimation model. Surveying six urban sites in Florida and Illinois, he found that models which predict 10 feet between vehicles are too conservative. His team collected their data at signalized approaches, marking the length and location of each vehicle with bean bags, which they picked when they recorded each measurement.

Simulation and Modeling

Bertoli, B., and J. M. Wojtowicz, 2010 *(13).* Bertoli and Wojtowicz demonstrated the utility of microscopic methods for special events based on their analysis of the 2007 NY State Fair. They collected volume and speed data and created an origin-destination matrix. Then they modeled the network in TransModeler and proposed alternative treatments. EZPass speed and travel-time data were used for calibration. They presented animations from their model and demonstrated for the stakeholders how to program multiple traffic management strategies and how to interpret the results. This resulted in confirming that the plan in place was the best plan, but also proved that TransModeler could effectively simulate real-world traffic associated with special events.

Guseynov, R., P. Keridi, and V. Zyryanov, 2009 *(14)*. Guseynov, et. al., expound upon microscopic simulation as an estimation of "road capacity, velocity, trip time, and detection of congestion reasons." They discuss a variety of topics including LOS, specific scenario estimation, and forecasting system effectiveness. Their focus is the statistical validity of the AIMSUN model in simulating event traffic from the 2014 Sochi Olympics. They conclude that, based upon U-testing, F-testing, and ANOVA, AIMSUN can model multiple aspects of the special event traffic, but do not provide any final simulation results.

Ding, N., Q. He, and C. Wu, 2014 *(15)*. Nan Ding, et. al., collected data from an intersection in Buffalo, NY two hours before a college football game in 2012. This game had an attendance of <10,000, so it is of much smaller scale than the subject of this thesis, but their research implies that officers can be simulated in VISSIM. They created a VISSIM model, which they integrated with a human-traffic control interface, a system known as MIC-Sim. Then, officers participated in a MIC-Sim study to determine their effectiveness as compared to standard cabinet control. The researchers did not detail their data collection. They found that the MIC-Sim was able to model oversaturated conditions and provide a basis for comparison of officer control with cabinet control. They also believe that officer training programs that employ the MIC-Sim can improve officer performance during special events.

Special Event Management

Glazer, L. J., and R. Cruz, 2003 *(16)*. Glazer, et. al., studied the operation of the ATMS and ATIS components of Salt Lake City's ITS Architecture during the 2002 Winter Olympics. This 160-page report documents their data collection, including surveys, interviews, news anchor observation, traffic data collection, and TOC observation. They concluded many things about how well the ITS performed and what other cities using ITS should do, but no mention is made of how their data collection efforts, or those of the ITS itself, could be employed in simulation modeling. It is purely a report on how to operate an ITS during special events.

Latoski, S. P., W. M. Dunn Jr, B. Wagenblast, J. Randall, and M. D. Walker, 2003 *(17)*. In 2003, FHWA published a report on managing event traffic intended for wide audience. They focused on the "nitty-gritty" of planning and management (control plans, officers, parking, public information, etc.) rather than on specific operational strategies, data collection methods, or modeling methods. TSL chose Latoski's, et. al., definition of "Planned Special Event" as this Study's working definition: "A planned special event is a public activity, with a scheduled time and location, that [sic] impacts normal transportation system operations as a result of increased travel demand and/or reduced capacity attributed to event staging." Clemson Football Traffic certainly meets all of these criteria, except that staging doesn't change capacity here.

Additional literature are available which discuss management and planning for special events using Intelligent Transportation Systems *(18-21)*, but this thesis is targeted at communities that cannot afford an ITS. Indeed most of the literature the author discovered on special events is ITS-focused. Because of this, this thesis addresses an aspect of special event traffic planning that is under-researched.

Conclusions

While planning for data collection in 2014, TSL was convinced through experience in 2003-05 that they would need queue data to accurately estimate demand. The special event literature did not address queue data collection for queue growth beyond several hundred feet. However, TSL found Long's findings on queue length-to-queued volume conversion useful when processing its own data (Section 4.4: Data Processing). While the literature does suggest that microsimulation can be effective in modeling traffic and treatment for special events, it does not provide a clear data collection methodology to accompany it. Various packages are addressed here, including the "Big Three": TransModeler (TransCAD-based), VISSIM, and SimTraffic (Synchro-based). How to obtain input data for these packages when networks are severely oversaturated is another matter. Furthermore, research like Murphy's presents a clear system for data collection, but doesn't use it for modeling. Thus there is a gap in the literature between large scale data collection for special events and simulation modeling of those *same events* using those *same data*.

CHAPTER 3: BACKGROUND

Clemson as a town is not designed to accommodate a level of traffic generation rarely seen among even most NFL franchises, but must do so seven times a year. Of course, public roads are not usually designed for the year's highest (or even seventh-highest) hourly volume; they're typically designed for the 30th-highest volume (referred to in HCM Section 3.2 as the design hourly volume or DHV) *(22)*, which is nothing compared to Game

Day. Even if it assumed that all home games produce two of the highest hours of year both before and after the game, this is 28 hours. Not every game produces this level of congestion before the game (or even after it), and holiday travel in Upstate SC is rarely at Game Day levels. Thus, the 30th highest hour would still be an afternoon peak hour on a regular day in a small town. If this town was designed to accommodate Game Day, many roads would have to be widened significantly, creating excessive pavement areas that are not needed except during game days.

Traffic Study: 2003 Edition

In 2003, CU Athletics received complaints from the public about traffic conditions before the September home game versus Georgia. *(3)* That year, the volume of paying fans (75,000) had surpassed the Highway Patrol's critical point of 65,000 for good traffic management. A crash along SC 93 west of campus exacerbated the problem for the Georgia game. To find solutions to this problem, the Athletic Department asked the Glenn Dept. of Civil Engineering to study the problem and propose treatments.

The Transportation Systems Laboratory (TSL) began by collecting data from home games versus Florida State and Virginia later that year. Then they created models of the network in Synchro's simulation package SimTraffic for before-game and after-game scenarios. Using these models, they simulated various treatments to the traffic plan and made recommendations to the Athletic Department in 2004. They also researched how parking could be reallocated to more efficiently use the network. This work formed the basis for two theses at that time, one of which was Adam Gibson's. His thesis dealt specifically with the data collection and modeling efforts in SimTraffic. *(3)*

Gibson concluded that, given the learning curve associated with other packages, SimTraffic would be the least-costly to use. Nonetheless, he would have preferred to use a more advanced car-following model than employed by SimTraffic, so he recommended that his research be extended to a more robust microsimulation model. This thesis addresses this by drawing on TSL's use of VISSIM the past three years. By the time TSL began work on this traffic study in 2014, several of the students were already familiar with the software, greatly reducing the learning curve.

SimTraffic is Synchro's method of calculating a microsimulation given inputs from its signal-timing interface. SimTraffic provides some microscopic ability by calculating vehicle response to the Synchro network based on the speeds and vehicle spacing, *(23)* but its car-following capabilities end here. It is insensitive to some ground effects of real-world traffic, unlike VISSIM. VISSIM is based on the Wiedemann models, car-following models that take into account stochastic behavior amongst each individual vehicle in a network. This produces different simulation results for such effects as lane-changing, blocked intersections, and unacceptable gaps for turning vehicles. The stochastic variation of interaction parameters allows VISSIM to calculate results that better match the ground-truth. VISSIM's simulation is based upon these interactions and calculates MOEs by first calculating at each time-step the kinematic properties of each vehicle and constraining its behavior based on surrounding vehicles and the network. *(24)*

The football program's recent success and new campus construction have increased the strain on the network on Game Days, the former intensifying demand, and the latter reducing parking capacity. Concerned about the visitor experience, CU Athletics approached TSL again in September, 2014. TSL selected VISSIM for its robust microscopic car-following model.

The Clemson Network: Game Day

As a town, the City of Clemson is a rural bedroom community in the larger SC Upstate region. Many Game Day visitors come from Greenville, the region's principal city, arriving by the US 123 freeway. In addition, there are other access routes to the town and University. Principally these include five arterial highways: US 123/76 from Seneca, US 76 from Anderson, SC 28-BUS from Pendleton and points east, SC 93 from Central, and SC 133 from Six Mile and points north. There are also two minor western routes into campus: Seneca Creek Road from south of Seneca and W Cherry Road from the same area are also popular with fans from Oconee County. The reader can find all of the arterial routes and some collector routes on the map in **Figure 1** (Section 4.2).

US 123 from the east is a four-lane freeway that changes to a four-lane with two-way left-turn lane arterial at SC 93 northeast of campus. It takes this form from here to Lake Hartwell, and from Lake Hartwell to Seneca it is a four-lane divided arterial. The segment between SC 93 on the east and the Lake on the west is unique within the network for having a high driveway density. This can cause issues when vehicles enter and exit the highway at many locations simultaneously, leading to turbulence and crashes which decrease the capacity. US 76 is a four-lane divided arterial from Anderson to SC 93, and from SC 93 to Lake Hartwell it has a two-way left turn lane, being concurrent with US 123 from northeast of campus. SC 93 is a four-lane with two-way left-turn lane arterial from Central to Newman Road, where it drops the two-way left-turn lane. Between Perimeter

Road and US 123/76 west of campus, it is a four-lane arterial and is not contra-flowed either before or after games, but does incorporate shuttle lane designation to serve Game Day parking west of the Lake with transit. SC 28-BUS is a two-lane minor arterial that serves visitors arriving from points east and south of campus that don't use the I-85 or US 123 freeways. SC 133 (College Avenue) is a two-lane minor arterial from Six Mile and the mountains north of campus which changes to a four-lane with two-way left-turn lane arterial north of US 123/76. At US 123/76, the primary route designation is dropped, but the highway continues into campus as a minor arterial (See next paragraph). W Cherry Road is a collector that serves Oconee County visitors while Seneca Creek Road is an underutilized collector from the same origin area whose use by Seneca visitors TSL hopes to encourage.

Inside the community, there are several collectors and arterials whose geometry is altered to accommodate Game Day. First, several roads are contra-flowed before and after the game. Old Stone Church Road two lanes and is contra-flowed into campus before games, and contra-flowed out of campus after games. Perimeter Road is only contra-flowed after games between the stadium and US 76. West of Cherry Road, it is a four-lane minor arterial, but it is only two lanes between Cherry Road and US 76. The lack of before-game contra-flow exists to allow emergency vehicles to access campus from the EMS station at McMillan Road and have easy entrance and exit before games. Between the stadium and SC 93, Perimeter Road is contra-flowed northbound only after games. SC 93 is a four-lane minor arterial and is contra-flowed westbound before games between Cherry Road and Centennial Blvd. After games before 2015, it was contra-flowed eastbound along the same alignment. Starting in 2015, Clemson extended this to US 76. College Ave is four lanes and a two-way left-turn lane from north of US 123/76 to Edgewood Avenue. From there to campus through Downtown, it is two lanes. It is contra-flowed only after games, and before 2015, was open northbound from campus. Starting in 2015, the segment between SC 93 and all of Downtown was closed after games.

All of the major intersections where these highways meet are managed by a law-enforcement officer, either a State Trooper or a local LEO. There are two types of operation: hand signals with whistles and cabinet pushbutton. The SCHP assisted at four intersections along US 123, US 76 – US 76/123, US 123 – SC 93 Ramps, and US 76/123 – SC 93, using a cabinet pushbutton to advance phases in the programmed weekend plans. This allowed officers to operate the traffic signal from the safety of their vehicles and still adjust timings on-the-fly, but required the officers to use normal phase plans programmed by SCDOT in Greenville. Officers did not operate US 76 – SC 28-BUS as this intersection's typical yield control is sufficient to handle both before-game and after-game demand.

Most intersections require alteration to geometry for Game Day, rendering the pre-programmed phase plans inadequate. At these intersections, SCHP and local LEOs placed the signal in beacon mode and phased approaches using whistles and hand signals to indicate change intervals and greens respectively. At locations with complicated geometry, large clearance intervals were also sometimes necessary. These were challenging to quantify from the video, as they neither were of consistent length nor had standardized indications. To avoid reducing capacity unnecessarily in VISSIM, TSL assumed a 2-

second clearance interval for most intersections and adjusted change intervals as necessary. These intersections included US 76/123 – SC 133 (College Avenue), US 76 – Perimeter Road, and US 76 – Old Stone Church Road, as well as all signalized intersections south and west of US 76. Additionally, some typically stop-controlled intersections also required officer-signalization. Officers used whistles and hand signals here as well. **Table 1** provides a complete list of intersections and their Game Day operation method. For the field "Normal Control," "TWSC" (two-way stop-control) refers to stop signs on the minor street(s) only; "AWSC" (all-way stop-control) refers to stop signs on all approaches, "yield" refers to a yield condition for all minor movements, "entrance only" refers to a prohibition on exiting traffic on normal days, and "closed" refers to an access point only open for Game Day.

Table 1: Operations at Important Game Day Intersections

Major Road	Minor Road	Normal Control	Officer Signal Method	Data Collection Site?	VISSIM Site?
US 76/123	SC 93	signal	pushbutton	2014, 2015, 2016	yes
SC 93	US 123 EB Ramp	signal	pushbutton	2015	no
SC 93	US 123 WB Ramp	signal	pushbutton	no	no
US 76/123	SC 133 / College Ave	signal	whistles and hands	2014, 2015, 2016	yes
US 76/123 / US 123	US 76 / hardware store	signal	pushbutton	2014, 2015, 2016	yes
SC 93	US 76 SB Ramp	TWSC	monitored, unsignalized	2015	yes
SC 93	US 76 NB Ramp	signal	whistles and hands	no	yes
US 76	Perimeter Rd	signal	whistles and hand signals	2014, 2015	yes
US 76	SC 28-BUS	yield	none	no	yes

US 76	Old Stone Church Rd	signal	whistles and hand signals	2014, 2015	yes
SC 93	Perimeter Rd	signal	whistles and hand signals	2014, 2015, 2016	yes
SC 93	Centennial Blvd	TWSC	monitored, unsignalized	2014, 2015	yes
SC 93	Williamson Rd	signal	whistles and hand signals	2014, 2015, 2016	yes
SC 93	Lot 1	closed	monitored, unsignalized	no	yes
SC 93	College Ave	signal	whistles and hand signals	2014, 2015, 2016	yes
SC 93	Sherman St	TWSC	monitored, unsignalized	no	yes
SC 93	Calhoun Dr	signal	whistles and hand signals	2014, 2015	yes
SC 93	Cherry Rd / N Palmetto Blvd	signal	whistles and hand signals	2014, 2015, 2016	yes
SC 93	Newman Rd	TWSC	whistles and hand signals	2015	no
College Ave	Keith St	signal	monitored, unsignalized	no	yes
College Ave	Edgewood Ave	signal	monitored, unsignalized	no	yes
Perimeter Rd	Lot 5/Stadium / Motorhomes	TWSC	monitored, unsignalized	2015	yes
Perimeter Rd	Jervey Mead / Press Rd	TWSC	monitored, unsigalized	2015	yes
Perimeter Rd	Centennial Blvd/Lot 6	TWSC	hand signals and whistles	2015	yes
Perimeter Rd	Williamson Rd	signal	monitored, unsignalized	2014, 2015	yes
Perimeter Rd	Old Stadium Rd	TWSC	monitored, unsignalized	2014, 2015	yes
Perimeter Rd	Lambda St/Lot 22	entrance only	monitored, unsignalized	2014, 2015	yes
Perimeter Rd	Kappa St/Lot STI	TWSC	monitored, unsignalized	2014, 2015	yes
Perimeter Rd	Cherry Rd	signal	whistles and hand signals	2014, 2015, 2016	yes
Perimeter Rd	Zeta Theta St	TWSC	whistles and hand signals	2015	yes

Perimeter Rd	McMillan Rd	TWSC	whistles and hand signals	2015	yes
Old Stadium Rd	Delta St / Walker Course	TWSC	monitored, unsignalized	no	yes
Cherry Rd	Old Stadium Rd	TWSC	monitored, unsignalized	no	yes
Cherry Rd / Old Stone Church Rd	W Cherry Rd	AWSC	monitored, unsignalized	no	yes
Old Stone Church Rd	New Hope Rd	TWSC	monitored, unsignalized	2014, 2015	yes

Discharge Flow versus Demand

There is a fundamental difference between the operations and modeling of large special events and regular operations, especially at intersections. For normal day-to-day operations, intersections are designed to handle an amount of traffic that is less than their hourly capacity on a 15-minute basis. If this condition is true, then HCM Section 4.2 says intersections will clear their queues at least once every 15 minutes, and the volume that demands service will be less than capacity. *(25)* HCM defines demand as "the number of vehicle occupants or drivers (usually expressed as the number of vehicles) who desire to use a given system element during a specific time period," *(25)* in this case an intersection. So long as the intersection capacity is sufficient to meet this demand in a timely manner, the intersection has a non-failing level of service (LOS A through E).

Special events, however, can produce demand that far exceeds most intersection capacities. This causes the intersection to fail as it can no longer clear the queues, which get longer with each cycle. Meanwhile, the intersection itself still lets traffic through, but only at or below capacity-level. This presents a problem for traditional data collection and modeling.

Traditionally, real intersections are modeled by first collecting turning movement counts, either on-site or by video using an automatic counter (e.g. Miovision). These counts are perfectly suitable for normal operations, even at intersections that are at capacity, so long as cycle slips are not persistent. When demand greatly exceeds capacity or is unmet for long periods, traffic counts are capped at capacity (and sometimes less than capacity if there are failures downstream). The intersection cannot be modeled correctly because the turning movements only indicate how many are being served, not all that desire service. *(3)* The model may report that the intersection is at LOS E or D. In reality, the v/c could be 1.5. To accurately reflect reality, turning counts must be adjusted to indicate actual demand. The section "Data Processing" in the following chapter discusses TSL's methodology for doing this.

CHAPTER 4: DATA COLLECTION

The author obtained assistance from Clemson University's Transportation Systems Laboratory (TSL) to carry out data collection before and after games in 2014-16. While others have used sports cameras to collect traffic data at intersections, TSL used them on a massive scale, collecting data at as many as 20 intersections for some games. A campaign this size required TSL to find low-cost methods, including inexpensive cameras and clever mounting techniques to make this Study financially feasible. TSL then used both data from these videos and volunteer-collected queue data from the same games to model the network and treatments in VISSIM. During this process, TSL made proposed treatments to CU Athletics supported by simulation animations and VISSIM's travel-time evaluations. CU

Athletics implemented them beginning in 2015. Data collected during 2015 and 2016 allowed TSL's VISSIM models to confirm treatment benefits.

Data Requirements

In the past, TSL had used Synchro and its simulation app SimTraffic to model Clemson's Game Day network. Because SimTraffic is Synchro-based, its microscopic abilities are limited. The simulation handles approach volumes at each intersection separately, using midblock flows to smooth-out discrepancies. *(23)* This time, TSL used VISSIM, a microscopic model that constantly calculates the position, velocity, and acceleration of every vehicle in the network to provide performance measures. This means volumes at downstream intersections are not input by the modeler but determined from upstream discharges. For SimTraffic, researchers required demand data for each movement at every intersection, but VISSIM requires demand only at the input links (known as gateways). Turning movements are strictly percentages.

There are seven primary types of data that are needed. First, how many vehicles want to pass through each intersection in the area? This is **demand volume** V_{di}. Second, where do they want to go? This is **movement flow rate** v_{di}. Third, when can each movement go? This is called **signal phasing**. Fourth, how often is each movement allowed to occur? This is represented by **signal timing** and **cycle length**. Fifth, what space is available for each movement at each intersection? This is **intersection geometry**. Sixth, what space and length is available along each link? This is **network geometry**. Finally, how fast does each vehicle get from intersection to intersection? This is **link speed**.

TSL estimated link speeds from the video during periods when headways were at saturation or when flow was not fully-saturated. TSL is confident these are good estimates because spacing between signals and the congested nature of the network prevented large amounts of platoon dispersion. Furthermore, travel-time measurements taken during 2015 and 2016 served as a reasonableness check.

It is not as simple to collect the other types of data. Even though departures during the modeling period were regular, arrival patterns at intersections were not always uniform due to signals being largely uncoordinated and due to officers using varying cycle lengths. However, departure data at intersections can be easily captured using a traffic counter, generating movement flow rate pretty easily.

Just because a certain number of vehicles leave an intersection each hour doesn't mean a certain number of vehicles arrive each hour, and in fact, the arrivals can exceed the departures at times, and not necessarily equally for all approaches. Every time this happens, a line of vehicles will build backward along the approach(s), forming a queue. *(3)* If most vehicles in the queue can leave the intersection in a reasonably short period of time, the queue clears, and the network can function normally. But if the disparity between arrivals and departures is severe enough, there is no way to accommodate everyone, and the queue continues to grow, fouling much of the network. In this case, departure data do not accurately tell how many vehicles want service, so these data must be augmented with another type of data, **queue length** Q_i. By adding the rate of change of Q_i (d_{qi}) to the rate of departures v_i for approach *i*, the demand flow rate v_{di} can be determined. *(26)* Demand volume V_{di} is then simply the demand flow rate over a one-hour period, factored as necessary if the flow rate for the period measured is higher than the average rate over an hour.

TSL gathered signal phasing and timing data at the intersection. In normal operation, TSL could find these data by contacting the local SCDOT district traffic engineering office and asking for the controller inputs. For Game Day, it is not so simple: each intersection is operated differently and without the controller timing plans. *(27)* In some cases, officers place the signal in *beacon mode* (a flashing signal that operates like two-way stop-control), but phase *and* time the intersection using whistles and hand signals on the fly as they see fit. In other cases, officers do not change the phasing, but vary the timing (and cycle length) as necessary using a controller pushbutton to advance each phase. Thus, TSL had to collect these data over several cycles during peak operations and recreate an average phasing and timing plan for analysis.

Finally, TSL needed the approach geometry for each intersection, as well as the departing lane assignments. This includes such data as shared turn-thru lanes, number of lanes, turn lane storage length, and channelization. AASHTO Greenbook defines channelization as "the separation or regulation of conflicting traffic movements into definite paths of travel by traffic islands or pavement marking to facilitate the orderly movements of both vehicles and pedestrians" *(28)*. For events such as football games, channelization relies principally on cones and barrels. In this project's context, channelization refers specifically to the assignment of a movement to a particular path using temporary devices (e.g. cones or barrels). For normal operations, a site visit or even Google Earth is sufficient to obtain channelization data. Thus TSL had to gather the data on-site during Game Day operations. For this Study, TSL collected network geometry (alignment of highways, number of lanes, and location of lane merges and tapers) by observing midblock alignments and the geometry at the intersections and by estimating from video where the changes should occur.

Sites and Games

There were two games in 2014 and two games in 2015 for which intersection data were collected to some degree. TSL collected additional data at the first two games of the 2015 season to ensure the previous recommendations had the desired effects. **Figure 1** shows where in Clemson the team collected data during all three years. In 2014, TSL collected data for model development from games versus Louisville (October 11) and South Carolina (November 29). TSL selected these two games because in August the Athletic Department anticipated that they would have the largest attendance. For both games, TSL collected data before and after the game, with the South Carolina-Before and Louisville-After having the most intense hourly travel demand for those time periods respectively. However, Louisville-Before was used in before-game model development with aid from South Carolina data because of issues during data collection in the latter game. Of the four scenarios, only the South Carolina-After did not see heavy congestion that year.

In 2015, TSL used games against Wofford (September 5), Notre Dame (October 3), and Florida State (November 7) for data collection. Of all games in both years, Notre Dame was the largest draw for attendance, even earning a spot in ABC's primetime football lineup with an 8:00 PM EDT start. For this reason, TSL collected no before-game data.

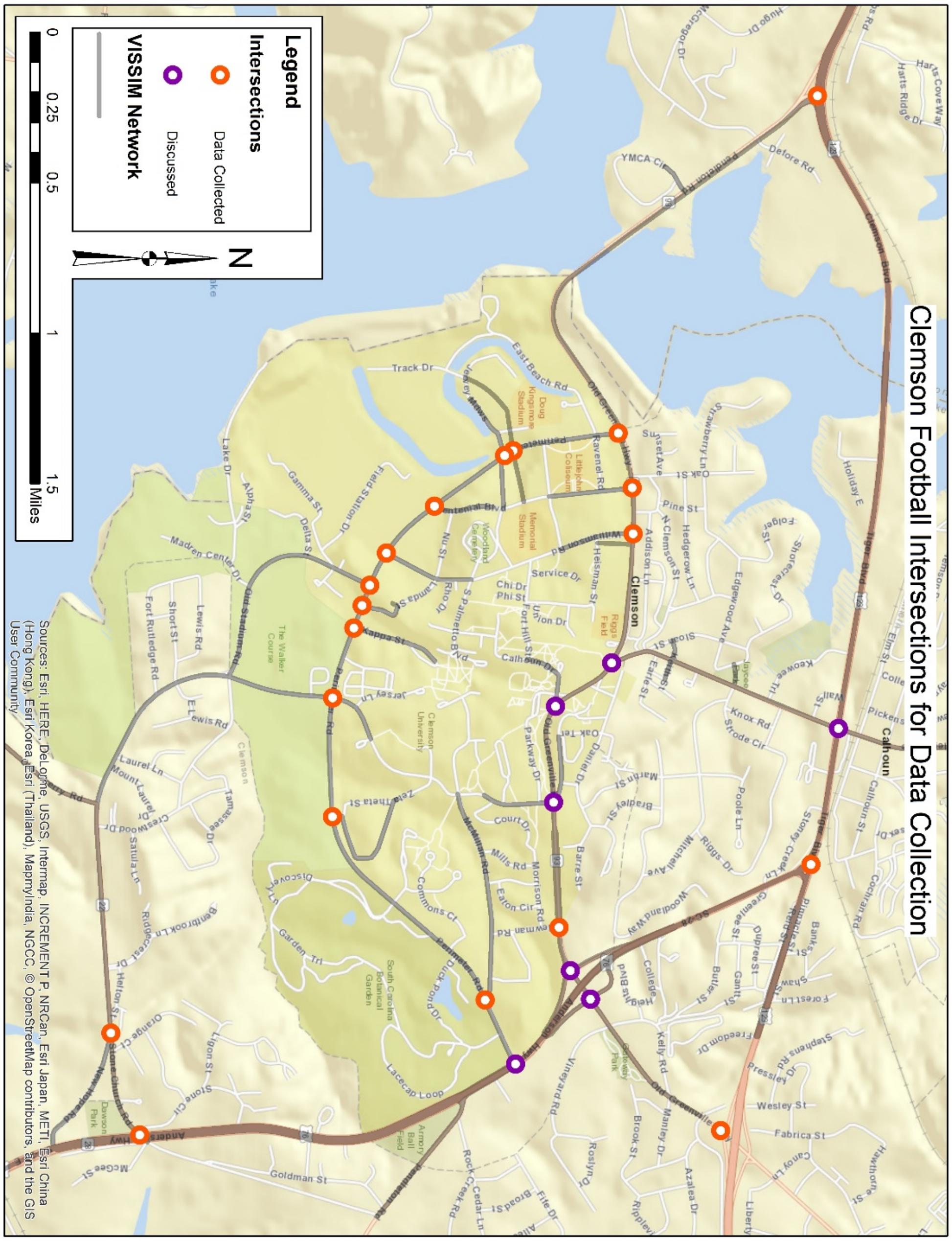


Figure 1: Clemson Football Intersections for Data Collection

FSU was a typical 3:30 game, like Louisville in 2014, so TSL collected data both before and after. Data collection for Wofford only consisted of spot checks at one intersection before-game and five intersections after-game to allow TSL to ensure operations were as predicted. These two games are not discussed further in this summary. TSL used the data from these games to improve the models' geometric accuracy at locations not observed in 2014 and to form models demonstrating operations where law-enforcement burnt-in TSL's recommendations. After 2015, TSL focused on modeling after-game scenarios because the after-game traffic routinely experienced the worst problems.

In 2016, TSL focused largely on transit operations on the west-side of campus, as CU Athletics relocated ~2000 parking spaces beyond the lake to make way for new soccer practice fields. However, TSL did collect intersection data from the night following the game versus Louisville. This game exceeded even the 2015 ND game in its demand-producing intensity. Even under these conditions, TSL was able to collect data that confirmed that drivers were slowly acclimating to the new traffic patterns, but that full benefits would not be achieved in only a year.

The process of collecting data began by determining which intersections are important to modeling the network. In 2014, this included most intersections along the two highways north and south of campus, (Old Greenville Hwy) SC 93 and Perimeter Rd (S-39-320), and the highway north of downtown, (Tiger Blvd and Anderson Hwy) US 123/76. For the 2015 season, greater resources allowed TSL to add additional intersections to better model where major vehicle inputs were generated and where major turning movements occurred. Knowledge of operations on the west-side of campus and of turning movements at SC 93's interchange with US 76 were important additions to TSL's modeling.

Collection Techniques

Data collection relied on three principle techniques: recording of videos, observation of intersection approaches, and importing of map images. TSL used the first technique to collect data for movement flow rates, signal phasing and timing, departure speed (used to derive link speed), and some aspects of intersection geometry. They used the second technique to collect queue length data (used to convert movement flows to demand flows and volumes) and intersection geometry. Lastly, they used the final technique to recreate the network geometry for modeling.

When TSL and Gibson performed this study in 2003, they used a different camera system than TSL used in 2014. The typical 2003 setup, termed "Johnny-Five," *(3)* consisted of an Autoscope camera mounted on a tripod, connected to a VCR, TV, and deep-cycle battery. While this setup allowed basic functionality (pan, tilt, zoom, view-find, and record), it suffered from its cumbersome portage and storage. Also, good coverage of an intersection and all movements required a topographically advantageous location, such as the one at US 123/76 and College Ave. When TSL began planning in 2014, they sought a more user-friendly system.

Advances in video technology and in internet shopping have prompted TSL to investigate new camera choices and support systems. TSL acquired Vivitar and ANART sports cameras at little cost and combined them with paint poles (also low-cost) and surveying tripods already in their possession to create a new setup that was easy for students to transport and store. Because sports cameras have rechargeable batteries built-in, have write-to-memory card functionality, and have a view-finding screen, extra equipment is eliminated. Furthermore, TSL's use of paint poles, zip ties, and duct tape allowed students to position cameras from high vantage points without the aid of topography and make them immune to fans who might otherwise disturb them.

For each intersection, the process was more or less the same. TSL used a low-cost traffic data collection system to collect video at each intersection. They then processed this video manually using JAMAR digital count boards. The key components of the system are the generic all-weather action camera, mounting device, and support system (either a surveying tripod or a telescoping paint pole). Cameras were light weight, portable, and environmentally protected, and afforded sufficient memory (16 GB memory cards) and power supply to last for a minimum of 1 1/2 hours. TSL desired this time period to allow at least an hour of data collection just before and during the peak period.

Figure 2: ANART Camera, Pole Mounted

Before operation, students enclosed their cameras in a protective case (**Figure 2**) and connected them to one of two types of mounting devices. Students who used surveying tripods mounted their cameras with a pivot-screw to a shaft which they attached to the tripod's trivet screw. Students who used paint poles mounted their cameras with a sports clamp to the pole's extensible end and raised the pole to the height necessary for capturing all turning movements.

TSL used tripods only for a select few intersections where topography allowed a good field-of-view from the near the ground. Therefore, these students only had to look into the viewfinder to check their field-of-view. Students who used paint poles required a little more effort.

TSL gave zip ties and duct tape to students who used paint poles to enable the support to be both flexible and fixed. First, they mounted their cameras on the paint pole with the clamp, then raised and attached the pole to an existing utility pole in the field, taking care to avoid current-carrying lines. (However, TSL did use plastic-insulated poles to avoid a grounding connection.)

Figure 3: Attaching and Raising Vivitar Camera

Before raising, the student started recording a sample video and set the downward tilt angle of the camera using a good estimate. Then, the student raised the camera, filmed at various pan angles, and lowered it to playback the sample. They checked the tilt and pan angles used in the sample. If the tilt angle was not correct, the camera clamp was adjusted. Next, the student started recording the actual intersection video, raised the pole, and secured it to the utility pole using the zip ties. Then the student adjusted the pan angle to the desired direction by twisting the pole. Finally, the student fixed the paint pole in place with duct tape. **Figures 3** and **4** show an example setup at

Figure 4: Raised Camera Recording Video

Figure 5: Louisville-Before Video from Pole Camera

Perimeter Rd – Cherry Rd, and **Figure 5** shows the resulting video image. The complete installation usually takes about 5-10 minutes in the field.

ANART and GoPro cameras provide Wi-Fi capability, so some students who were assigned these types were able to pan the camera while observing the view from their phones. Instead of filming at several different pan angles, students only practice-filmed for the tilt angle. They then adjusted the tilt, enabled the Wi-Fi, started recording, and raised the pole. Next they used the Wi-Fi display on their smartphones set the pan angle before disabling the Wi-Fi. There are several points of caution when using Wi-Fi to pan. First, Wi-Fi drains the battery supply, so it must be turned off as soon as possible, or the camera must be connected to an external source (requiring removal of the protective case). Second, ANART cameras recorded in 1-minute segments when the record button was selected while Wi-Fi was still on. Where this occurred, TSL solved this problem by merging and re-cutting the collected video into 30-minute segments using a video-editing software. This made traffic-counting with JAMAR boards easier.

Professional video-based traffic counting systems are available from a number of vendors but cost thousands of dollars. TSL used components that cost approximately $125 per setup. Using higher quality GoPro cameras could significantly add to the cost, but the increased resolution of a GoPro camera is unnecessary. In fact, there is a benefit of using lower resolution to conserve memory. **Table 2** summarizes the features of the video data collection setup TSL used.

Table 2: TSL Video Data Collection Features

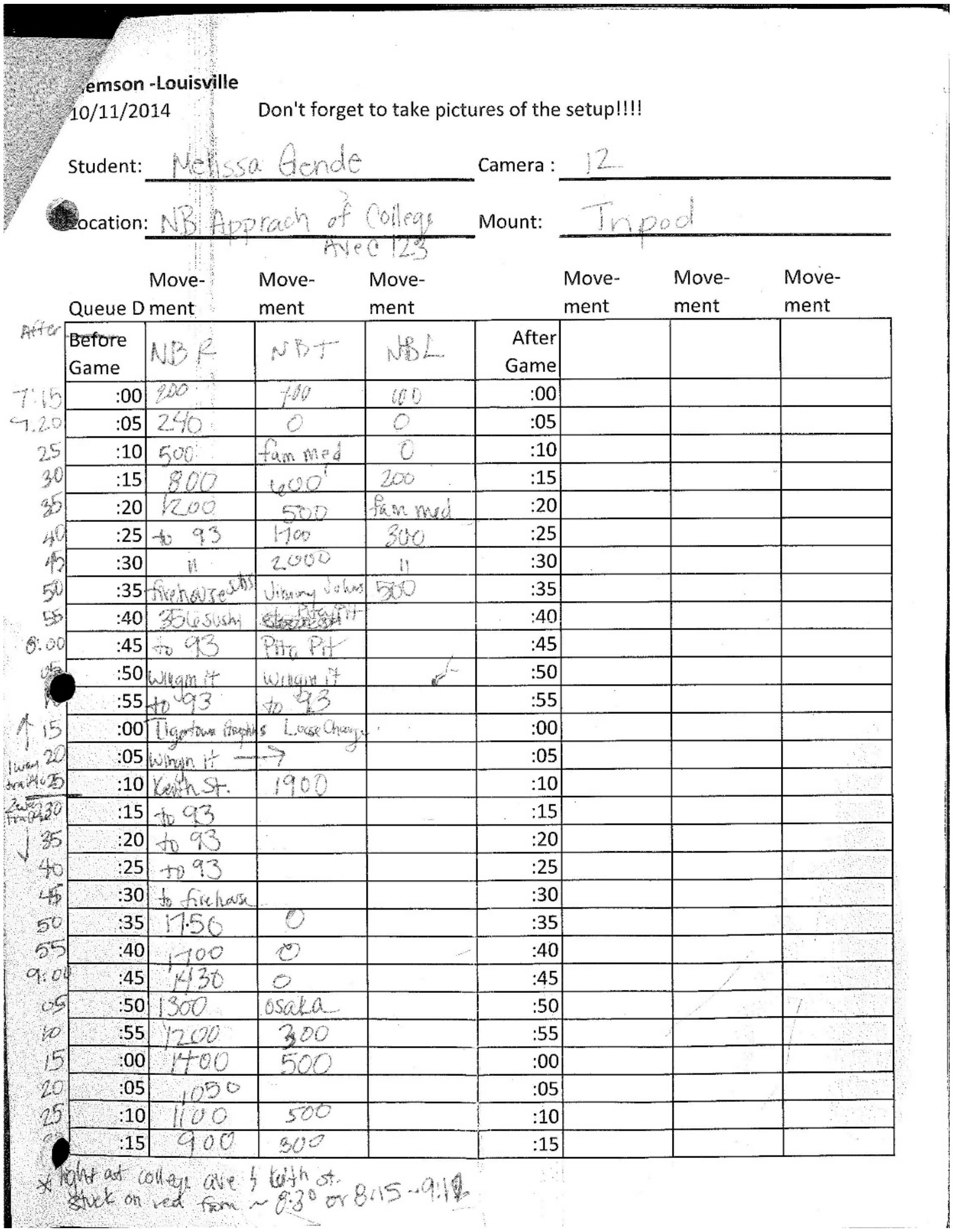
System Components	Available Features
Total System Cost	$100-$500 (depending on camera)
System Contents	Camera, mounting clamp or screw, weather-proof case, tripod or paint pole with 2 feet of duct tape and 3 feet of zip ties
Memory	16 GB SD Card (4 hours)
Video Resolution	1920 X 1080 pixels
Video Format	AVI, MOV, MP4
Battery Life	45 min to 2.5 hours (depending on camera brand and Wi-Fi usage)
Support Structure	Surveying tripod (max height 7 feet) or Mr. LongArm Telescoping Painter's Pole (max height 23 feet)

TSL assigned to each intersection 1-3 students recruited through Clemson's student chapter of the Institute of Transportation Engineers (ITE) and the Glenn Dept. of Civil Engineering. They gave students either a Vivitar, Go Pro, or ANART sporting camera, a mounting system, and a clipboard with a queue sheet. Before the game, all participants and volunteers in the Study met at the CE Department to receive their equipment and final instructions.

For games involving before-game data collection, they departed between 2.5-3.5 hours before the start time of the game for their assigned intersections. When they arrived at each intersection, they mounted their cameras, recorded a sample video, checked their field-of-view using the sample, and re-set the camera to record video of the intersection for 1-2 hours, depending on the location.

Once their camera was set, they used their queue sheets to record the location of the back end of the queue along a particular approach that they were assigned. By recording the location in feet from the stop bar every five minutes, TSL could obtain a record of the queue buildup at the most severely-congested intersections. After the peak travel period had passed, students removed their equipment, returned it to Lowry, and went to the game where they waited to complete the same process for after-game travel.

The method of collecting queue data changed after the first game (2014 Louisville). For this game, TSL used the same method they used in 2003. They measured half-station (50-ft) distances from each stop bar with a wheel, marked them at the gutter pan with spray paint, and planted flags at every five stations. Volunteers used these marks to record actual distances in feet from the stop bar every five minutes in real time. **Figure 6** gives an example recorded by a TSL member at US 76/123 – College Ave. This created issues when the queues backed beyond the end of the markings, and students were unsure how to code these distances.



Clemson -Louisville
10/11/2014 Don't forget to take pictures of the setup!!!!

Student: Melissa Gende Camera : 12

Location: NB Apprach of College Ave @ 123 Mount: Tripod

	Queue D	Movement	Movement	Movement		Movement	Movement	Movement
After	~~Before~~ Game	NB R	NBT	NBL	After Game			
7:15	:00	200	700	100	:00			
7:20	:05	240	0	0	:05			
25	:10	500	fam med	0	:10			
30	:15	800	600'	200	:15			
35	:20	1200	500	fam med	:20			
40	:25	to 93	1700	300	:25			
45	:30	"	2000	"	:30			
50	:35	firehouse	Jimmy Johns	500	:35			
55	:40	356 sushi	~~[illegible]~~ Pita Pit		:40			
8:00	:45	to 93	Pita Pit		:45			
05	:50	Wingin it	Wingin it		:50			
	:55	to 93	to 93		:55			
15	:00	Tigertown Graphics	Loose Change		:00			
1 way 20	:05	Wingin it →			:05			
traffic 25	:10	Keith St.	1900		:10			
2 way traffic 30	:15	to 93			:15			
35	:20	to 93			:20			
40	:25	to 93			:25			
45	:30	to firehouse			:30			
50	:35	1756	0		:35			
55	:40	1700	0		:40			
9:00	:45	1430	0		:45			
05	:50	1300	osaka		:50			
10	:55	1200	300		:55			
15	:00	1400	500		:00			
20	:05	1050			:05			
25	:10	1100	500		:10			
	:15	900	300		:15			

* light at college ave & Keith st. stuck on red from ~ 8:30 or 8:15 - 9:10

Figure 6: Louisville-After Queue Sheet Using Flag-and-Paint Method

Another advancement came to TSL in internet form. With the availability of digital online maps, TSL developed a new methodology to collect queue data. This method required much less field preparation and also permitted collection for queues of longer lengths. Satellite-imaging had progressed to the point where students could use pavement

Figure 7: Back-of-Queue Locations Using New Method

markings and landmarks visible in Google Earth to identify ground locations. For the 2014 South Carolina game, TSL used these printed Google Earth maps. Students could now mark approximate locations using letters (example from the same NB approach given in **Figure 7**) based on surrounding landmarks (still every five minutes). Each letter corresponded to a timestamp recorded on a separate page. This allowed volunteers to estimate queue lengths beyond what could be wheeled and spray-painted. During post-processing, TSL converted these map mark-ups into distances.

While at the intersections, students also noted any alterations in traffic patterns and channelization and recorded a map of the intersection showing lane assignments. During post-processing, TSL compared these with the videos and with Google Earth imaging to determine as precisely as possible the geometry of the intersections and network.

Data Processing

Once TSL collected the data, they had to process them into a form usable for modeling. The team used video data for most of the data types needed for modeling, and breaking down these data required that they be time-stamped accurately and precisely enough to be coherent from intersection to intersection. TSL used several different recording systems, and each had its own method of time-stamping. Swann Security cameras (used south of campus) have a time-stamp built into the monitor feed, as do the ANART sports cameras. Vivitar sports cameras both display the time stamp on video at the start and also name each video file according to start time. GoPro sports cameras typically display the video file's end-time stamp in the properties dialog once the file has been uploaded to a Windows operating system. Of the four types, TSL preferred Vivitar cameras for their reliable time-stamping, 30-min recording intervals, and easy-to-learn interface.

Next, TSL counted turning movements at each intersection using a JAMAR traffic counter while replaying the video. They aggregated counts to the nearest 5 minutes because few intersection cycle lengths are shorter than this, but TSL required a fine enough resolution to capture changing flow rates. Finally, they uploaded count data to spreadsheets using PetraPro to obtain movement flow rates.

In addition to flow rate, the videos also provided signal phasing and timing. Because the exact timing changed as the officers saw need, it is necessary to record the start and end times of each phase for several cycles (at least three) during the peak travel time. The phase lengths and cycle lengths can then be averaged to develop a timing plan. TSL selected a phase order based on the prevailing phase pattern used by the officers, so long as all the required movements received service. Finally, the videos helped to establish intersection geometry by indicating which lanes were allowed to move during each phase and into which lanes officers guided each movement.

TSL processed queue data by first measuring from each mark on the volunteers' queue map to the stop bar. Next queue lengths were plotted against time, and the rate of arrival was chosen to be the maximum sustained rate of increase of queue length over a period of at least ten minutes. TSL converted this rate d_q into vehicles per hour by dividing the length by the standstill spacing (coverts feet to vehicles) and multiplying by 12 (12 five minute periods in one hour). To estimate the number of vehicles queued at the end of an interval, TSL used Gary Long's queue length estimation model. According to his model, inter-vehicle spacing is 12 feet. *(12)* Because TSL assumed that nearly all traffic generated by the games would be passenger cars, this meant standstill spacing should be 27 feet per vehicle (given 15-foot vehicles *(12)*).

The actual volume demanding service at an isolated intersection is produced in VISSIM by specifying the demand flow rate v_d on the approaches. This is the sum of the departure volume occurring in interval i (q_i) and the d_{qi} in that same interval, in this case factored by 12 to produce an hourly flow rate. Even though Roess's, et. al., theory of queued arrivals *(26)* implies that each interval's flow rate should be determined separately, TSL used average values of departure flow and maximum values of queue growth to model the worst-case scenario that could occur given the collected data. For networks of intersections, arrival volumes were only specified at approaches that are link inputs, as other approaches took their arrival volumes from departures at upstream intersections.

Finally, TSL generated the geometry of the network and of the intersections in VISSIM using video and students' field observations.

CHAPTER 5: MODELING

The author spent several months constructing models in VISSIM using TSL's data and evaluating their performance against observations from the videos and queue sheets. While VISSIM could not exactly replicate observed conditions, the models could still predict in an approximate manner how treatments would affect the ground network, based upon travel-times collected during 2015-16. Assumptions made by VISSIM's car-following model about reaction times, following distance, and lane changing could have contributed to the model's variation from ground conditions.

Challenges

TSL's efforts over the period of this study were not immune to challenges. First, TSL experienced low resolution (due to fog and lack of weather visors for cameras), bias, and selection set loss (both due to cameras not always having the best field-of-view) at a select few intersections. On the whole, these were rare, but generally due to inexperience. Second, these methods were highly sensitive to weather because camera cases did not have visors to shield the cameras from rain and because rain interfered with paper data collection methods. While this was only a problem for ND-2015, there are no guarantees regarding the weather. Third, inexperience created the potential for faulty data that could cause modeling errors. At a couple intersections, cameras missed turning movements due not being optimally directed, and some cameras did not collect data. Most of these issues occurred in before-game scenarios, so TSL is confident they had little impact on the results in this thesis. TSL minimized these risks simply with a little practice. Finally, TSL's modeling could have benefited from additional data types, but their goal of a limited budget didn't permit these additional research avenues (e.g. standstill spacing values specific to Clemson).

When costs are a priority, field labor-hours become a precious commodity. In TSL's case this meant collecting only during a targeted peak period instead of the several-hour periods when football traffic arrived, not collecting data at all intersections, or being asked to collect queue data only at ten-minute intervals, rather than five-minute intervals. This last issue arose when TSL asked observers responsible for two approaches to alternate their queue data collection between approaches. The second issue caused TSL to make theoretical assumptions about 2014's missed locations until TSL obtained data from 2015. These issues illustrate that good mission planning is required to identify which aspects of the data are most important and guard against corruption in those areas.

Special events are characterized by unique circumstances that cannot be replicated by the normal transportation modeling constructs. For TSL, these included the following: large crowds of spectators and unfamiliar visitors, changes in streetscape to accommodate the events, potential for weather impacts (*e.g.* a football game in a torrential downpour), presence of security with whom data collection had to be coordinated, and potential for crowd-caused disturbance (e.g. goalposts moving down a state highway after a big home win, which happened in 2003 *(3)*). These are all events which cannot be reproduced week-after-week or fully replicated in most traffic modeling software. To get around these issues, TSL used Bluetooth data from ND-2015 and travel time data from 2015-16 to calibrate the models.

Flexibility is required to maneuver around unforeseen occurrences, and backup plans should be arranged in case planned data collection cannot be accomplished. It is possible to simulate some effects of these events in traffic software, but only synthetically. For example after ND-2015, hard rain and high winds reduced the capacity of the network links, so ideally the driver model should have been adjusted to allow for longer following distances and higher reaction times. However, VISSIM could not model a changing weather system as it moved through. Furthermore, this became even more complicated as the weather hindered data collection.

Through this project TSL learned that good data collection requires experienced observers who know how to handle unforeseen events and can interpret unusual traffic behavior in light of the data types desired and the big picture. For example, a major issue TSL experienced with queue data was the definition of where a queue was and wasn't within a traffic flow. TSL addressed this by instructing observers to keep themselves positioned at the boundary between stationary and moving traffic, walking back a few thousand feet if necessary. Queues are relatively easy to spot when looking top-down at a simulation because the modeler can see the shockwave boundaries that define queues. Queue boundaries were much harder to identify when vehicles were moving at eye level, particularly when the front (backward-moving) shockwave met the back-of-queue (also backward moving) shockwave.

Additional Resources

In a few cases, TSL's collected data were not independently sufficient for microscopic methods. In some cases, the data collection window did not begin long enough in advance to capture the periods of increasing queue length. In other cases, cameras captured video almost exclusively during saturated conditions, making it hard to determine the demand for each turning movement.

In many cases, TSL needed to estimate demand from specific areas of campus based upon the capacity of the lots in the catchment area for specific input links. They compared this to cases where TSL had good quality queue data to determine a realistic demand.

To obtain the percentage of demand for each turning movement, TSL used Bluetooth data collected by Stantec *(29)* from the night of the 2015 game versus Notre Dame. At intersections not included in Stantec's study, TSL used 2014 and 2015 video data collected during the periods when saturation appeared to abate.

VISSIM Models

TSL's first model (results not presented) simulated how the network performed using operations before the 2014 game versus Louisville. This simulation turned out to be relatively trivial in the larger scheme of the research. Though congested, before-game operations were (and are still) reasonably smooth for 3:30 p.m. kickoffs (which Louisville was). TSL also collected data from before the South Carolina game that year, which had a 12:30 p.m. kickoff. These noon-kick games experience much higher peaking than afternoon games because of the lack of time for pregame tailgates. However, TSL's estimated the peak to begin later than it actually did, causing data collection to begin too late to provide useful queue data. Furthermore, TSL could suggest only one network improvement: contra-flow of all lanes of Perimeter Road into campus. This was not popular due to this route being an emergency vehicle route. TSL also suggested improvements to transit operations on the west side of campus, and TSL collected data but did not model transit ridership in VISSIM at this time. Modeling efforts then focused on the tremendously important after-game scenarios.

The second model (Model #1) simulated network performance after the game as visitors departed Clemson, also using operation conditions following Louisville. After-game was especially critical because vehicles tend to leave over a shorter period right after

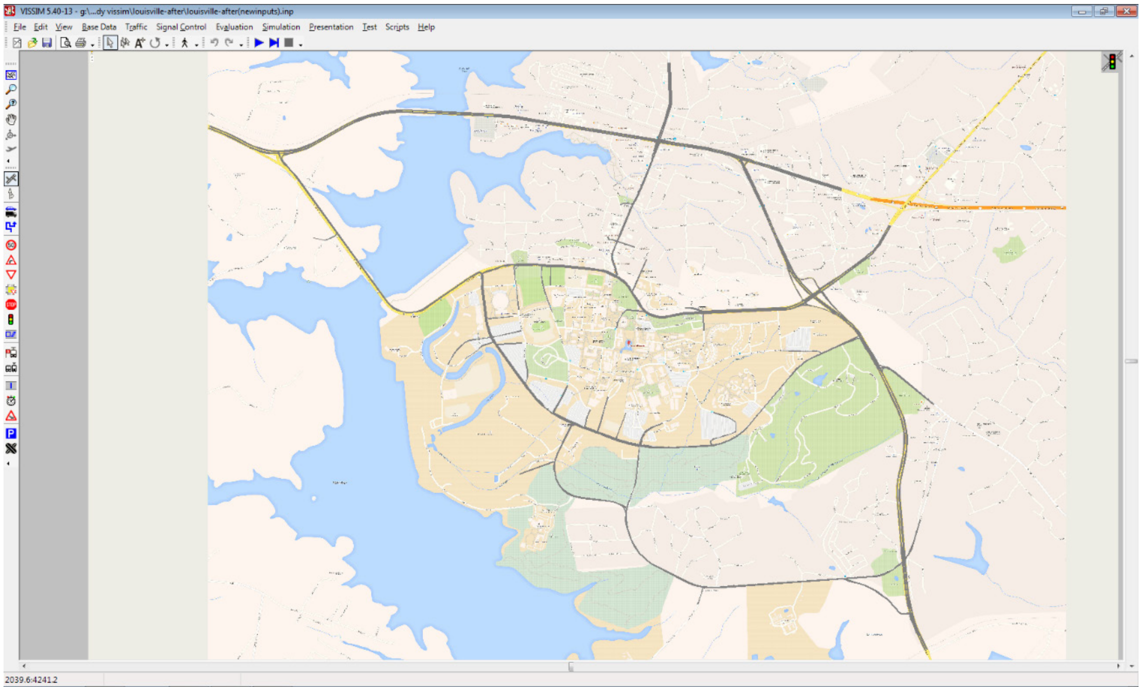


Figure 8: Louisville-2014 After-Game Network Displayed in GUI

the game ends (there tends to be greater peak-spreading before games). These conditions consisted of geometries, phasings, and signal timings unique to the Clemson Game Day experience. For all after-game models, TSL based network-input volumes, speed zones, and conflict rules upon data collected from the 2014 Louisville game. Where TSL could not collect data that year, data from 2015 informed the modeling effort, as TSL did not propose treatment for every intersection. Bluetooth data collected from the 2015 Notre Dame game informed turning movement percentages. Results from this model fall under the heading of "Base 2014." **Figure 8** shows the entire network for this model from the VISSIM GUI.

Before the 2015 Fall Semester, TSL recommended treatments to the Athletic Director (who commissioned this Study) based upon results from the after-game model previously discussed. At this time, information on the Louisville traffic situation was incomplete, but the simulation responded well enough to the treatments that TSL felt comfortable in their recommendations. The following chapter summarizes these recommendations. Later, TSL corrected assumptions in both the original 2014 model and the model containing the full implementation.

Next, TSL modeled (#2) performance under operating conditions following the 2015 game versus Notre Dame, the famous BYOG game that produced epic levels of after-game congestion, but none before-game. In addition to the treatments proposed earlier that year, two changes in geometry occurred following the 2014 Louisville game. First, the northbound approach at the critical US 123/76 – SC 133 intersection gained an additional thru lane after a restriping removed an offsetting median. This change allowed two full lanes to make the NB thru movement instead of just one.

Second, officers began operating a double eastbound left turn from Perimeter Rd onto US 76 following the 2015 ND game. Even though Clemson didn't use this for ND, TSL learned that the stakeholders could make it permanent, and so decided to incorporate into all three treatment models. Despite the responsiveness and amicability of the stakeholders to TSL's recommendations, treatments weren't fully realized, mostly due to the limitations of human-actuated traffic control. TSL is confident that, with repeated practice, benefits will eventually be fully realized. Results from this model fall under the heading of "Officer 2015-16."

In most cases, TSL modeled only the traffic control from the ND game, not the volumes. This was due to two factors. First, massive rainfall stymied quality queue data collection, making it difficult to determine actual network demand after this game. Second, if demand for ND-2015 was significantly less or more for than Louisville-2014, this could confound treatments effects. To sidestep this, TSL qualitatively assessed actual performance through queue-clearance observation from the game day video where possible. Nonetheless, the final model of the ND-2015's operations as imposed upon Louisville-2014's demand returned favorable travel-time results, validating the VISSIM's ability to handle non-customary traffic control.

Then, a fourth model (Model #3) simulated how the network should've behaved had all treatments been fully implemented. The next chapter summarizes the differences. Chiefly, TSL adjusted the timing at US 123/76 – SC 133 to better serve the eastbound thru and left turn movements. Also, TSL shortened the cycle at US 76 – Perimeter Road to provide better queue clearance along all approaches. Results from this model fall under the heading of "Recommended w/ Reservice."

Finally, a fifth model (Model #4) simulated network performance with the addition of eastbound left turn reservice at US 123/76 – SC 133. Because the left turn demand is quite high compared to the storage-clearance per cycle, the late part of the east-west thru phase experiences queue-spillback from the eastbound left-turn lane. As left-turners stop in the interior thru lane 150 feet from the intersection (waiting to enter the taper), spillback restricts flow to only the exterior lane and cuts capacity in half. Reservice of the leading eastbound left (following a period of E-W thrus) restores full capacity to the thru movement. Results from this model fall under the heading of "Recommended w/o Reservice."

Treatments

Base conditions and treatments used in models simulated for this study are listed below. Except where indicated, TSL took phasing and timing for Model #1 from Louisville-2014 and phasing and timing for Model #'s 2-4 from ND-2015. Model #'s 2-4 are the treatment models, with Model #2 reflecting actual observed treatment conditions. Intersections

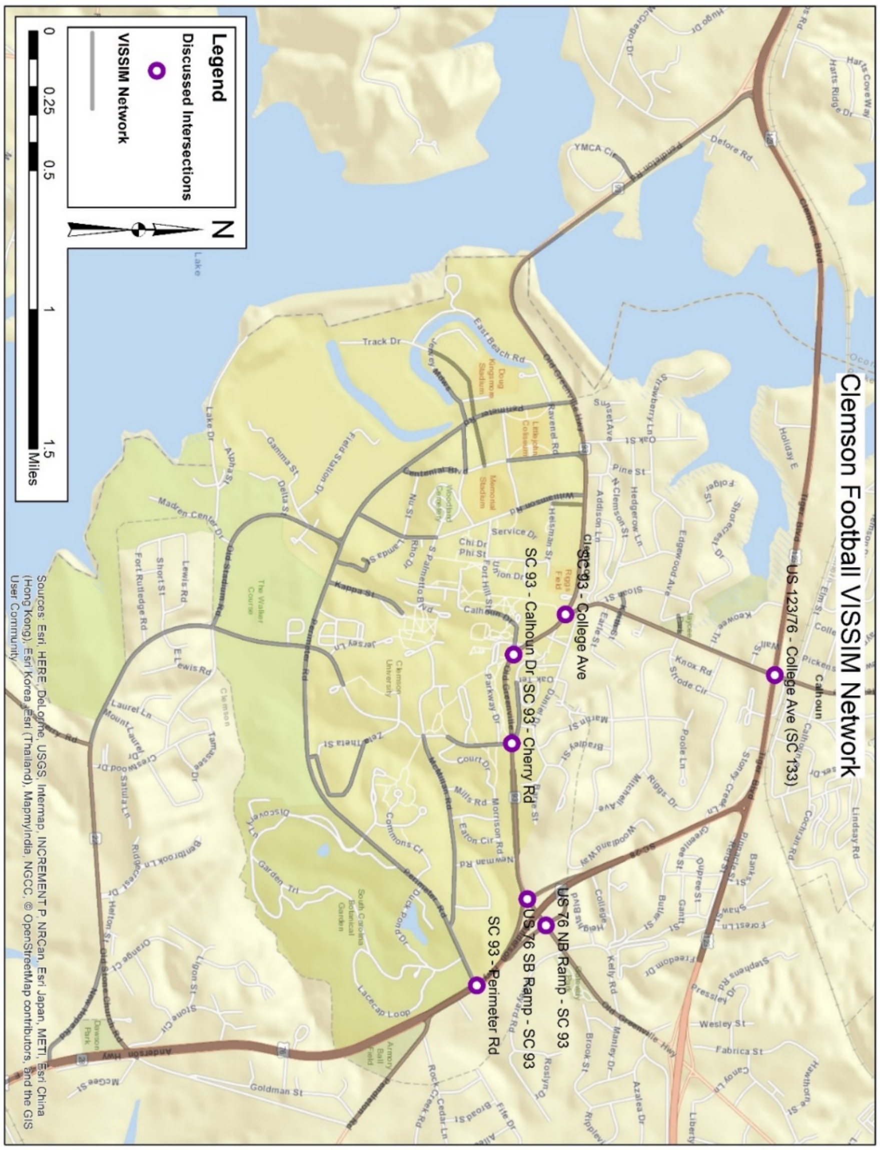


Figure 9: Clemson Football VISSIM Network

whose treatments are discussed in this thesis are highlighted in **Figure 9**. Appendix A gives the geometry and signal plan for each treatment and intersection.

Model #1: Base 2014

This modeled original operations from post-Louisville.

US 123/76 – College Ave (SC 133): The SC 133 NB approach had one left-turn lane, one thru-lane (going into two thru departure lanes), and a dual right turn, with the interior right turn operating out of the one thru lane. TSL phased this signal differently than in the models which follow. Specifically, they used phasing similar to a traditional 8-phase ring-barrier controller, with the E/W sequence beginning with a leading EB left and the N/S sequence beginning with NB/SB lefts. Afterward the controller permitted left turns across their companion thrus. The controller timed small all-PED phases between the two major sequences. Only the WB right (and not the SB right) overlapped with its opposing left turn. All of this ran on a very long 480-sec cycle.

SC 93 – College Ave: Officers operated the SC 93 Corridor from Centennial Blvd to Cherry Rd as four EB lanes. At this intersection, the leftmost lane turned left, and the network re-added the fourth lane downstream of the intersection.

SC 93 – Cherry Rd: Here, the four EB lanes merged into two lanes while also receiving a SB left turn and a NB right turn. Unique phasing alternated right of way between the right-most and left-most lanes with leading turns from Cherry Rd (e.g. a short phase of NB right + right-side interior thru followed by both right-side thrus). TSL used a short all-PED phase between the right-side phases and the left-side phases, all of which TSL placed in a long 439 sec cycle.

SC 93 – US 76 (ramps): At the southbound ramp, vehicles made right turns out of a shared thru lane, while at the northbound ramp, vehicles made left turns out of a left-turn bay. The NB ramp intersection was a two-phase signal, which stopped the entire EB approach for NB left turns.

US 76 – Perimeter Rd: TSL used a single EB left turn. Phasing here favored the EB left turn by 52%-48%, and the cycle was 246 sec.

Model #2: Officer 2015-16

This modeled operations used after ND in 2015, except for two intersections.

US 123/76 – College Ave (SC 133): The SC 133 NB approach had one left-turn lane, two thru-lanes, and a dual right turn, with the interior right turn operating out of the exterior thru lane. Here, TSL based phasing upon that used by officers after Louisville in 2016, rather than Louisville-2014 or ND-2015. They did this to model how officers following the latest TSL recommendations would affect the network. TSL set the cycle length to 480 sec even though the video showed quite a variable cycle because this seemed appropriate for conditions, and 2014 used the same length. This plan used a short leading EB left before its main E/W thru phase with a SB right overlapping the left turn. An all-PED phase followed, then a phase of leading NB/SB left turns overlapping a NB right. 2015 marked the first year this type of dual-departure phasing was implemented. By coning-off a portion of the departure lanes' striping, vehicles could make right turns from the south into the right-side lane while SB left-turners entered the left-side lane. Following this phase, the controller served all lanes of the NB approach, then served a second all-

PED, and a final NB right-turn. This phase sequence proved inefficient compared to TSL's recommended plan.

SC 93 – College Ave: Here, officers prohibited the left turn, and all lanes made only thru movements. Phasing did not change, but TSL modeled on those used after Florida State-2015. TSL observed that heavy rainfall affected the operations along SC 93 after ND-2015, but didn't affect FSU's conditions later that year.

SC 93 – Calhoun Dr: At Cherry Rd, SC 93 becomes a divided highway, meaning that if all lanes are EB, the two left lanes will separate from the two right lanes, but TSL placed the diverge here at this intersection instead in order to move any queue-jumping to the departure from this intersection. TSL observed that queue-jumping downstream caused SC 93 – Cherry Rd to operate below capacity. This change was in effect for all three treatment models. The treatment is not visible in VISSIM's GUI, so it is omitted from the Appendix.

SC 93 – Cherry Rd: Four EB lanes entered, and four EB lanes exited, though split by a median. Officers also preserved the NB right-turn, but eliminated the SB left-turn in 2015 and in 2016. This movement will not reopen until campus construction to the north is complete. Due to the geometry change, TSL eliminated the alternating phases used to merge the two sets of thru lanes, simplifying the phasing to a three phase signal. The controller modeled a major EB phase and a phase for NB right turns overlapping the other three EB thru lanes, then repeated that sequence before finishing the cycle on a short all-PED phase. In addition, TSL lowered the cycle time to 278 sec.

SC 93 – US 76 (ramps): The two leftmost thru lanes merged into one, while the right-side-interior thru lane led into the exterior thru lane on the overpass. Vehicles made right turns from the rightmost lane (referred to as a lane-drop in the MUTCD *(30)*). At the NB ramp, Officers prohibited all left turns, and the phasing alternated only between the exterior thru lane and NB right turn. EB traffic approaching US 76 could pass on either side of the median (referred to as contraflow) before merging onto the right side of the overpass. TSL assigned 75% of the EB thru traffic to the left-two thru lanes, and 25% to the thru lane on the right side as part of modeling the treatment for the SC 93 Corridor. If implemented, this would encourage proper utilization of the full EB capacity and could be ground-implemented in the form of a notice published to game day visitors. Visitors' comfort level with using a contra-flowed highway is critical to this treatment's effectiveness. Therefore for this treatment to be effective, TSL recommends that stakeholders assuage drivers' natural fears of left-hand driving.

US 76 – Perimeter Rd: Here TSL used a double EB left turn. TSL did not observe this the night of ND-2015, but did observe officers using it following FSU later that year. TSL incorporated this into their recommendations. Phasing and timing here favored the EB approach by 61%-39%, and TSL took this from ND-2015, which used a long 408-sec cycle.

Model #3: Recommended w/ Reservice

This modeled how TSL would have liked to the network to be operated, specifically at two critical intersections involving US 76.

US 123/76 – College Ave (SC 133): In Model #2, TSL here used geometry that they used in all three treatment models; the cycle time also remained the same. TSL's modeled their recommended phasing and timing plan using EBL Reservice. This plan operated a series of EB/WB phases followed by a series of NB/SB phases without need for an all-PED phase. This plan also returned service to the EB thru and left turn following an EB and WB thru phase to clear any blockage in the EB thru lanes caused by queue spillback from the turn bay. Once clear, the rest of the EB/WB sequence reverted to East and West thrus only, allowing E/W pedestrians to cross alongside when not conflicting with EB left turns. The controller followed this by phasing the NB left, SB left, and one of the NB rights together, then finished the cycle with a phase of N/S pedestrians and NB thru and right.

SC 93 – College Ave, SC 93 – Calhoun Dr, SC 93 – Cherry Rd, and SC 93 – US 76 (ramps): TSL modeled operations at these five intersections the same for all three treatment models.

US 76 – Perimeter Rd: Here, all three treatment models used the same geometry. Phasing favored the EB approach 60%-40%, just as before, but TSL dropped the cycle length from 408 seconds to 150 seconds to provide quicker queue-clearance near the intersection. TSL has found that long cycles and phases do not fully use the capacity as flow tends to drop below saturation, negating the benefit of reduced lost time per hour provided with longer cycles. Originally TSL intended to lower the phase split given to the EB left, but the modelling conditions couldn't accurately represent actual conditions along

Perimeter Rd. (TSL suspects that, if they are going to match Clemson tailgaters exactly, VISSIM needs a different car-following model.)

Model #4: Recommended w/o Reservice

This is a redux of Model #3 except at one intersection.

US 123/76 – College Ave (SC 133): Instead of operating the E/W sequence as 1) EB thru + EB left, 2) EB/WB thrus, 3) EB thru + EB left (reservice), then 4) EB/WB thrus to close, TSL combined the leading EB left phase time with the reservice time into a long leading EB left. TSL returned lost times between the E/W thrus and reservice to the appropriate phase, lengthening the effective greens for the EB left and E/W thrus. Total phase time devoted to the E/W sequence did not change between Model #3 and Model #4. This timing plan is how the intersection would operate without reservice but while still keeping the same amount phase split.

Other intersections: There were no other differences between Model #3 and Model #4.

CHAPTER 6: MODELING RESULTS

Statistical Distribution of VISSIM

TSL ran each model in VISSIM 20 times using a different random seed each time. Random seeds allow VISSIM to stochastically vary many distributions, chiefly arrival volume rates at the network input links, but also driving behavior. *(24)* Each seed causes VISSIM to randomly select distributions for its inputs, and the characteristics of these distributions are normally-distributed because VISSIM uses a random number generator.

Each run that uses a different seed produces different performance results. TSL assumed that the population results from all possible runs using every seed allowed are normally-distributed, even though some specific distributions might not be (e.g. arrivals would Poisson-distributed, but aggressiveness of drivers could be linearly-distributed). Thus, a random sample of such a population should provide an unbiased mean, test-statistic, and confidence interval describing that model's performance. *(31)* TSL chose a sample size of 20 for each model because computing limitations cause such a size to take 1.15 hours to complete when the model calculates results for one hour of simulation time.

TSL evaluated travel times over six routes and calculated means and standard deviations for each route in each model. Each run produced an average route travel-time, which TSL then averaged across all 20 runs. For each travel-time route, TSL performed t-tests (Appendix B) to determine if means of travel times from different models were significantly different from each other. The author also identified confidence limits for each of these means. For all routes, in all cases where TSL compared means between models, confidence intervals for comparisons whose differences were significant also did not overlap. This analysis used 95% confidence for both confidence intervals and hypothesis tests. Thus, the confidence interval plots in **Figures 12** and **13** also indicate which means were significantly different at the 95% level.

Routes

VISSIM evaluates travel-time over routes with preset start and end points. When vehicles cross the end point of a route, VISSIM records the travel-time from the start point of that route. *(24)* VISSIM then reports the average of all such records for each route recorded during simulation as that route's average travel-time.

TSL set six routes for evaluation, whose locations **Figure 10** illustrates. Routes 1 and 2 covered the US 123/76 Corridor, and both ended in the middle of the intersection with College Ave. Route 1 started before the merge with the SC 93 NB right-turn on the other side of Lake Hartwell while Route 2 starts after the merge from the NB right turn from this intersection (**Figure 11**). This allowed for separate analyses of vehicles originating from Seneca and those originating from both Seneca and campus.

Routes 3 and 4 covered the SC 93 Corridor from Centennial Blvd to the diamond interchange with US 76. VISSIM did not measure vehicles entered SC 93 downstream of Centennial Blvd. Route 3 ended on the approach to the overpass, measuring times for vehicles bound for points west of Clemson. Route 4 ended on the SB ramp to US 76 (**Figure 11**), measuring times for vehicles bound for points south of Clemson. The signal at Perimeter Rd impacted Route 4 more than other routes.

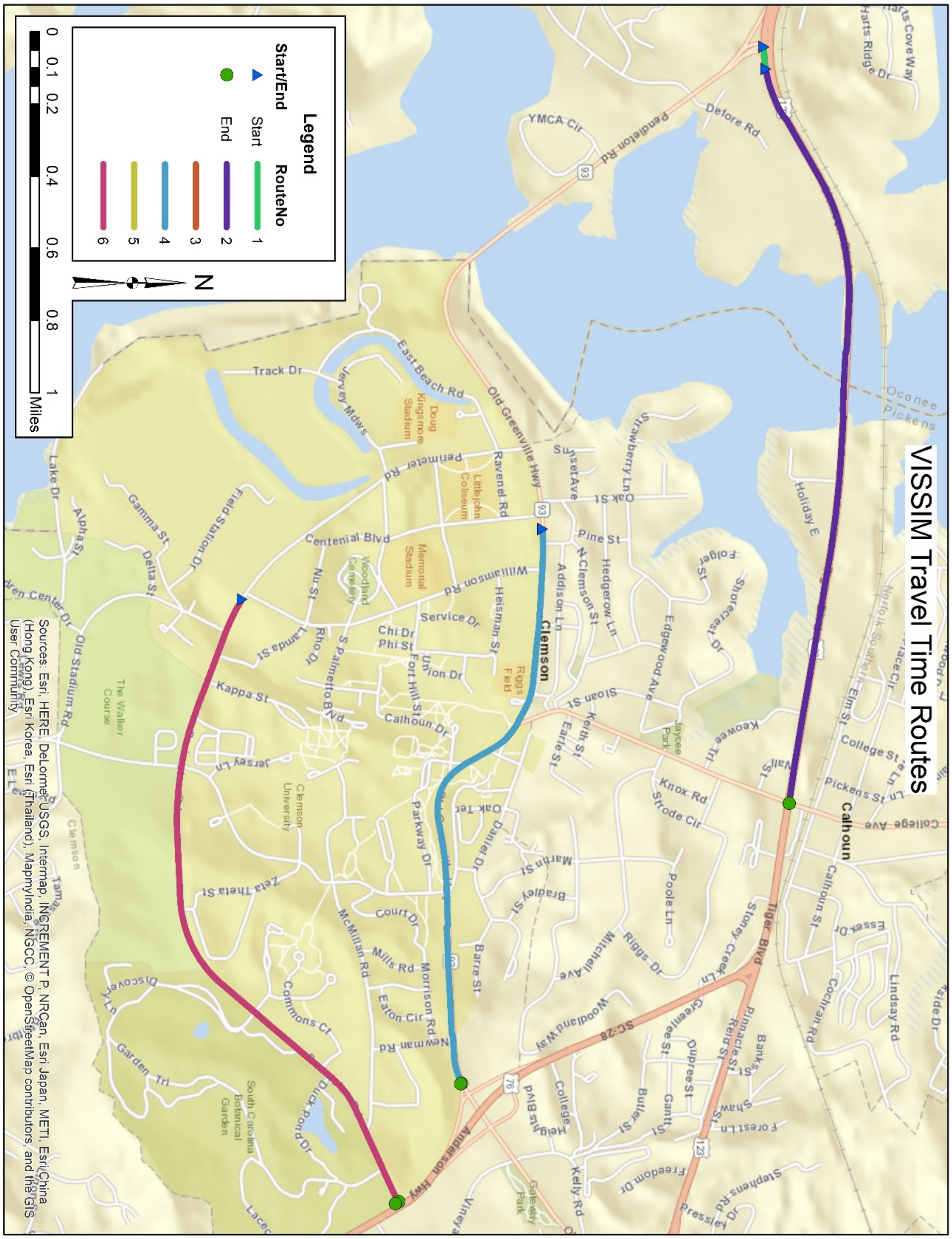


Figure 10: VISSIM Travel Time Routes

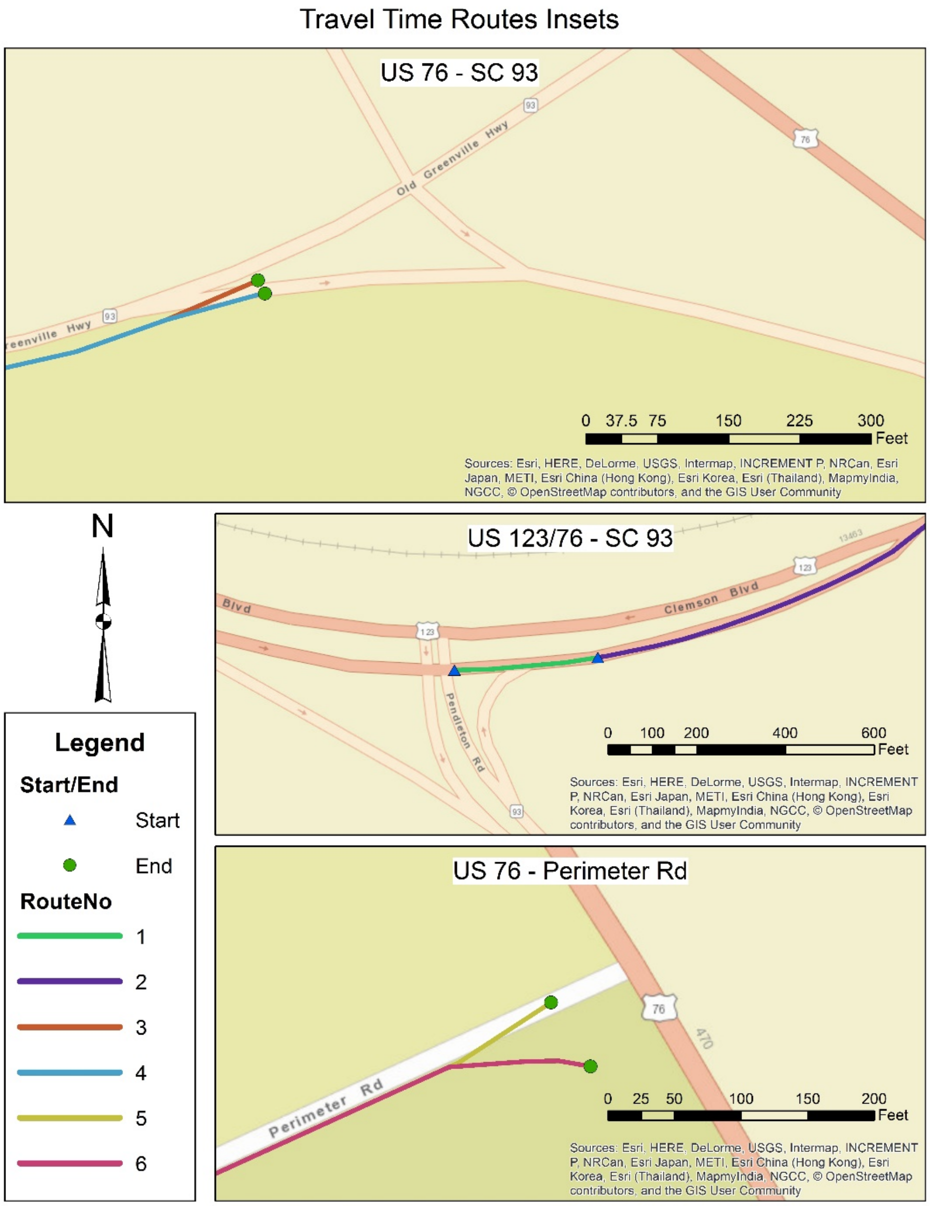


Figure 11: Travel Time Route Insets for Slightly-Differing Termini

Routes 5 and 6 covered the Perimeter Rd Corridor from Williamson Rd to US 76. VISSIM did not measure vehicles entering downstream of Williamson Rd. Route 5 ended on the left-side of the approach, measuring times for vehicles bound for points west and north of Clemson, while Route 6 ended on the right side (**Figure 11**), measuring times for vehicles bound for points south of Clemson.

TSL kept lengths of routes on the same corridors (e.g. 1 and 2) as close to each other as possible (while also keeping the start and end points the same across models) to ensure VISSIM measured the same corridor space for each pair of routes. **Table 3** summarizes the characteristics for each route.

Table 3: Route Characteristics

Route No	Corridor	Start	End	Model 1 Length [ft]	Models 2-4 Length [ft]
1	US 76/123	SC 93 (crossing)	College Ave (mid-crossing)	9370.0	9370.0
2	US 76/123	SC 93 (downstream)		9030.0	9030.0
3	SC 93	Centennial Blvd (downstream)	Past SB ramp (thru)	7245.4	7245.4
4	SC 93		On US 76 SB ramp	7245.4	7245.4
5	Perimeter Rd	Williamson Rd (downstream)	US 76 (left)	8450.0	8447.6
6	Perimeter Rd		US 76 (right)	8450.0	8450.0

Confidence Interval Results

For each sample mean, TSL constructed confidence intervals at the 95% level of significance. Because the sample size of 20 is less than 30, but the population is assumed to be normally-distributed *(31)*, these intervals are based on the Student's t-sampling distribution at 19 degrees of freedom. The following two charts (**Figures 12** and **13**) plot these intervals. Each vertical graph represents one of the six routes and includes the intervals for determined from each model.

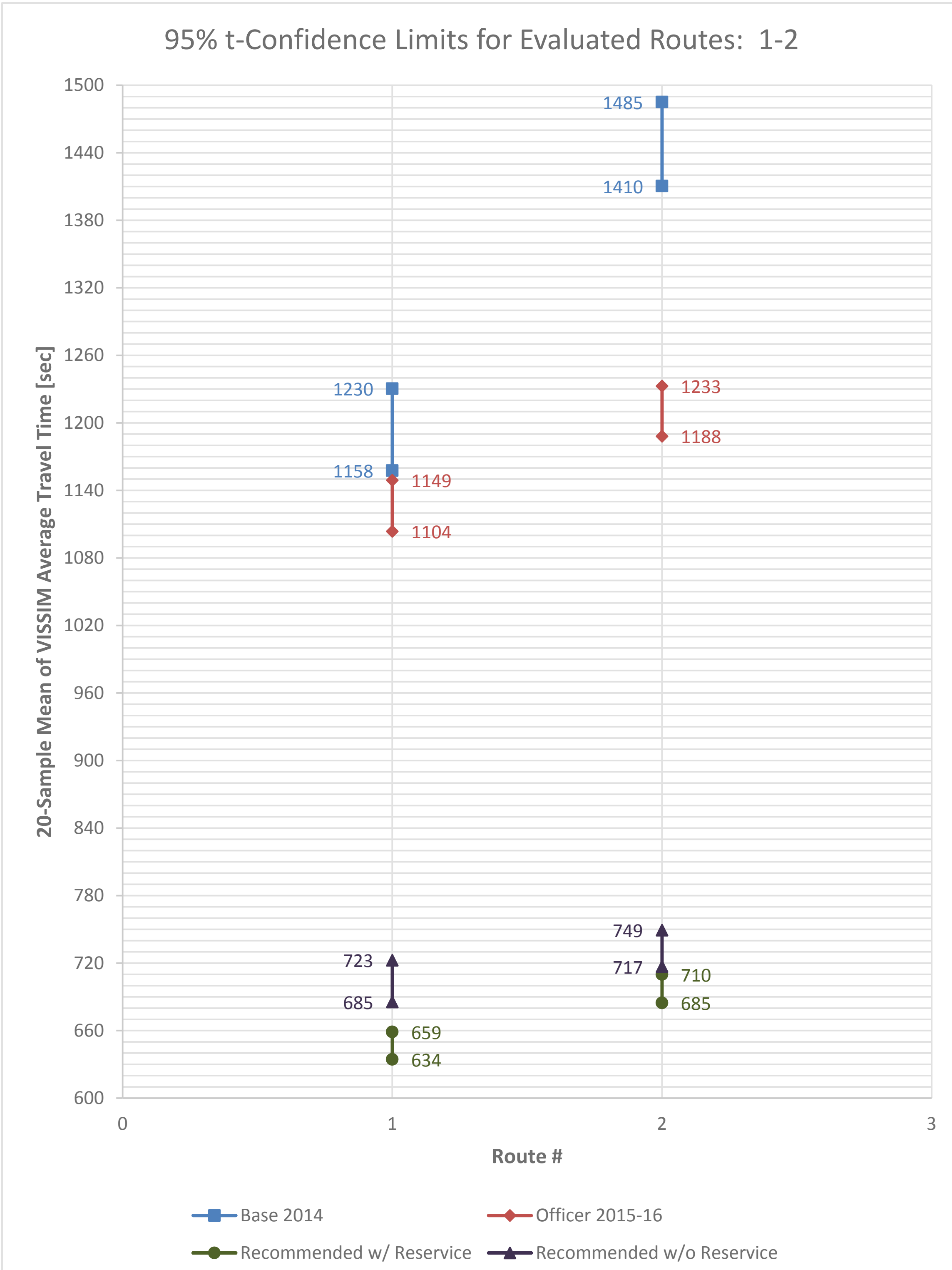


Figure 12: 95% t-Confidence Limits for Evaluated Routes: 1-2

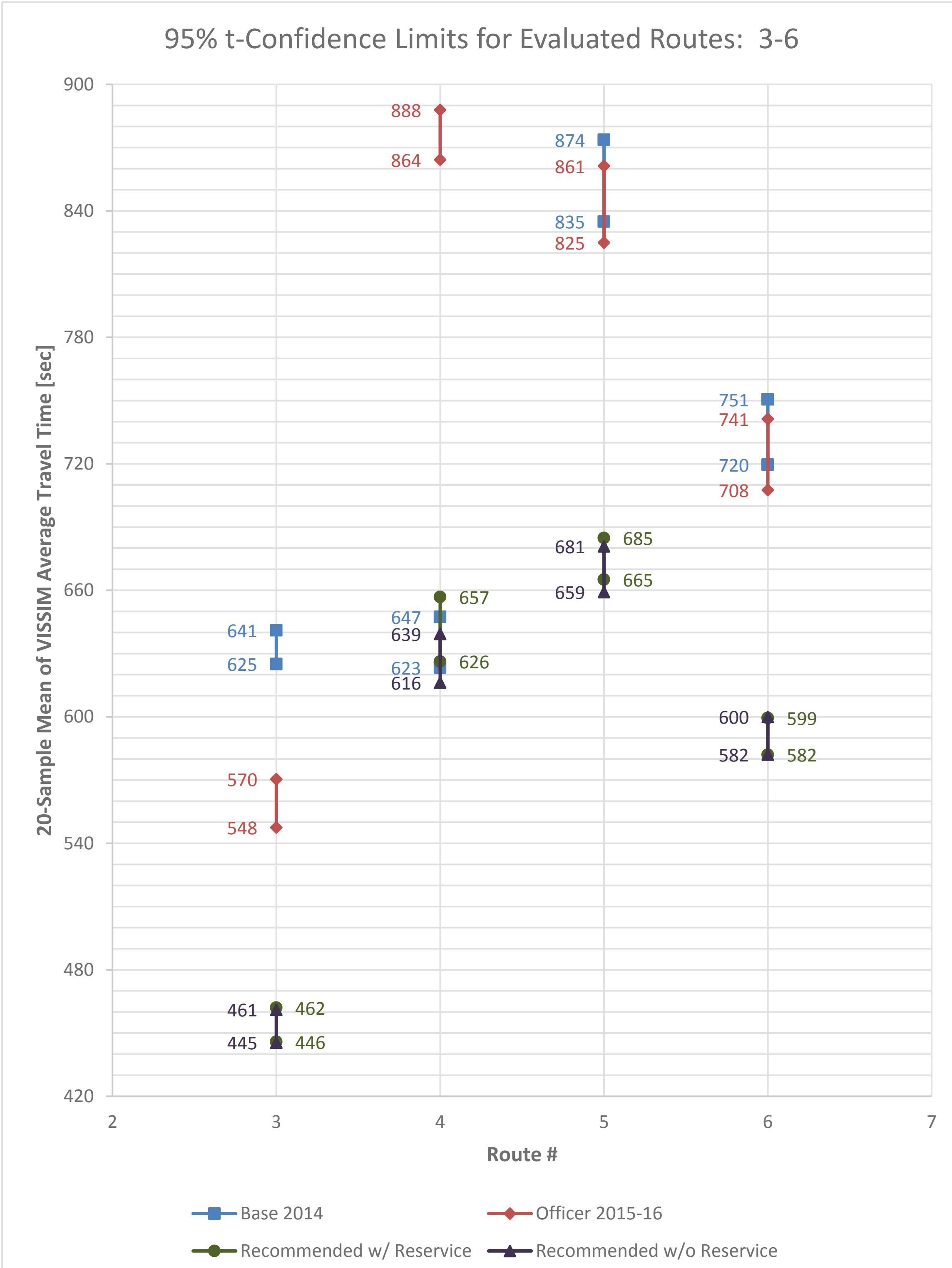


Figure 13: 95% t-Confidence Limits for Evaluated Routes: 3-6

General Trends

For Routes 1, 2, and 3, there is clear modeled travel-time improvement from 2014 operations to 2015 officer-actual operations. The signal at US 76 – Perimeter Rd impacted these three routes (US 123/76 and SC 93 to the overpass) the least. This suggests that changes in geometry implemented along US 123 and SC 93 are beneficial even without the apropos re-timing. Route 4 suffered a massive increase because the increased throughput along SC 93 conflicted with Perimeter Rd when it reached the ramp to US 76. This was expected, and TSL proposes that those who intend to use I-85 NB continue on SC 93 and use US 123 to Easley instead of turning right here. TSL believes this will better use the full capacity of all four lanes. Routes 5 and 6 (Perimeter Rd) experienced no significant effect from the changes in geometry.

For all routes, adding to the geometry updates the recommended timing plan at US 76 and Perimeter Rd and either of the plans for US 123/76 – College Ave produced marked improvement in travel time. In the case of the problematic Route 4, this full implementation even reduced travel time to its 2014 level in VISSIM.

Between Models 3 and 4, there was an observed effect on travel time for only Routes 1 and 2. In this case, Reservice of the EB left-turn improved travel-time for both routes. Nonetheless, the simulated improvements could be greater if the signal had been modeled as a semi-actuated signal. In this case the phasing, cycle length, and E/W sequence length would be the same, but the reserved EB phase would only be called when a queue presence detector in the turn-bay is called. The reserved turn would then gap out upon clearance. The ground version of this would be an officer to observe the left-turn queue and reserve it before it spills into the thru lane. This would likely produce an even greater benefit than what is given here.

CHAPTER 7: CONCLUSIONS

Even though this project has seen challenges, its overall success in treating Clemson's Game Day traffic demonstrates that 1) extensive data collection in an oversaturated condition can be carried out with cost-effective techniques, 2) the data can be used in a microscopic simulation environment, such as VISSIM, 3) and produce beneficial results.

Through the efforts of TSL, led by this thesis' author, this thesis has provided positive outcomes for the thesis' objectives, which were as follows:

1. To demonstrate how large quantities of data required for a microscopic simulation (microsimulation) can be collected in a cost-effective manner
2. To develop an efficient method to measure queue growth caused by severe saturation for use in modeling
3. To identify challenges in creating and calibrating a severely oversaturated model and how Bluetooth data can benefit calibration
4. To develop transferable (and scalable) methods that could assist in special event traffic planning.

Objective 1

First, this thesis presented a methodology for collecting video data and queue data across a large area in a network. This methodology is based upon the efficiency and low cost of small sports cameras and paint poles available from any home improvement store. An improvement over the bulky system used in 2003, the 2014 system allowed easy transport, setup, and storage of equipment. TSL used this method to collect many hours of video data that they processed with JAMAR boards. Public agencies can use low-cost sports cameras, mounting systems, and paper and pen to collect as much data as necessary to simulate the network of a small town.

Objective 2

Second, this thesis presented a methodology for collecting queue length data when a network is severely oversaturated and how to interpret these data in a modeling context and recapture demand lost through traffic counting in saturated conditions. TSL collected queue length data using two different methods, and both returned results that TSL could use to adjust intersection counts when the network was severely over-saturated. However, the latter method of printed satellite maps allowed for more precise data and is TSL's recommended technique. Students who collected data walked back as far as 2500 feet in some cases, certainly a longer distance than most cameras can capture even if there was a line of sight.

Objective 3

Third, this thesis identified challenges that can occur when collecting special event traffic data and when modeling special events. While some methodologies may be sophisticated and produce extremely good data, these extremely precise methods are not always necessary, but they are very expensive. TSL's methods, though inexpensive, do incur challenges. TSL found ways of mitigating these challenges, either through additional practice or use of external resources. The thesis also points to the benefits of Bluetooth data in solving these problems. TSL used these data to inform the model on turning movement percentages at intersections where movements were consistently saturated. With the progress of time, Bluetooth will achieve better market penetration, and these data will become even less expensive to obtain than they are currently.

Objective 4

Fourth, TSL's work on this project gave this thesis methods for special event traffic planners that are transferable to a community of any size. TSL faced almost no restrictions in deploying an extensive group of volunteers to collect data. The reward of passes to sold-out games certainly helped, and this thesis recommends this incentive to other special event planners who need volunteers. Just because these methods are targeted at communities that don't want to pay for an ITS doesn't mean they are limited to a small network. Furthermore, materials required by these methods (with the exception of modeling software) are readily available from the internet or a home improvement store.

Having met these objectives, this thesis offers these methods to communities that deal with special event congestion and don't have the resources to invest in an ITS solution like Salt Lake City's.

Lessons and Recommendations

TSL's work on the Clemson Football Traffic Improvement Study provides the special event traffic modeler with several lessons. First, simulation of severely oversaturated networks is more challenging than simulation of networks experiencing weekday peaking. Modelers should seek out other resources to augment their own data collection efforts when these challenges (such as turning movement percentages restricted by saturation) arise. Second, Bluetooth data are useful in this regard, particularly for turning movements and routing decisions, and are not resource-intensive to collect if the authorities are amenable (as they were in Stantec's case). Third, compact camera systems can be purchased at little-to-no cost compared to traditional traffic camera systems, yet can still provide useful data for modeling. Fourth, these methods may be a little challenging to implement by those without much experience, but they are easy to learn, and a little practice goes a long way toward cost-effective data collection. Fifth, TSL assumed the standstill spacing of queued vehicles was 27 feet based on the literature, but TSL recommends to each community that they use Long's Method to find this value on their own. His method is very simple, just as easy and low-cost as the rest of TSL's methods, and provides very accurate standstill spacing results.

TSL would have liked to analyze other aspects of Clemson's Game Day network, but for time, could not for this thesis. Thus, this thesis first recommends that future researchers investigate how VISSIM predicts travel-time savings for transit usage on the west side of campus. This was one of TSL's most successful treatments, but was not within the scope of this thesis. Second, researchers with access to a school of computing may want to seek development of a tablet app that volunteers can use to record queue data, as this would eliminate the chance of data loss from misplaced sheets and would reduce the impact of weather on queue data collection. The app could also potentially interface with the sports cameras, so queue observers on long queues need not go back to their intersections to check their cameras. TSL asked students to do this sometimes to make sure their cameras were still recording. This recommendation is contingent upon a university setting, like Clemson, where software development for research is common. Third, TSL chose not to model the network using VISSIM's parking lot feature due to a learning curve associated with learning it. Perhaps future work can look into how turbulence associated with parking lots might change the results. Fourth, TSL also performed a parking reallocation study using relevant parts of the Four-Step Model. Future research ought to investigate how origin-destination parings from this model can affect network performance in VISSIM.

The author learned much about how data collection and microsimulation can be performed for severely-oversaturated networks without expensive equipment or ITS. Through the work on the Clemson Football Traffic Improvement Study, TSL developed a transferable methodology to accomplish this. The author hopes that these methods can bridge the gap between large-scale data collection and robust microsimulation, while doing so in a cost-effective manner.

GLOSSARY

Here some terms with specific meanings in the context of this thesis are defined. These definitions may differ in scope from those in authorized references.

After-game: All activities, traffic events, and data collection efforts that occur in the time period starting immediately after a game is decided (or fans begin to depart) until all demand generated by the event is served by the network; also any model in VISSIM that simulates traffic operations during this period. Characterized by heavy convergence on destinations within the network.

Before-game: Similar scope as After-game, but occurring within the timespan starting when traffic generated by an event begins to demand service on the network until no such traffic is demanding service. This typically ends shortly following the start of the game. Characterized by heavy divergence to destinations away from the network.

Louisville-2014: Before-game and/or after-game scenarios associated with Clemson University's game versus the University of Louisville in October 2014.

Louisville-2016: Scenarios associated with the game versus Louisville in October 2016.

ND-2015: Scenarios associated with the game versus the University of Notre Dame in October 2015, known colloquially as the "Monsoon Game."

FSU-2015: Scenarios associated with the game versus Florida State University in November 2015.

Lane drop (also dropped lane): A thru lane whose traffic is required to make a turn. The number of thru lanes upstream of an intersection is equal to the number of lanes immediately downstream plus the number of dropped lanes.

Special event (also Planned Special Event): A prescheduled public event which generates large volumes of traffic and/or reduces capacity to handle normal volumes, affecting multiple corridors within a network. These events might not occur frequently enough to be considered in the geometric design of streets and highways in small communities.

Channelization: The assignment of a movement to a particular path through an intersection using temporary devices, such as cones and barrels. This assignment may be different than the intersection's permanent geometry and striping and is typically assisted by a law enforcement officer.

Microsimulation: Simulation of traffic using a computer model that calculates results based on interactions between individual vehicles and the network. Results can be presented in an animation of these interactions or as an evaluation of MOEs performed by the model during simulation.

Microscopic: Referring to a model based on interaction at the level of individual vehicles.

Macroscopic: Referring to a model based on the behavior of a flow of vehicles. The behavior is based on other theoretical relationships of traffic flow. Results are calculated based on how traffic flow theory predicts a flow should behave (e.g. Greenshields, Webster's Delay).

MOE (also Measure of Effectiveness): Variables calculated from a model or measured on the ground that indicate the performance level of network or parts of the network (e.g. corridors, segments, intersections, etc.). In this thesis, Travel-time is the preferred MOE.

Link input: An hourly flow rate assigned to the start point of a network segment ("link" in VISSIM) applicable for a set time period which VISSIM uses to load vehicles into the network. Vehicles first appear in the simulation at link input points. VISSIM can vary this rate of entrance, generating the stochastic variation of arrivals using a random seed.

Saturation: Condition present throughout the network or some network part (e.g. an intersection) such that flow of vehicles or persons is constrained to the maximum that the network will allow, either through or geometry or assignment of conflicting right-of-way. Saturation is slight or severe depending the ratio of demand-to-capacity (v/c).

Queue-clearance: Time required to fully discharge a queue of vehicles such that flow is not over-saturated (v/c > 1) at the end of this period.

Storage-clearance: Special case of queue-clearance where the queue is spatially limited to a turn bay. This period is the basis for the timing of turn signals within a signal cycle.

Reservice: Provision of a protected phase for a movement, typically a left turn, already served at least once in a signal cycle. Following the reserved phase, the controller can return to the phase that timed previously or move to the next phase in the cycle, depending on time allotted to sequence containing the reservice.

Phase sequence (also sequence): Series of phases within a signal cycle whose timings depend on the amount of cycle time dedicated to the sequence. Times allotted to phases in different sequences are do not affect each other.

Cycle time: Time required to serve all sequences (but not necessarily all phases). Demand from each approach to an intersection is served at least once through a cycle, even if several phases are omitted (permission).

Protection: Giving a movement a phase during which right-of-way is guaranteed.

Permission: Assigning a movement to a phase during which right-of-way is not guaranteed. During cycles which don't serve all phases, movements not otherwise served (typically left turns) can be given permission.

Demand: The number of persons or vehicles desiring to pass a certain point in a network during a unit of time.

Capacity: The maximum number of persons or vehicles able to pass a certain point in a network during a unit of time.

Ground [any suffix]: Real-time traffic events; opposite meaning of events occurring within simulation.

Travel-time: Time required to traverse a route (in this case, while driving) between a start point and endpoint in a network. Travel-time can be either be on the ground or simulated. VISSIM records travel-time for vehicles that cross the endpoint of a route.

Average Travel-time: Arithmetic mean of all travel-time measurements on a route recorded by VISSIM.

Sample Mean: Arithmetic mean of average travel-times VISSIM reports for each simulation run. Statistics, like sample mean, are based on the sampling of average travel-times where the sample is generated from a sample of random seeds.

Simulation Run (also Run): A simulation over a modeling period of all vehicles' activities. Which activities are reported depends on which evaluations the modeler asks VISSIM to perform. Each simulation requires a random seed.

Random Seed: An integer which VISSIM inputs into its random number generator to randomly determine distributions for arrival patterns and parameters used in the car-following model. The same random seed always generates the same results, but different seeds generate different results. Results obtained using a sample different random seeds are assumed to be normally-distributed.

APPENDICES

Appendix A: Base and Treatment Conditions

In this appendix, each treated intersection is presented with its timing plan. The first section (**Figures 14-24**) gives all of the intersections in their Base 2014 condition. Pavement markings are provided on the links to clarify complicated movements. Each movement has a phase number assigned, which is noted in the "No" field in the accompanying timing plan. The next sections (**Figures 25-42**) give the changes made in 2015 and 2016.

The author did not model any right-turns-on-red (RTOR) because, in most observed cases where it would have occurred, vehicles waited for the officers' signal instead. All right turns at modeled pushbutton intersections were channelized.

In the case of US 76/123 – College Ave, pedestrian movements are shown as blue arrows across the crosswalks where they would occur (the author did not model pedestrians). Refer back to Section 5.4 for specific pedestrian phasing details. In all other cases where pedestrian phases are provided in the VISSIM timing plans, the phase is an All-PED phase (no vehicles), or pedestrians are phased with their companion vehicle movements as if there were no pedestrian signals.

Model #1: Base 2014

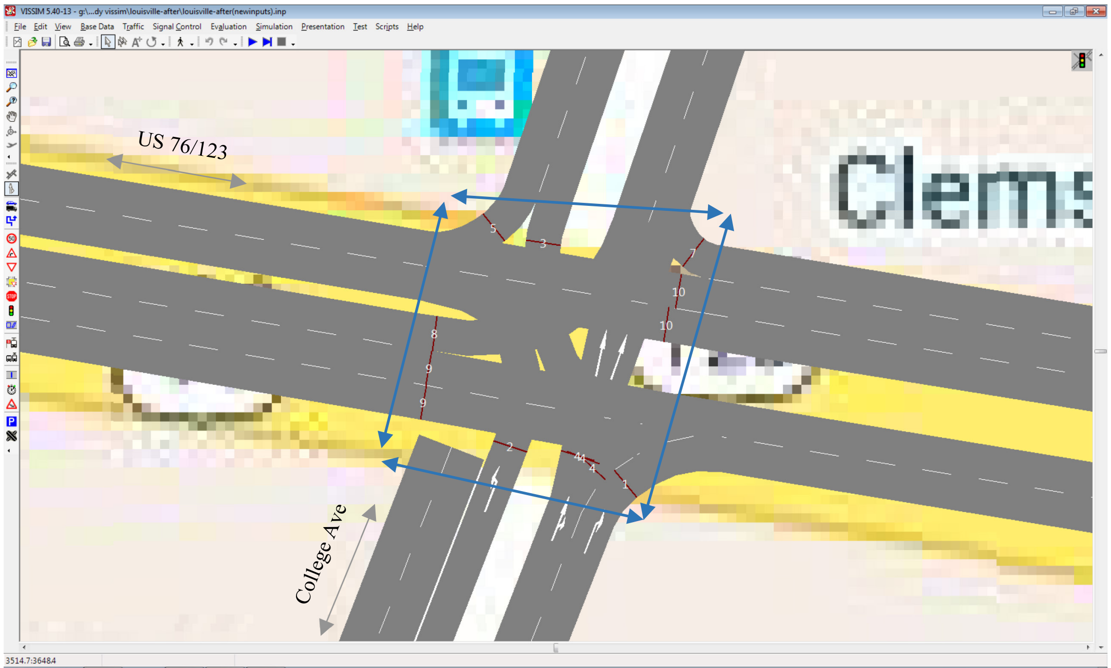


Figure 14: US 76/123 – College Ave Layout (Peds in Blue)

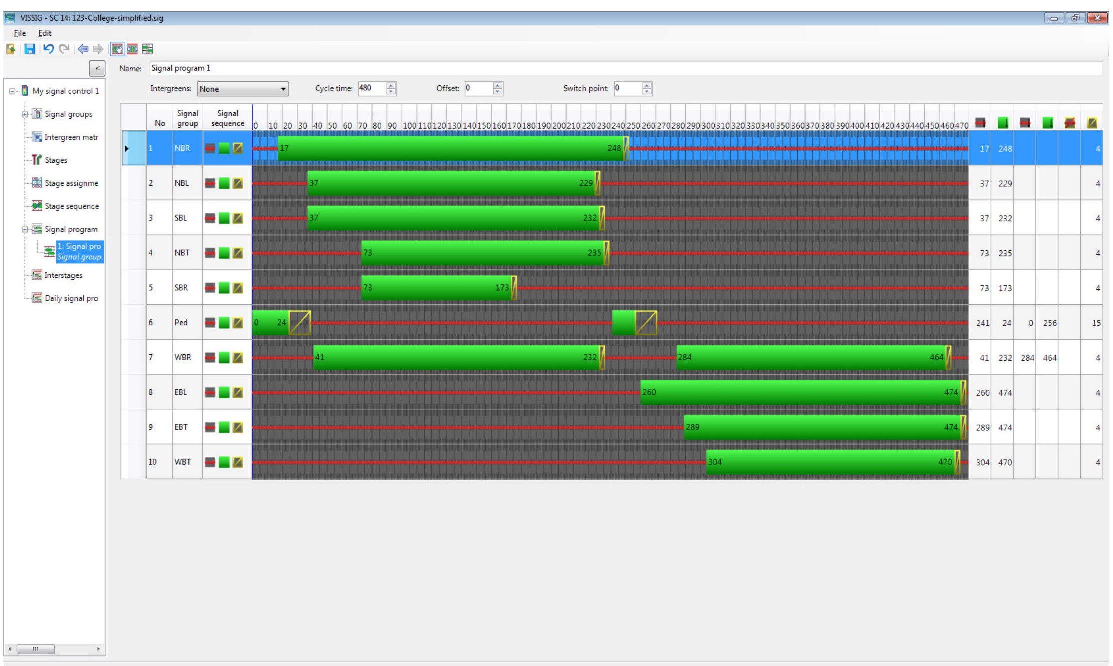


Figure 15: US 76/123 – College Ave Timing Plan (2014)

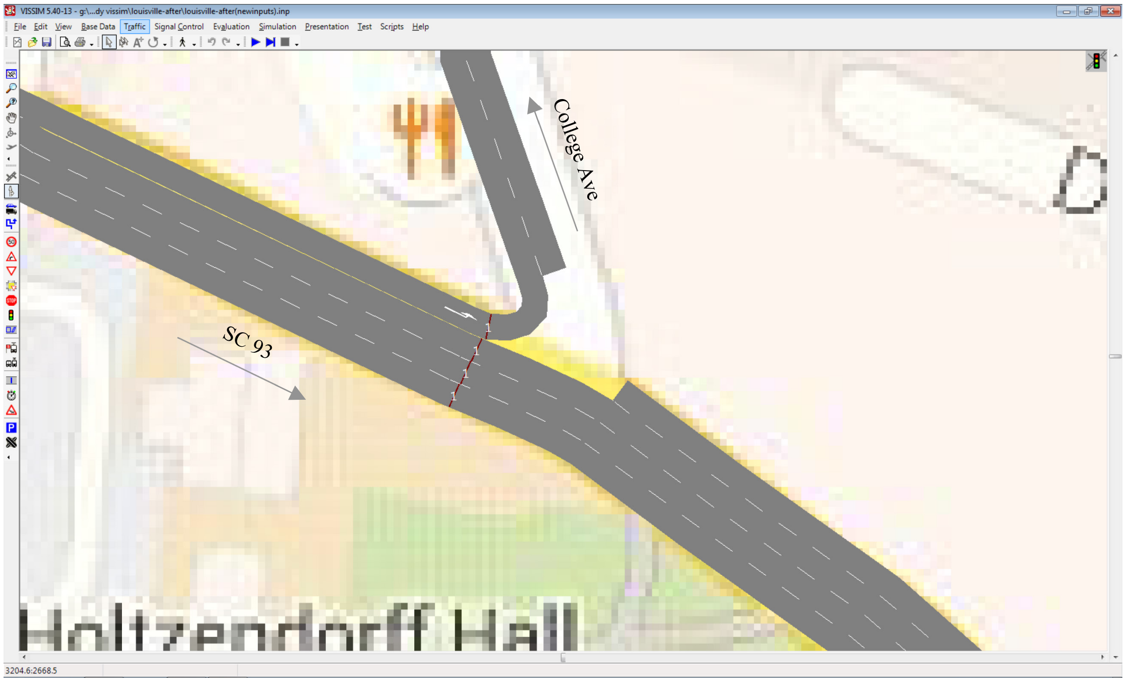


Figure 16: SC 93 – College Ave Layout (2014)

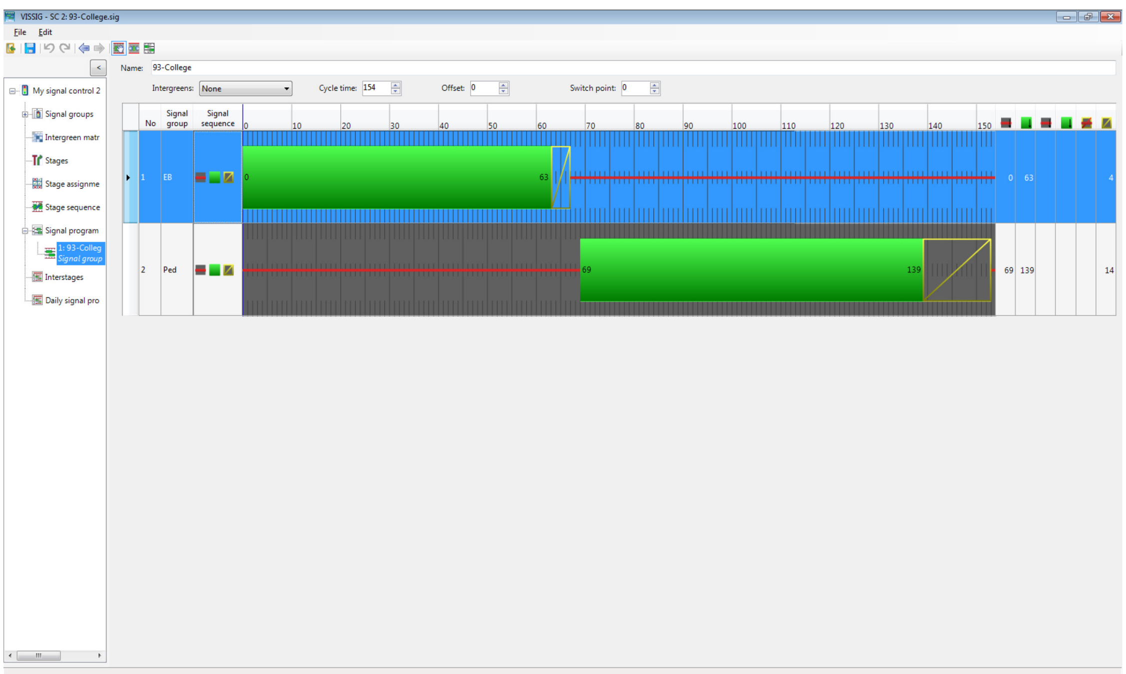


Figure 17: SC 93 – College Ave Timing Plan (2014)

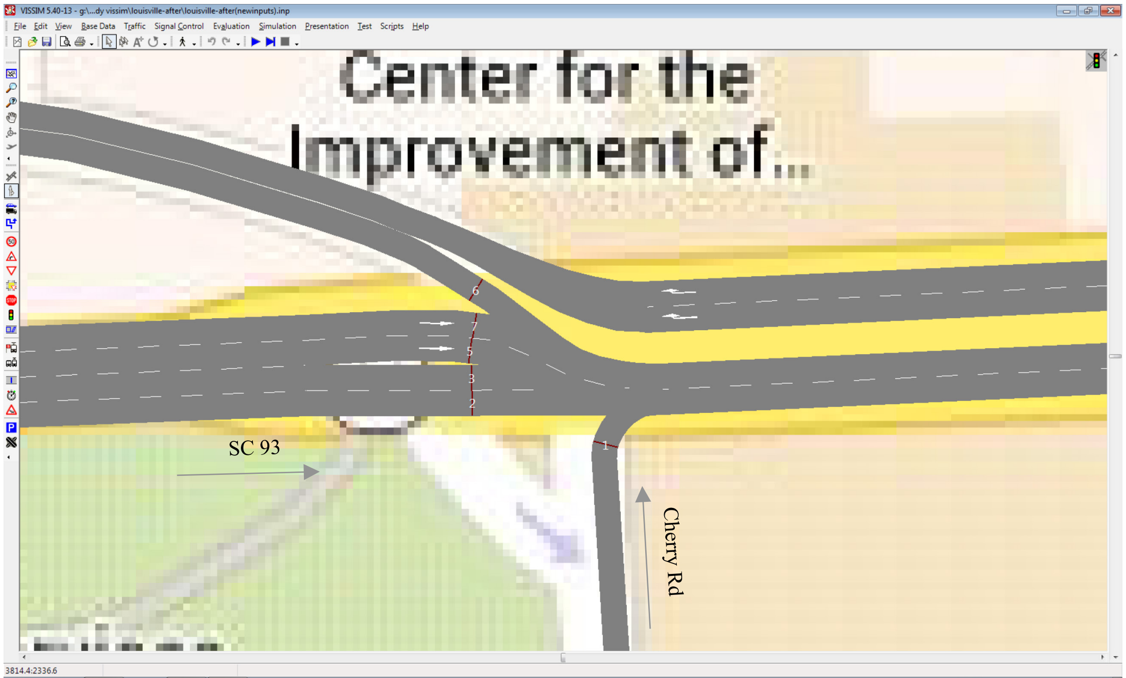


Figure 18: SC 93 – Cherry Rd Layout (2014)

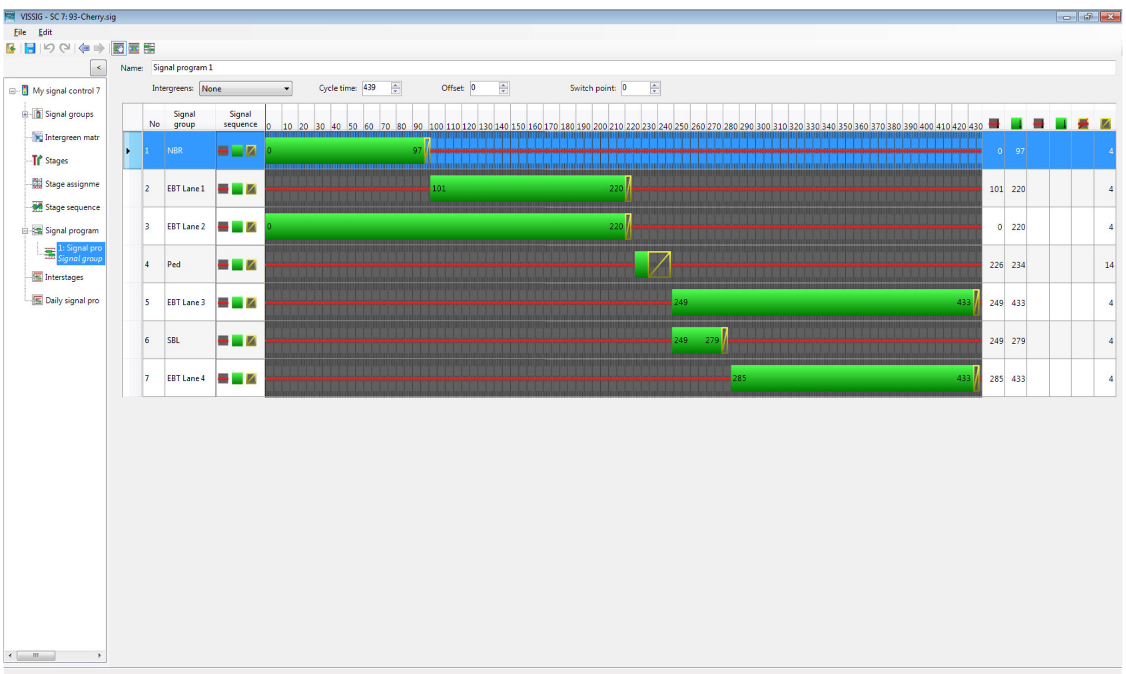


Figure 19: SC 93 – Cherry Rd Timing Plan (2014)

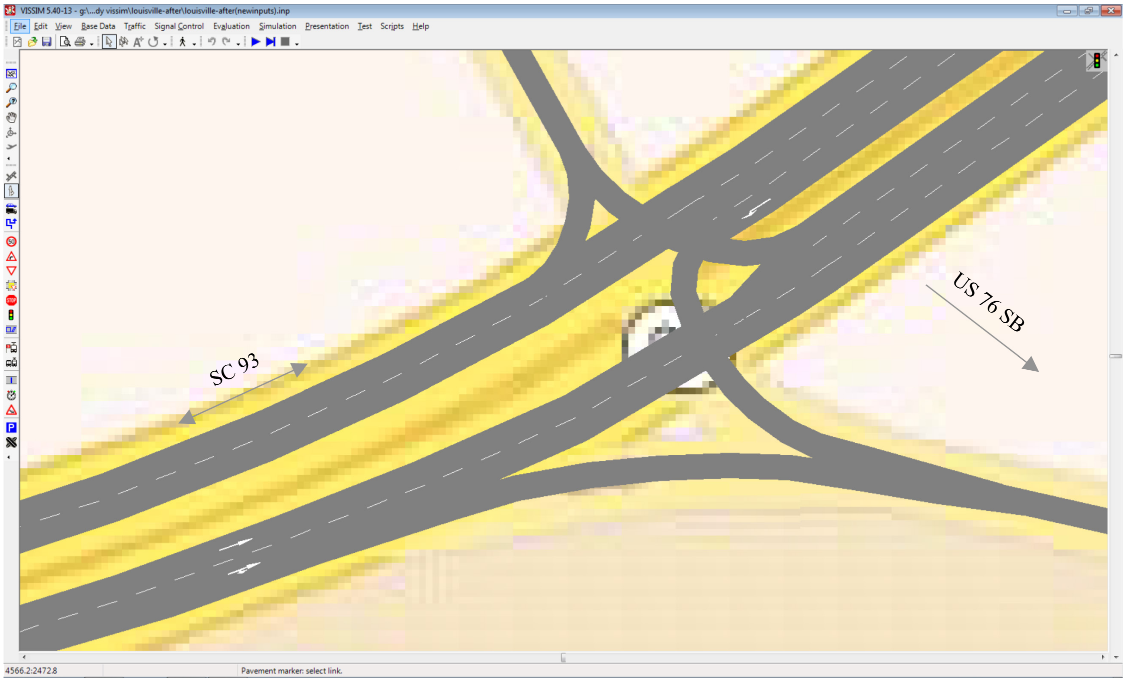


Figure 20: SC 93 – US 76 SB Ramp (2014)

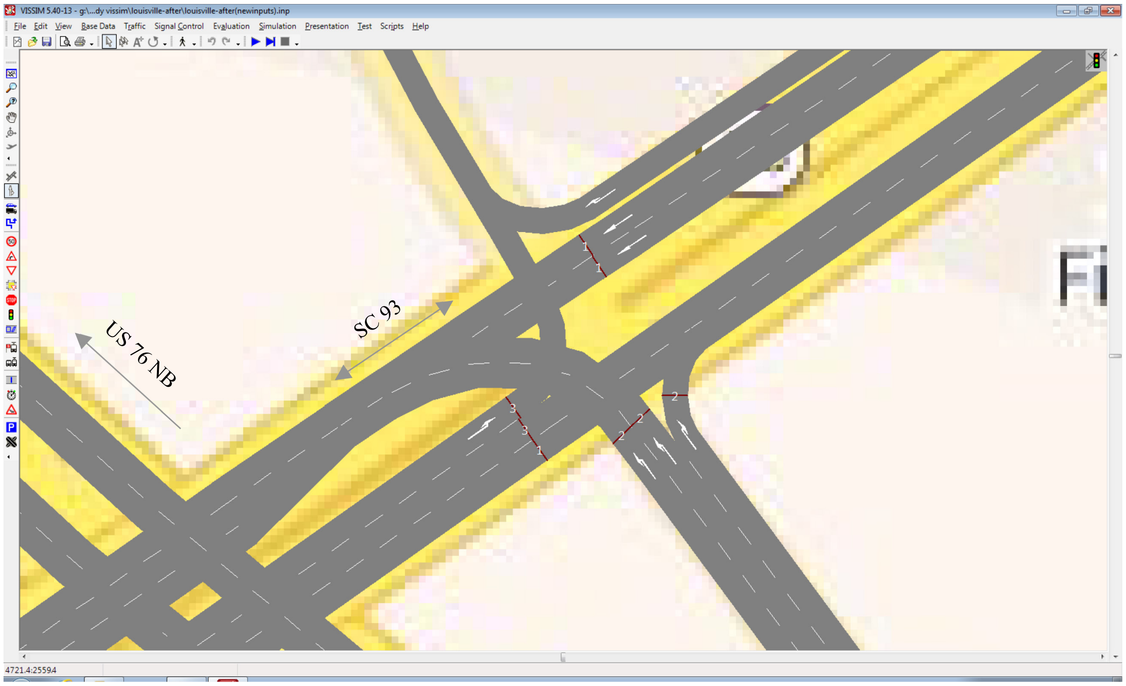


Figure 21: SC 93 – US 76 NB Ramp Layout (2014)

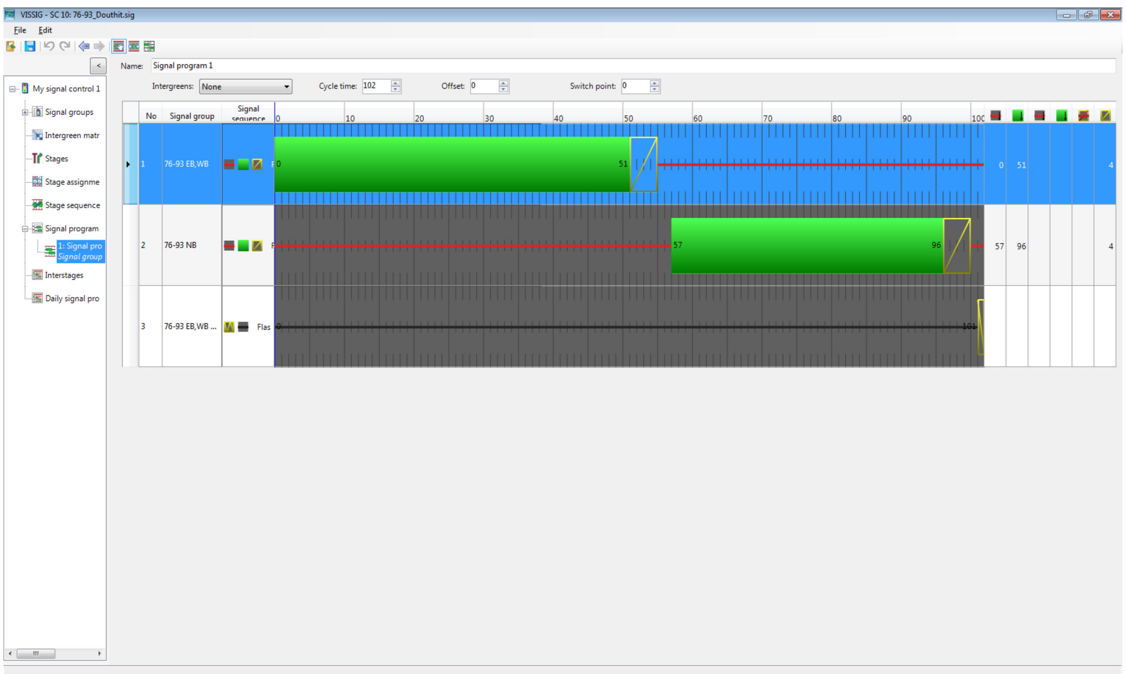


Figure 22: SC 93 – US 76 NB Ramp Timing Plan (2014)

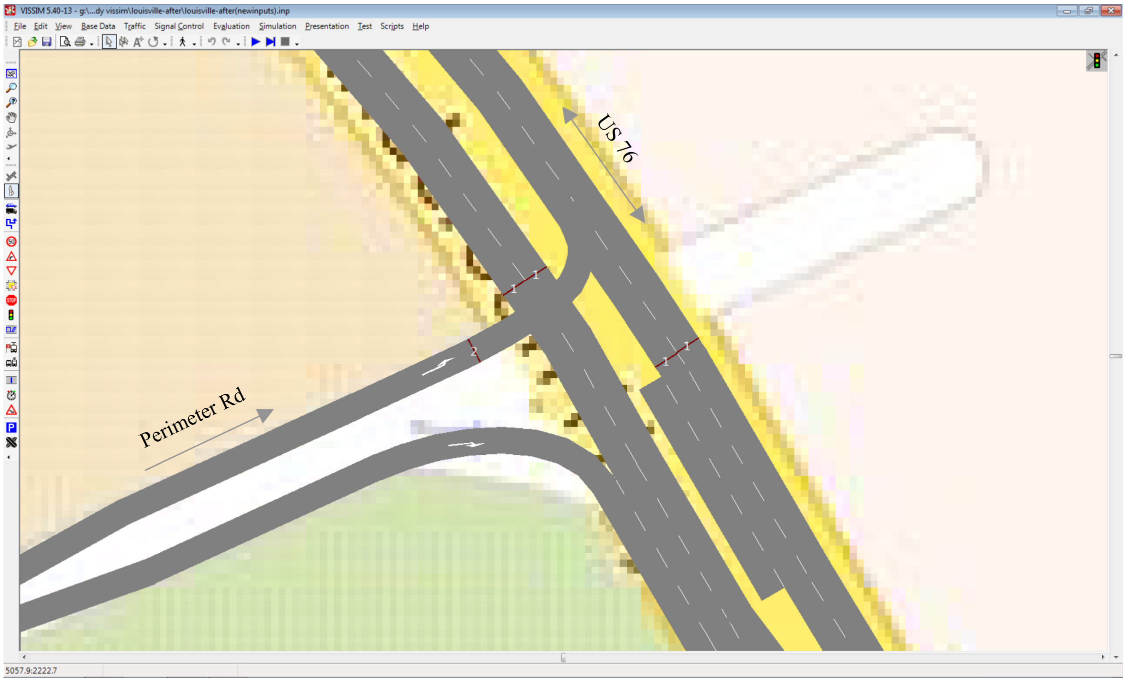


Figure 23: US 76 – Perimeter Rd Layout (2014)

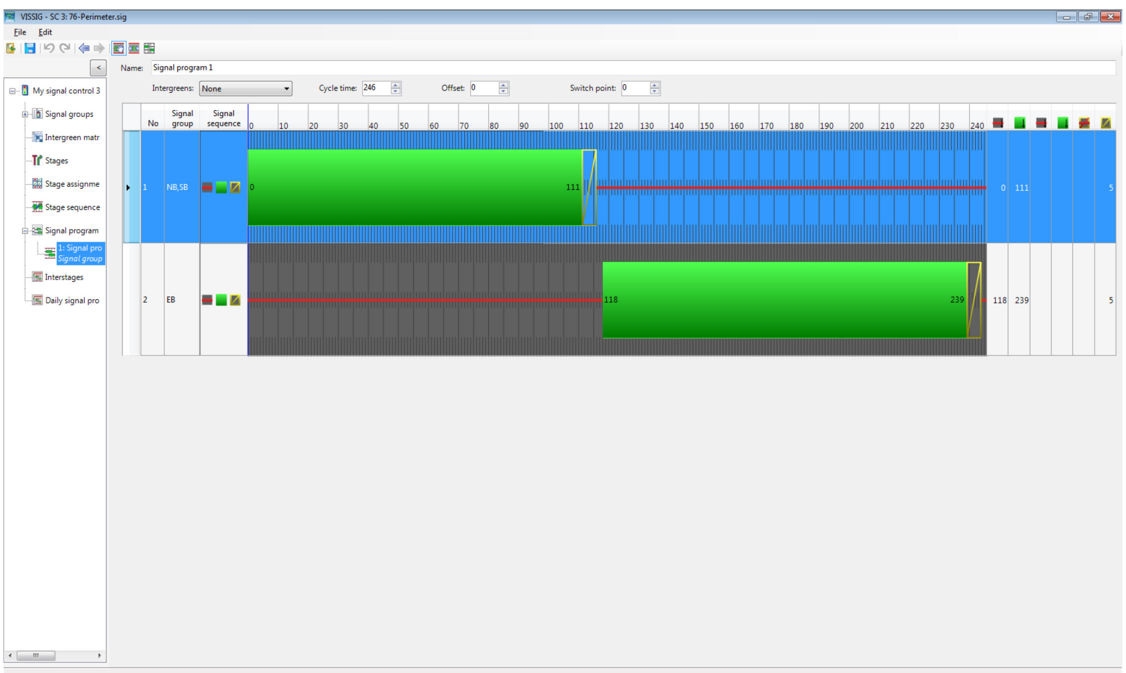


Figure 24: US 76 – Perimeter Rd Timing Plan (2014)

Model #2: Officer 2015-16

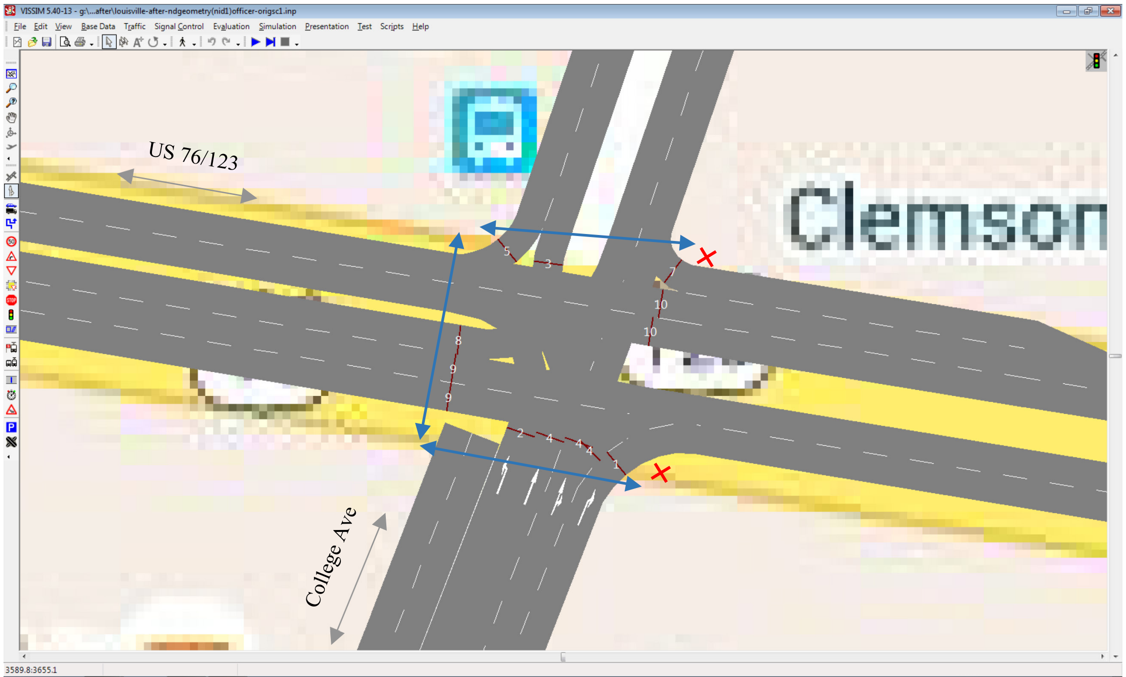


Figure 25: US 76/123 – College Ave Layout (2015)

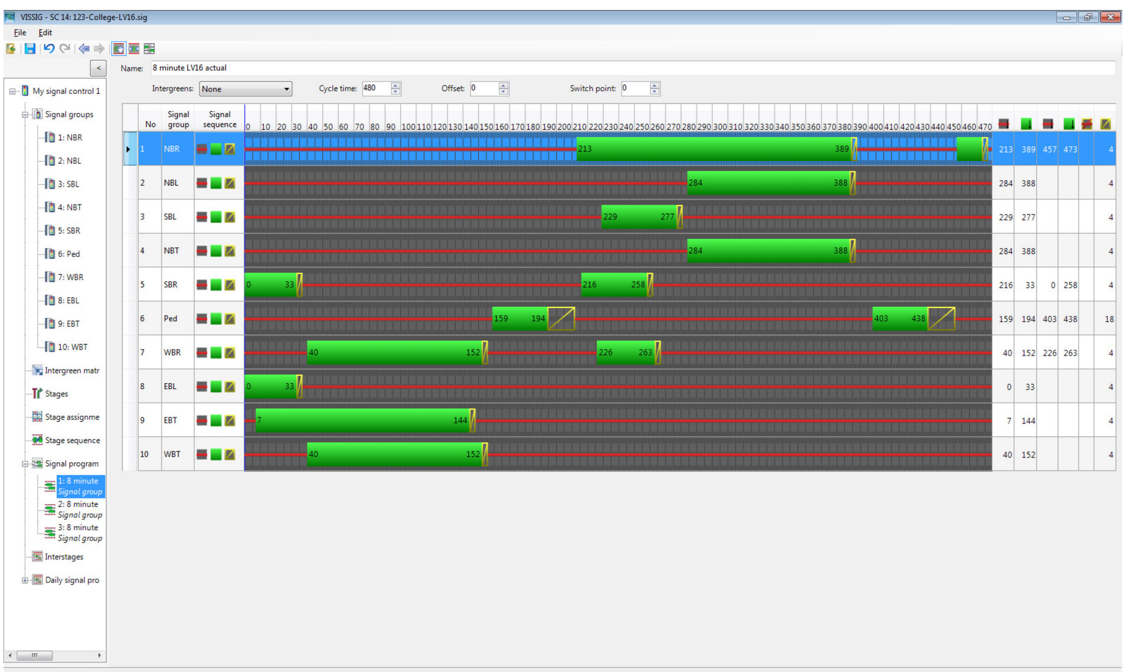


Figure 26: US 76/123 – College Ave Timing Plan (2015)

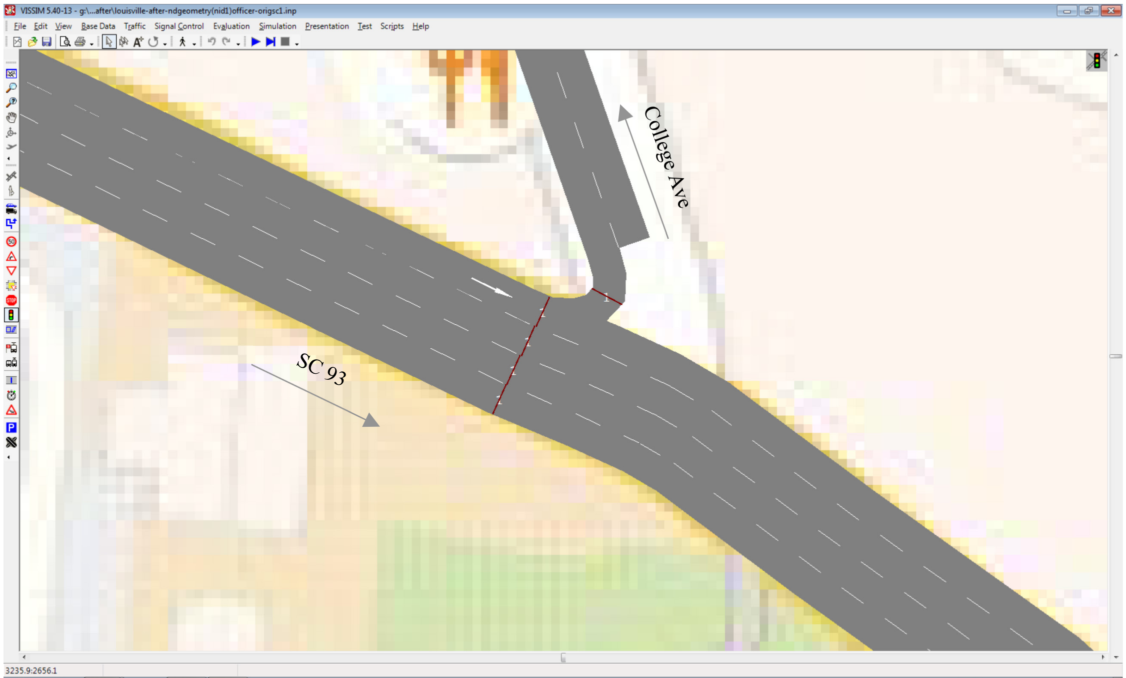


Figure 27: SC 93 – College Ave Layout (2015)

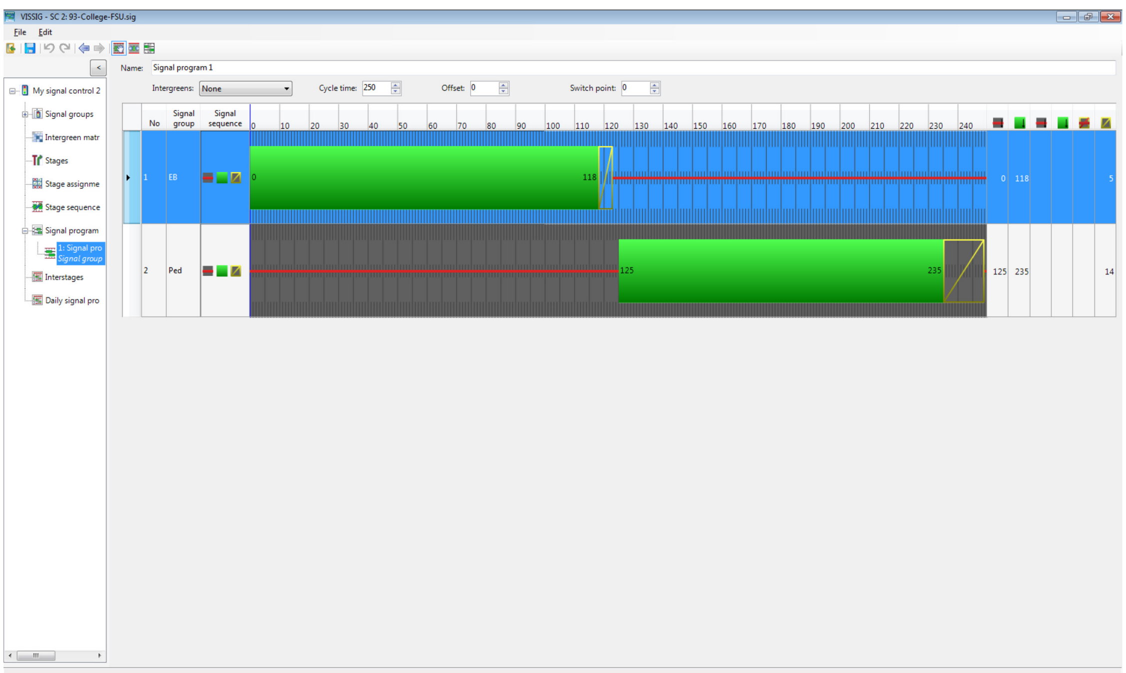


Figure 28: SC 93 – College Ave Timing Plan (2015)

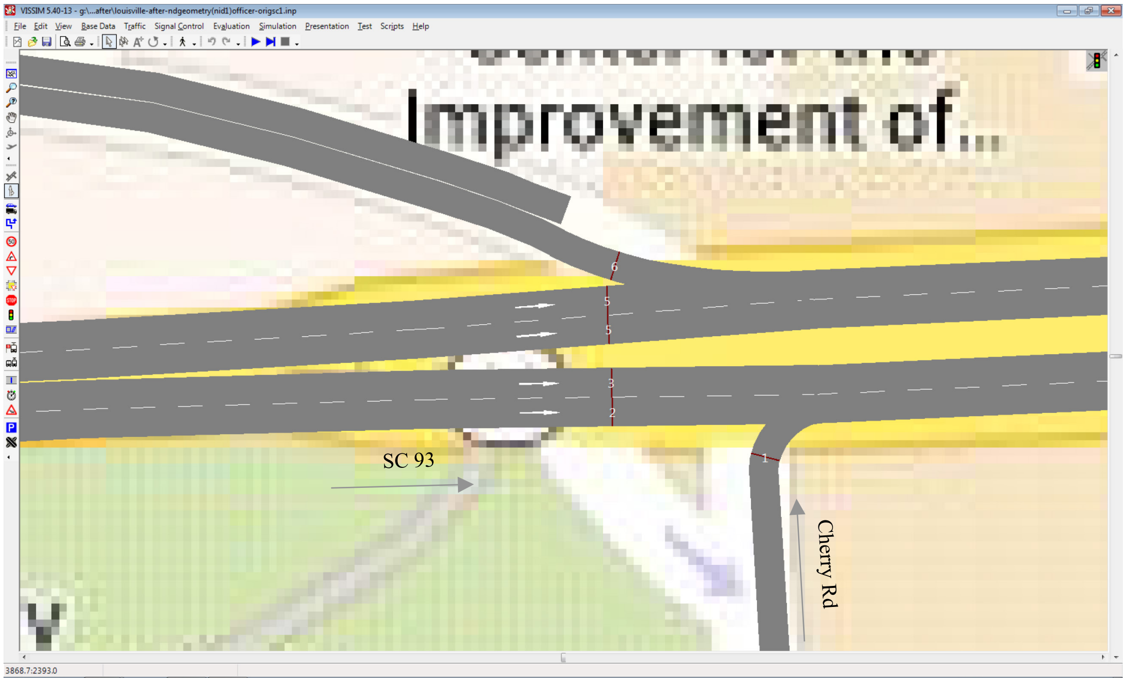


Figure 29: SC 93 – Cherry Rd Layout (2015)

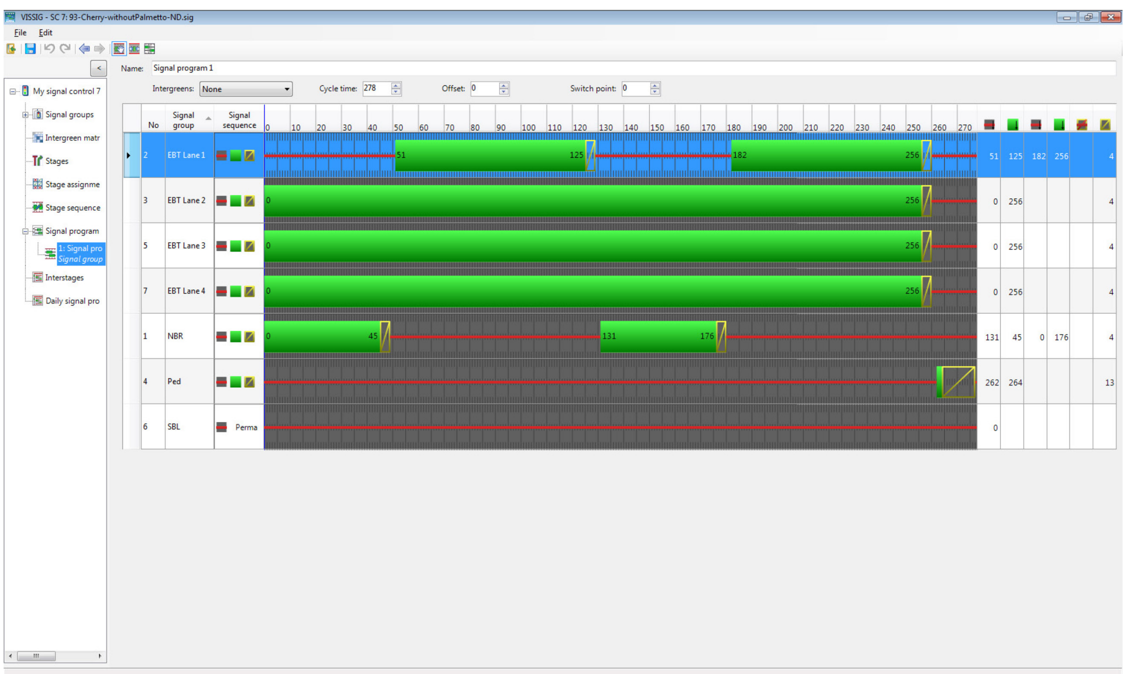


Figure 30: SC 93 – Cherry Rd Timing Plan (2015)

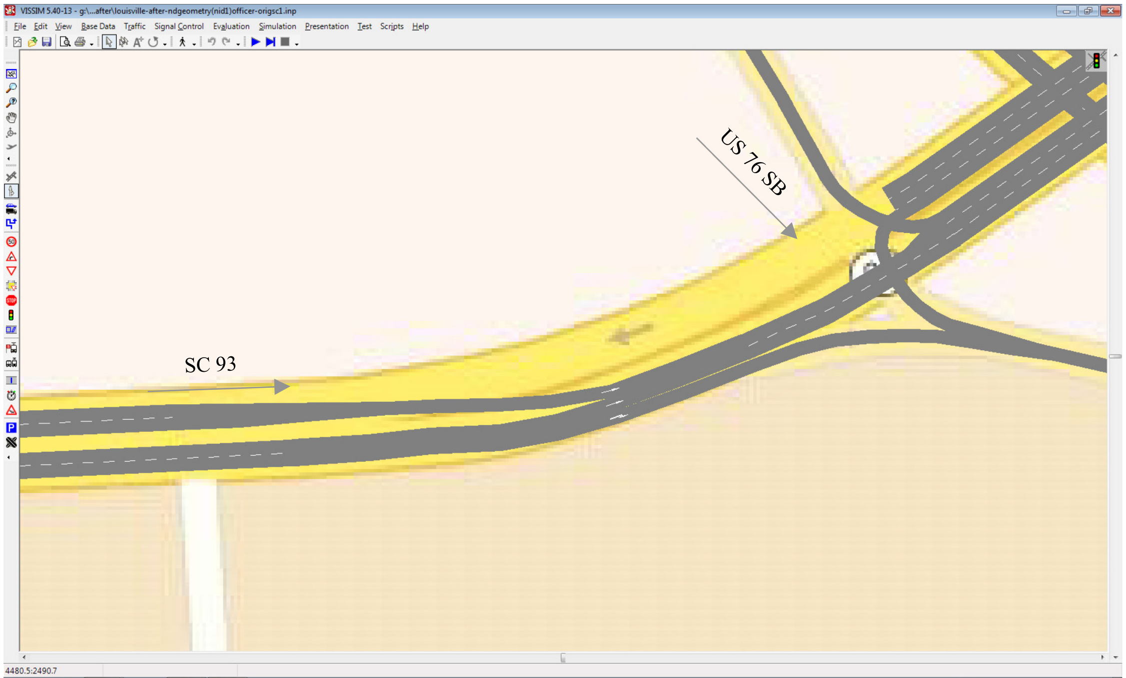


Figure 31: SC 93 – US 76 SB Ramp Region (2015)

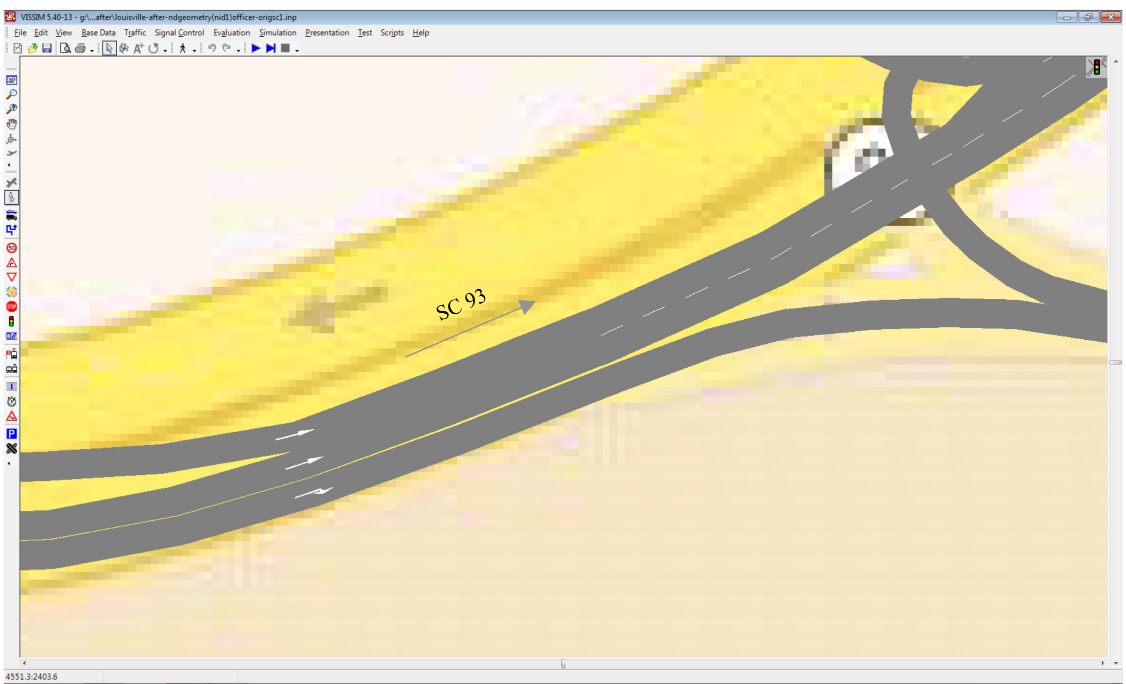


Figure 32: SC 93 – US 76 SB Ramp Layout (2015)

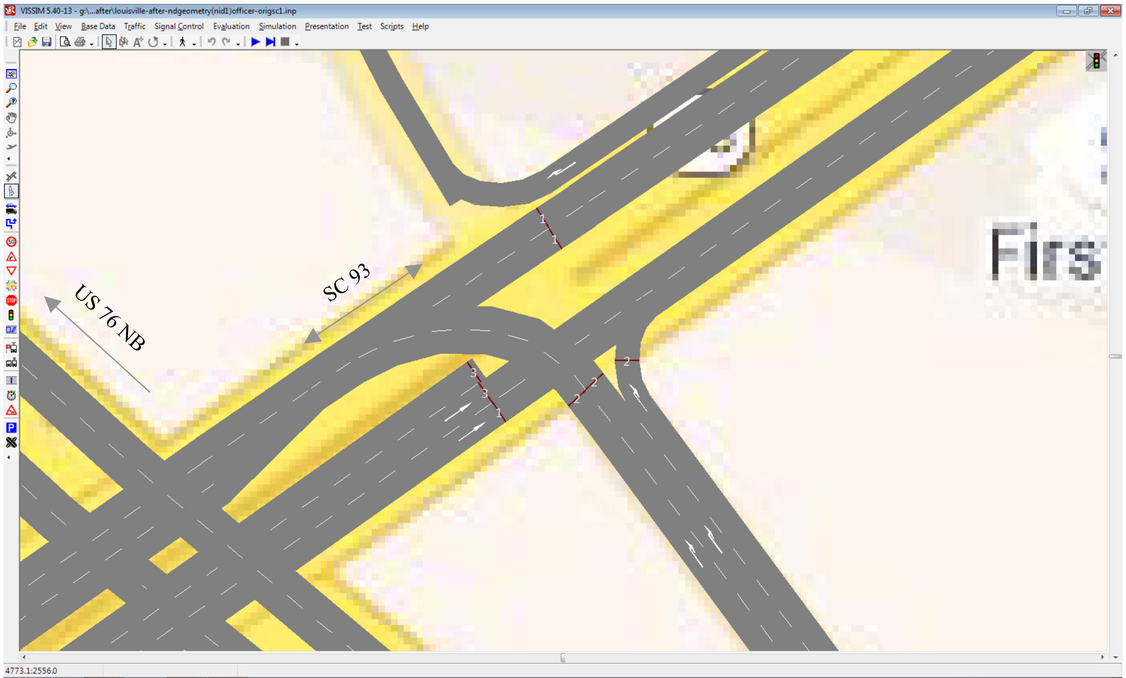


Figure 33: SC 93 – US 76 NB Ramp Layout (2015)

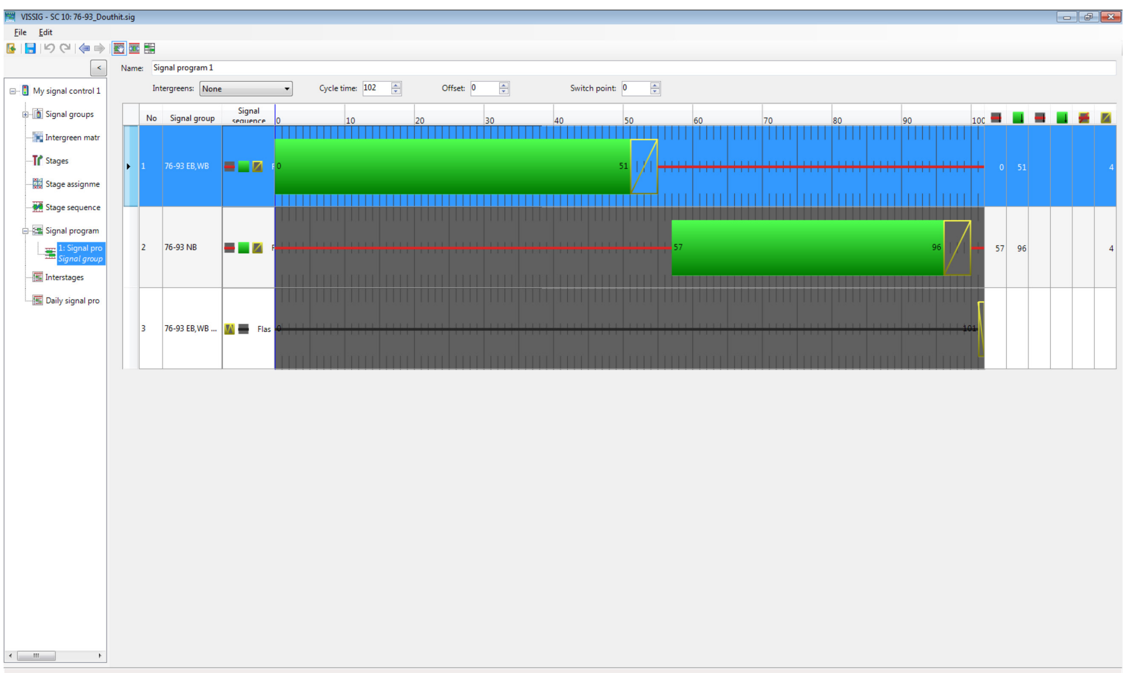


Figure 34: SC 93 – US 76 NB Ramp Timing Plan (2015)

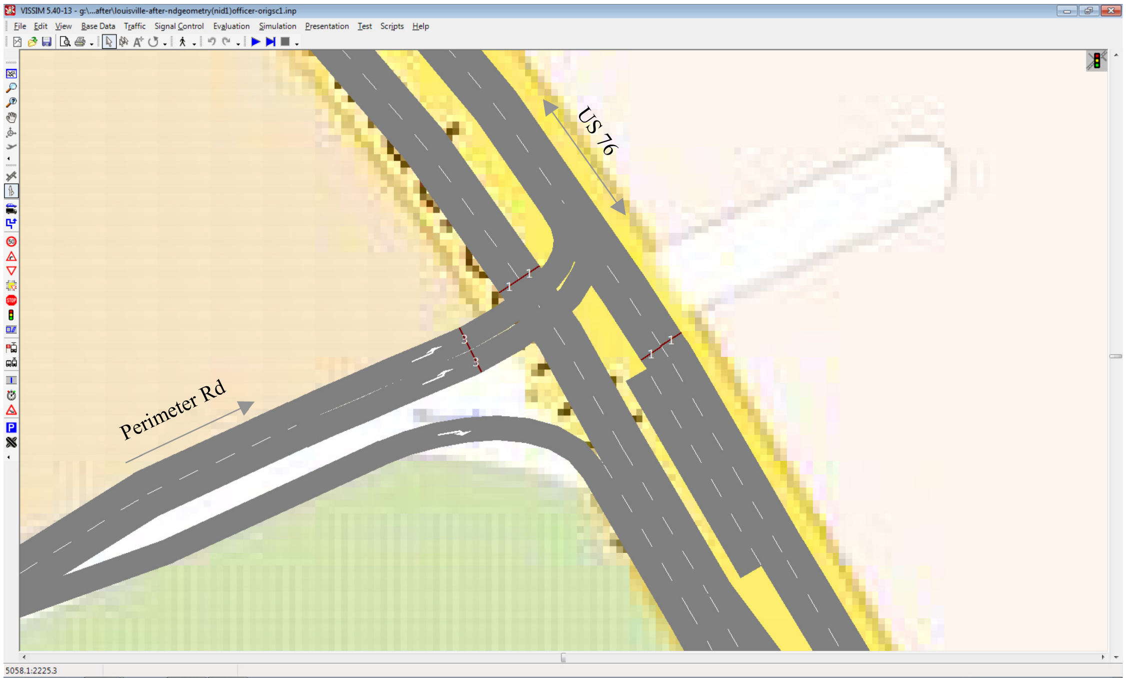


Figure 35: US 76 – Perimeter Rd Layout (2015)

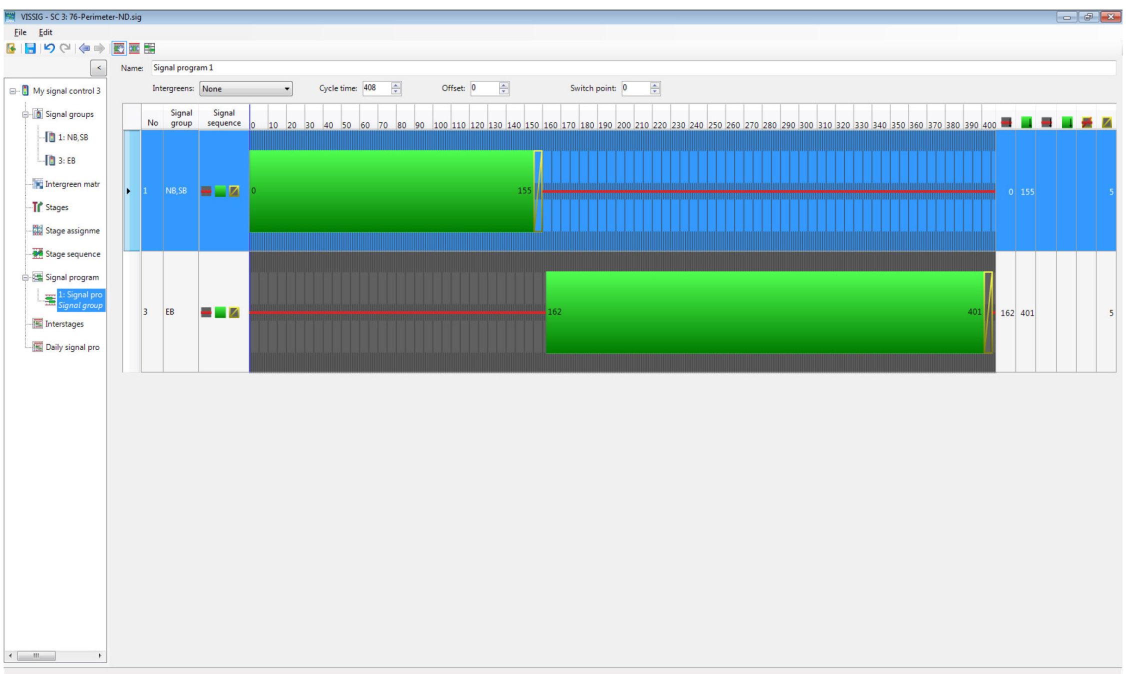


Figure 36: US 76 – Perimeter Rd Timing Plan (2015)

Model #3: Recommended w/ Reservice

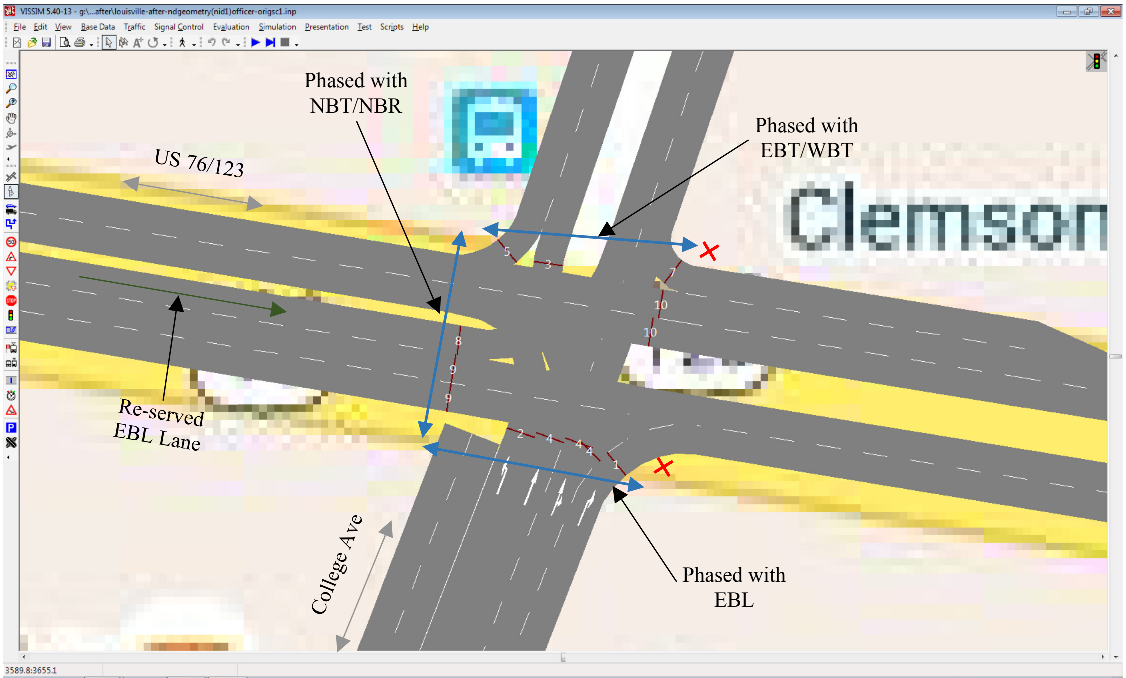


Figure 37: US 76/123 – College Ave Layout (2015, Reservice)

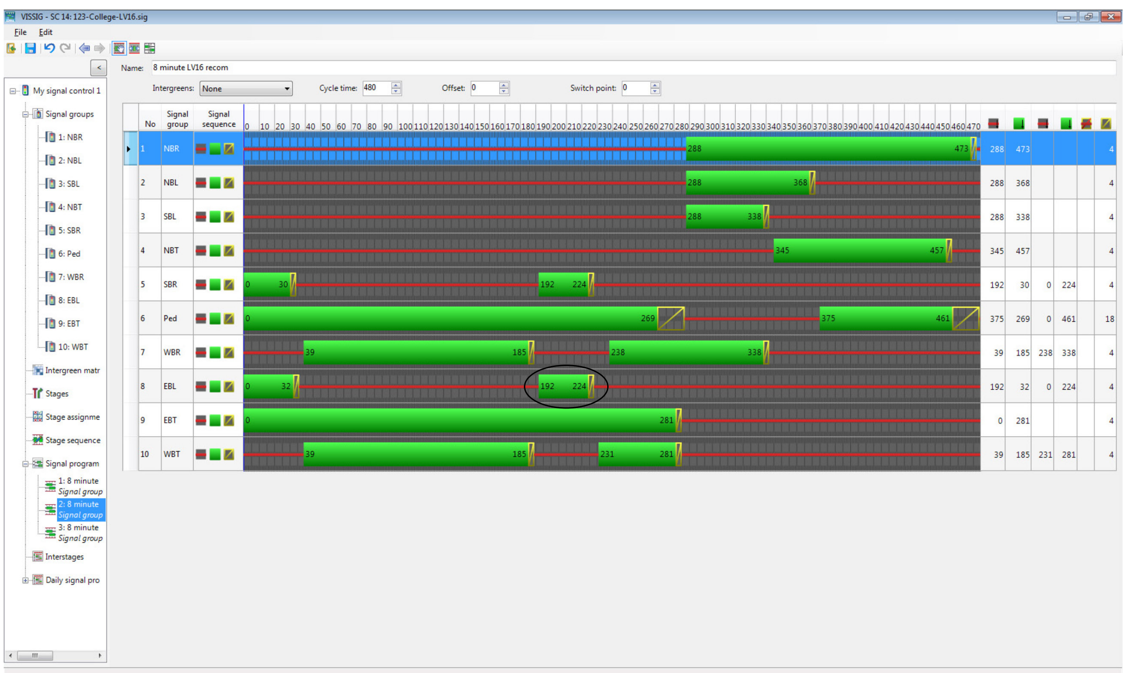


Figure 38: US 76/123 – College Ave (Reservice Circled)

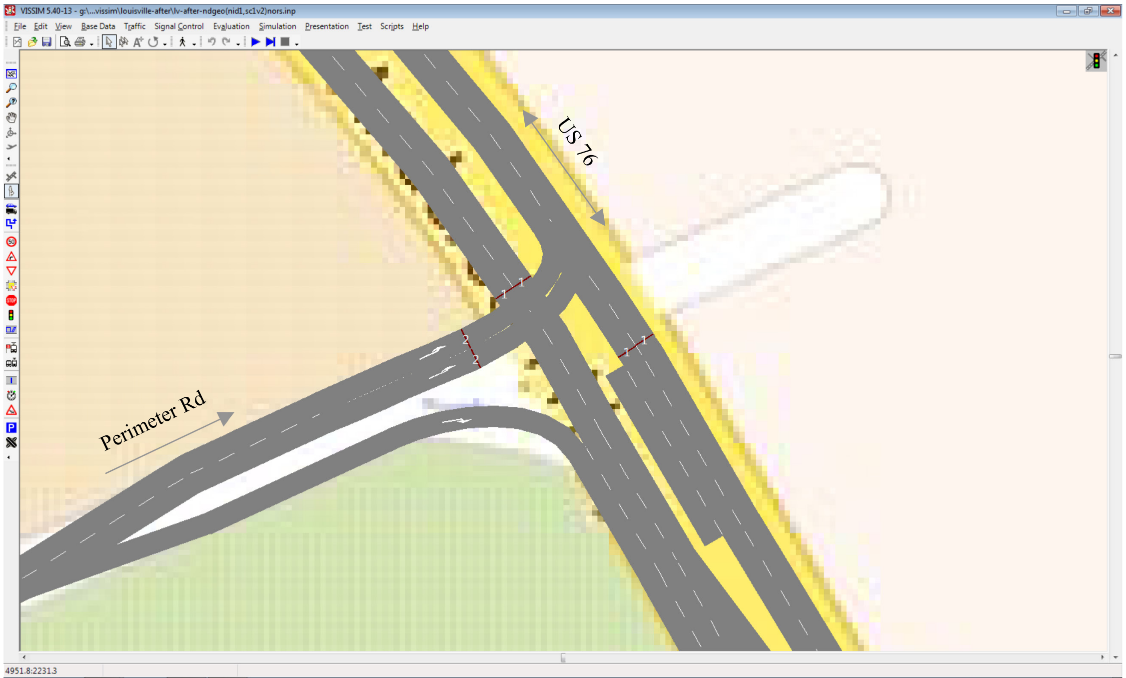


Figure 39: US 76 – Perimeter Rd Layout (2015, Recommended)

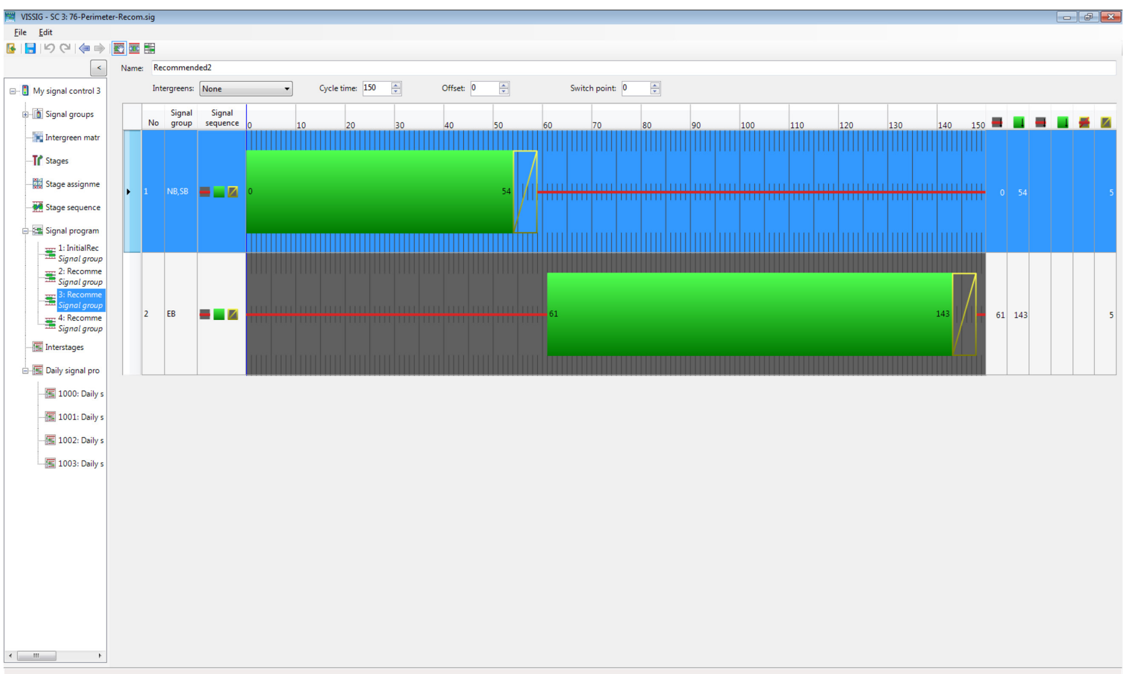


Figure 40: US 76 – Perimeter Rd Timing Plan (60-40 Split)

Model #4: Recommended w/o Reservice

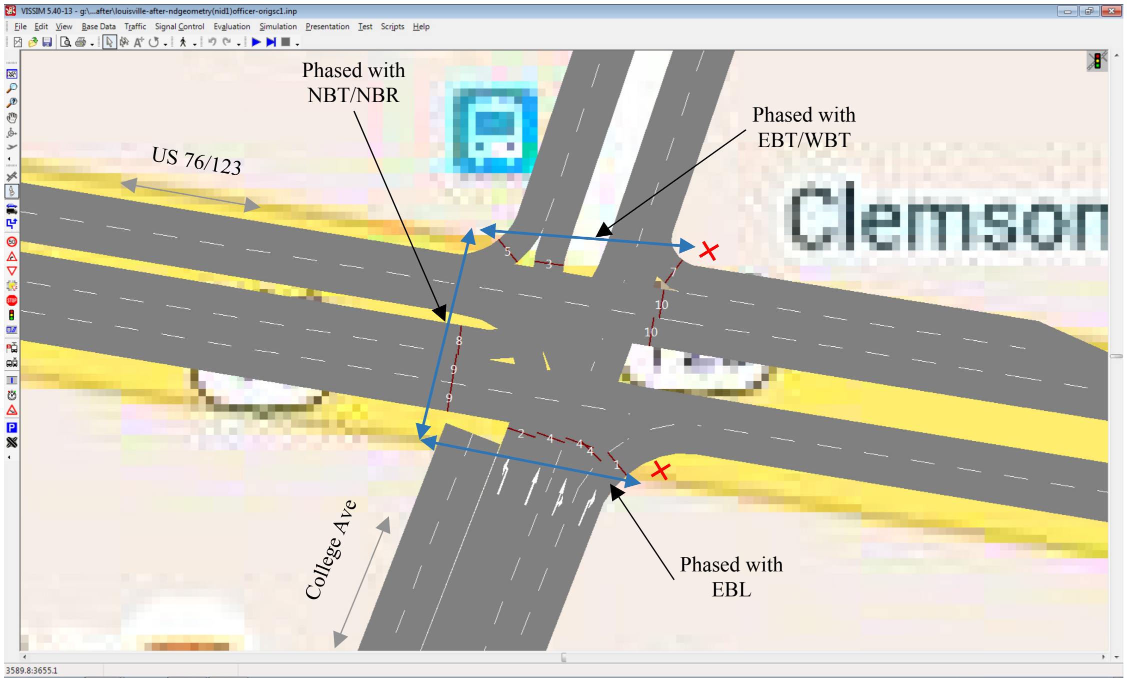


Figure 41: US 76/123 – College Ave Layout (2015, No Reservice)

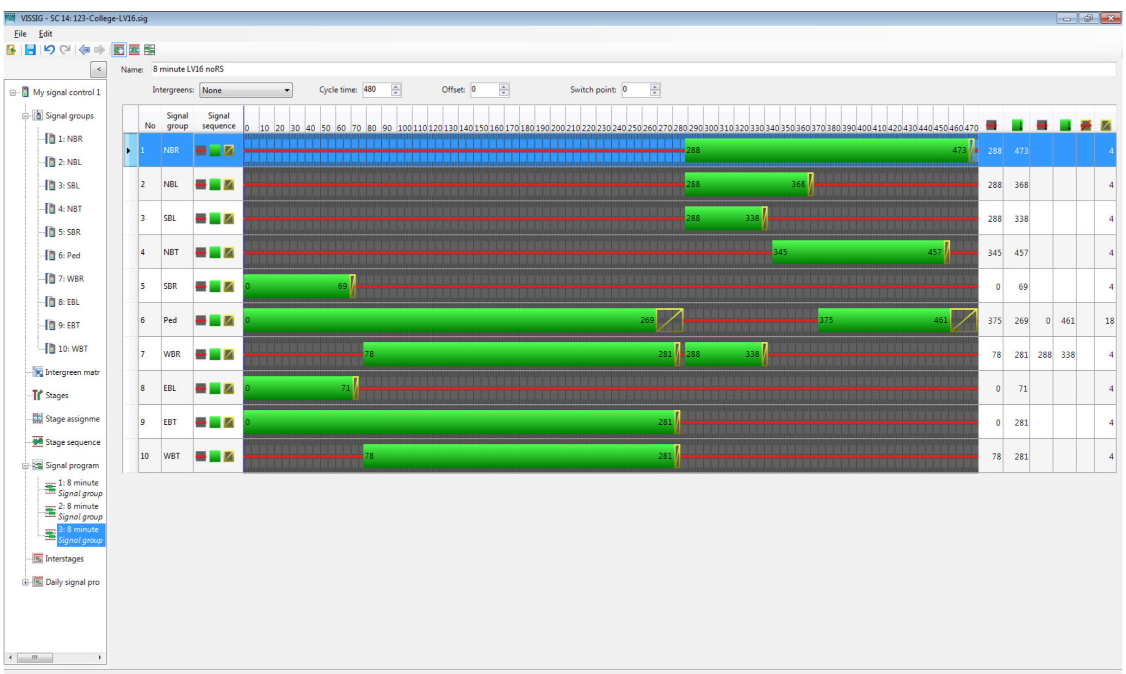


Figure 42: US 76/123 – College Ave Timing Plan (No Reservice)

Appendix B: Travel-Time Hypothesis t-Tests

First, the appendix gives the average travel time data for each model with their sample means and standard deviations (**Tables 4-7**). The "No.:" labels represent the Route Numbers in **Figure 10** (Section 6.2). Following this, the appendix presents the hypotheses and the t-test results (**Tables 8-13**). The author refers readers to a statistics textbook for the procedures on F-testing and t-testing.

VISSIM Travel Time Output

Table 4: Average Travel Times: Model #1

No.: Seed	1 TT [sec]	2 TT [sec]	3 TT [sec]	4 TT [sec]	5 TT [sec]	6 TT [sec]
11	1049.8	1311.4	646.6	631.1	895.4	794.1
29	1250.9	1461.8	605.4	622.1	802.3	706.4
47	1174.4	1444.7	650.6	662.2	858.9	716.2
65	1131.2	1386.2	651.1	653.6	884.5	727.1
83	1092.8	1328.5	625.4	639.7	864.3	717.0
101	1180.1	1421.4	664.6	667.8	874.4	746.1
119	1182.5	1427.4	622.8	593.6	900.6	735.2
137	1216.9	1460.2	630.2	639.3	772.5	686.3
155	1206.4	1477.4	624.8	628.5	867.0	762.9
173	1131.2	1370.9	611.2	622.4	830.6	712.5
191	1178.5	1430.8	611.9	605.1	835.3	703.1
209	1207.3	1477.7	648.7	662.0	820.6	712.9
227	1370.2	1618.8	617.1	616.7	872.3	787.7
245	1173.0	1445.9	624.7	613.6	918.1	769.0
263	1115.0	1368.6	644.7	646.7	780.0	681.9
281	1195.8	1465.5	610.1	581.9	908.9	778.1
299	1235.0	1477.1	648.8	670.0	811.5	715.9
317	1342.9	1581.2	630.5	628.7	858.4	727.0
335	1284.6	1585.7	648.7	672.8	844.7	753.6
353	1160.5	1412.5	642.6	650.3	885.4	768.2
Mean	1194.0	1447.7	633.0	635.4	854.3	735.1
St. Dv.	77.8	79.7	17.1	25.7	41.5	33.1

Table 5: Average Travel Times: Model #2

No.: Seed	1 TT [sec]	2 TT [sec]	3 TT [sec]	4 TT [sec]	5 TT [sec]	6 TT [sec]
11	1121.2	1210.0	572.6	860.5	833.0	751.8
29	1137.6	1206.0	557.4	887.7	801.1	703.0
47	1152.1	1232.9	543.7	865.8	843.1	737.3
65	1101.8	1191.9	529.0	854.1	884.2	744.1
83	1279.8	1372.0	539.3	887.0	833.7	689.5
101	1112.7	1203.7	587.0	904.1	903.4	765.8
119	1078.8	1180.7	558.0	880.8	864.7	722.8
137	1108.4	1202.4	516.8	830.8	776.9	669.4
155	1100.5	1184.6	591.4	882.4	853.1	730.7
173	1232.2	1307.4	535.6	839.7	800.9	678.2
191	1132.4	1182.0	581.4	874.2	776.7	676.8
209	1118.6	1185.7	573.4	944.4	857.0	744.0
227	1081.0	1166.4	591.8	878.3	889.3	750.5
245	1101.9	1195.1	544.8	861.1	803.3	678.2
263	1111.2	1189.8	586.5	869.1	836.7	730.6
281	1138.1	1209.2	516.9	867.0	830.5	705.8
299	1102.7	1186.7	586.6	903.6	829.8	730.0
317	1110.4	1202.1	544.8	878.2	887.5	745.1
335	1106.9	1208.5	564.7	853.9	904.9	816.3
353	1097.7	1191.2	557.8	898.1	852.4	719.0
Mean	1126.3	1210.4	559.0	876.0	843.1	724.4
St. Dv.	48.5	47.6	24.5	25.2	38.8	36.0

Table 6: Average Travel Times: Model #3

No.: Seed	1 TT [sec]	2 TT [sec]	3 TT [sec]	4 TT [sec]	5 TT [sec]	6 TT [sec]
11	658.5	715.1	468.8	673.0	714.3	593.8
29	690.4	737.6	444.7	645.9	663.7	605.2
47	619.3	667.2	469.9	675.2	687.7	602.2
65	639.1	695.5	475.9	669.7	703.0	603.8
83	594.8	639.5	437.4	635.8	684.3	573.5
101	672.8	721.8	458.0	616.6	672.3	578.9
119	642.5	691.9	429.4	624.7	674.0	600.7
137	648.5	705.7	440.3	615.8	676.5	588.0

155	647.4	702.0	459.0	661.8	647.1	568.6
173	674.7	721.4	447.8	634.3	652.1	566.0
191	609.9	656.7	438.3	611.9	677.2	604.3
209	611.9	657.9	495.5	719.7	676.2	592.6
227	622.7	670.9	457.6	648.1	659.4	584.9
245	658.1	722.7	469.0	625.6	657.6	572.9
263	675.7	717.2	474.3	579.9	664.4	596.1
281	662.3	720.6	429.8	638.1	649.7	582.3
299	672.6	719.6	442.6	623.6	674.9	588.6
317	648.7	695.8	448.5	667.1	729.0	621.3
335	621.8	678.9	444.4	592.2	674.5	632.8
353	661.3	706.4	447.7	671.5	661.6	558.5
Mean	646.7	697.2	453.9	641.5	675.0	590.8
St. Dv.	26.1	27.0	17.3	32.8	21.0	18.6

Table 7: Average Travel Times: Model #4

No.: Seed	**1 TT [sec]**	**2 TT [sec]**	**3 TT [sec]**	**4 TT [sec]**	**5 TT [sec]**	**6 TT [sec]**
11	694.6	716.2	442.4	635.7	675.1	595.7
29	689.5	716.4	462.1	661.7	661.6	608.7
47	773.7	799.3	431.4	591.1	679.4	578.6
65	663.8	707.7	452.0	646.4	668.4	592.3
83	669.4	687.1	454.0	636.6	676.4	575.0
101	738.7	767.8	480.9	639.6	652.2	576.8
119	696.0	711.8	443.0	624.3	700.7	605.7
137	691.4	736.9	439.7	621.5	684.3	580.2
155	677.3	713.9	447.3	611.1	681.7	572.2
173	685.9	722.7	452.9	647.0	670.4	589.4
191	714.7	737.2	443.9	620.5	673.3	589.4
209	729.9	743.1	477.7	654.8	684.5	609.7
227	673.9	707.1	450.0	626.9	659.5	585.6
245	688.2	745.8	460.0	594.0	650.4	582.6
263	822.5	827.9	478.9	590.4	662.1	604.4
281	740.3	759.6	416.5	608.1	634.7	582.3
299	676.2	692.1	445.8	630.0	662.0	583.0
317	682.8	726.6	475.3	685.2	738.8	635.2
335	695.1	730.5	466.8	600.6	649.3	622.4
353	675.7	712.2	445.4	630.5	635.7	551.6

Mean	704.0	733.1	453.3	627.8	670.0	591.0
St. Dv.	39.6	34.5	16.7	24.7	23.2	19.1

Hypotheses and Outcomes

Before t-testing each comparison, the author F-tested for differences between model population variances of the route average travel times (TT) across models. These results are not important, as their impact on whether to pool variances for the t-tests did not produce dissimilar outcomes in the t-tested hypothesis tests.

In all comparison cases, the null hypothesis was that there was no difference between the population means μ of the route average travel times (TT) across models (H_0: $\mu_x = \mu_y$). The alternative hypothesis is that there is a difference (H_a: $\mu_x \neq \mu_y$), requiring a 2-tailed test. All models were sampled 20 times, so the rejection region at 95% significance and 38 degrees of freedom is outside of (-2.024, 2.024). Comparisons for which H_0 is rejected (i.e. it is shown that mean travel times are different) are shaded.

Table 8: t-Statistics: Route 1 Comparisons

Model	1	2	3	4
1	--	3.30	29.85	25.11
2	-3.30	--	38.95	30.15
3	-29.85	-38.95	--	-5.41
4	-25.11	-30.15	5.41	--

Table 9: t-Statistics: Route 2 Comparisons

Model	1	2	3	4
1	--	11.43	39.86	36.77
2	-11.43	--	41.92	36.29
3	-39.86	-41.92	--	-3.66
4	-36.77	-36.29	3.66	--

Table 10: t-Statistics: Route 3 Comparisons

Model	1	2	3	4
1	--	11.09	32.92	33.61
2	-11.09	--	15.67	15.95
3	-32.92	-15.67	--	0.12
4	-33.61	-15.95	-0.12	--

Table 11: t-Statistics: Route 4 Comparisons

Model	1	2	3	4
1	--	-29.86	-0.66	0.95
2	29.86	--	25.37	31.46
3	0.66	-25.37	--	1.50
4	-0.95	-31.46	-1.50	--

Table 12: t-Statistics: Route 5 Comparisons

Model	1	2	3	4
1	--	0.88	17.24	17.33
2	-0.88	--	17.04	17.12
3	-17.24	-17.04	--	0.71
4	-17.33	-17.12	-0.71	--

Table 13: t-Statistics: Route 6 Comparisons

Model	1	2	3	4
1	--	0.97	17.00	16.86
2	-0.97	--	14.75	14.63
3	-17.00	-14.75	--	-0.05
4	-16.86	-14.63	0.05	--

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