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Handling Traffic for Major Events: Evaluating Traffic Officer Operations

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HANDLING TRAFFIC FOR MAJOR EVENTS: EVALUATING TRAFFIC OFFICER OPERATIONS

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by
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ABSTRACT

The campus of Clemson University hosts numerous planned special events every year. The largest seasonal events are the home football games played at Clemson Memorial Stadium. These football games attract crowds in excess of 80,000 fans, most of whom arrive by private vehicle. Trying to maneuver traffic for 80,000 people into one venue is a daunting task in itself. However, trying to maneuver it through a local transportation system designed for a campus with approximately 20,000 students and a city that has approximately 12,000 permanent residents can be a nightmare for state and local traffic enforcement officials.

One of the major traffic issues that needs to be addressed during home games is oversaturated intersections. Traffic officers typically manage right-of-way at major intersections either entirely or through push button override of traffic signals. The primary goal of the traffic officer is to try move traffic as efficiently as possible so that queues do not back up excessively causing added congestion at upstream intersections. The change of right-of-way is based entirely on the judgment of the officer. Because the queues at some intersections can back up as much as a mile, providing necessary right-of-way to alleviate the queues can cause cycle lengths to be extremely long. Studies have shown that there are diminishing returns on capacity in intersection operations as cycle lengths grow.

This research focuses on evaluating how well traffic officers optimize intersection operations in heavily oversaturated conditions. Traffic data, including volumes, queues,

and right-of-way times, was collected before and after four football games during the 2014 and 2015 season. The actual count volumes were adjusted to account for queues and input into SYNCHRO along with actual right-of-way timings provided by the traffic officers. The analysis compares the field observed splits and cycle lengths with optimized splits and cycle lengths attained from SYNCHRO which tries to minimize overall delay. Push button-operated signals are also evaluated. A VISSIM model was created for both manual control and optimized control scenarios to find average delays for each approach. Both SYNCHRO and VISSIM were used for the analysis part of this research. The findings of this research are, Officers are using extremely long cycle lengths in severely oversaturated conditions, and this is resulting in increased delays. When intersections are significantly oversaturated, officers tend to misjudge how long vehicles are in a queue, which leads to some approaches receiving significantly more delay than others

DEDICATION

I would like to dedicate this thesis to my parents. Your support and love made me the person I am today. Thank you for everything you have done for me.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to my committee chair Dr.Wayne A.Sarasua for providing me an opportunity to work with him. His continuous motivation and guidance helped me so much with completion of this project. I would like to thank Dr.Mashrur Chowdhury and Dr.Jennifer Ogle for the approval of my work and exemplary recognition.

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CHAPTER 1: INTRODUCTION

Extreme traffic congestion may occur during planned special events such as concerts, conventions, fairs, and sporting events. Public and private agencies are constantly being put to the test trying to control the flow of traffic for these events, both safely and efficiently. According to the FHWA report entitled *Managing Travel for Planned Special Events* (Dunn W, 2007) the term *planned* special event is used to describe these activities because of their known locations, scheduled times of occurrence, and associated operating characteristics. A planned special event creates an increase in travel demand and may require road closures to stage the event. Planned special events generate trips, thus impacting the overall transportation system operations. These impacts may include freeway operations, arterial and other street operations, transit operations, and pedestrian flow. Unlike roadway construction activities or traffic incidents that usually only constrain travel within a single corridor, planned special events affect travel in all corridors serving the event venue.

The campus of Clemson University hosts numerous planned special events every year. The largest seasonal events are the home football games played at Clemson Memorial Stadium. Some of these football games attract crowds in excess of 80,000 fans, most of who arrive by private vehicle. Trying to maneuver traffic for 80,000 people into one venue is a daunting task in itself. However, trying to maneuver it through a local transportation system designed for a campus with approximately 20,000 students and a city that has approximately 12,000 permanent residents can be a nightmare for state and local traffic enforcement officials.

Planning for special events poses a unique and diverse set of challenges to stakeholders charged with maintaining transportation system safety, mobility, and reliability. These challenges include:

- Managing intense travel demand;
- Mitigating potential capacity constraints;
- Influencing the utility associated with various travel choices; and
- Accommodating heavy pedestrian flow.

The existing traffic plan for Clemson football games attempts to address these challenges through coordination from multiple agencies. A number of techniques are used, including contraflowing selected roads, use of satellite parking lots combined with shuttle busses, and the extensive use of traffic officers at selected locations. These traffic officers typically manage right-of-ways at major intersections either entirely or through push button override of traffic signals. The primary goal of the traffic officer is to try to manage the extensive traffic queues as efficiently and safely as possible. The change of right-of-way is based entirely on the judgement of the officer. Because queues can back up as much as a mile or more at the greatest bottleneck locations, cycle lengths can be extremely long. Using Webster's equation and plotting cycle length versus capacity for a simple two phased signal it can be observed that the relative increase in capacity for cycle lengths greater than 100 seconds is very small. Routine observation of Clemson game day traffic at intersections controlled by traffic officers indicates that cycle lengths greater than 100 seconds is the norm rather than the exception. An obvious question to ask is “Are these cycle lengths necessary (or even beneficial)?

1.1: Thesis Goal, Objectives, and Tasks

For this thesis, I attempt to answer the question stated in the last section. Specifically, the overall goal of this thesis is to evaluate how traffic officers control traffic at Clemson football games. The objectives of this thesis are to:

- Evaluate how traffic officers control intersections in varying levels of oversaturated conditions;
- Evaluate how officers balance delay among different approaches;
- Evaluate how officers manage queues and promote quicker queue dissipation; and
- Develop recommendations on how officers can potentially improve traffic operation and comment on the transferability of these recommendations to other planned events besides Clemson football.

The general tasks and methodology involved with conducting this evaluation are: 1) conduct an extensive literature review to identify previous attempts on evaluating officer control at intersections; 2) collect data; 3) create a calibrated traffic simulation model; 4) use the simulation model to analyze and evaluate officer traffic control; and 5) develop recommendations and conclusions. A more detailed thesis methodology is discussed in section 1.3.

1.2: Thesis Outline

This thesis is organized into six parts. The first chapter introduces the thesis problem, thesis objective, thesis outline, and an overview of the methodology used on this research. The second chapter reviews existing literature on major event planning, traffic officer control of intersections, dealing with traffic in oversaturated conditions, and traffic simulation. The third chapter explains the data collection process. The fourth chapter explains in detail the simulation model development. The fifth chapter describes research findings and simulation analysis results. Finally, the sixth chapter provides thesis conclusions and recommendations for further research.

1.3: Overview of Thesis Methodology

The methodology includes data collection, data processing, model development, analysis, and interpretation of the findings. Game day traffic data was collected for Louisville and South Carolina games during the 2014 football season and for Notre Dame and Florida State games during 2015 football season. Data was collected at seventeen critical intersections on and around the Clemson University campus. This research was a part of football traffic study that was conducted for the Clemson Athletic Department. Three intersections selected for analysis as part of this research: 1) College Avenue-US 123 2) US 123-US 76; and 3) US 76-Perimeter Road. They were chosen because of their level of congestion, geometry, and control type. Two of these three intersections use the two most common types of manual intersection control. College Avenue-US 123 intersection was controlled by police officers standing in the middle of the intersection and providing ROW using hand gestures. US 123-US 76 intersection uses push button control. Push button techniques usually allow the officers to control the signal heads. Officers can continue or change a phase when needed just by clicking a button. A third intersection—US 76-Perimeter Road was added to the analysis because of its unique geometry and its level of congestion.

The data for the selected intersections was processed with help from the Clemson ITE student chapter. Count volumes were obtained from the video feeds and were adjusted based on queue data to estimate the approach demand volumes. A calibrated SYNCHRO model of the intersections that were operated by police officers manually and by push buttons was developed. The approach demand volumes were inputted into this SYNCHRO model. The performance measures for right-of-way timings given by police officers were compared with the performance measures for optimal signal timings obtained from SYNCHRO. Total delay at each approach is considered as the measure of the effectiveness in each condition. Since SYNCHRO is not a microscopic simulation model and because its delay model may not accurately reflect delay in oversaturated conditions, a calibrated VISSIM model of these three intersections was created to obtain delays at approaches and to observe the queue trend for manual control and optimized conditions. Using the results from the SYNCHRO and VISSIM models, the evaluation was done.

CHAPTER 2: LITERATURE REVIEW

2.1: Introduction

Special events such as football games produce nonrecurring congestion when attendees try to enter or exit the venue simultaneously. Special events cause overcrowding on primary routes, as people consider those to be the fastest and easiest way to reach their destination. Spreading the traffic over the entire network, however, is the best way to reduce congestion on all roads. Planners often distribute traffic onto alternate routes with the use of pre-event publicity, dynamic message boards, or road closures(Crawford J, 2011) .The Clemson University athletic department has been doing its best to address home football game traffic congestion. Efforts are made to distribute the traffic over all possible routes. Contraflowing is done, both before and after games to ensure that the attendees could reach and leave the venue as conveniently and quickly as possible. Despite all of these efforts, it is not easy to maneuver the humongous game traffic through a local transportation network that is designed for a lot less traffic. This results in oversaturated conditions at major intersections. In many cases, normal operation of traffic signals cannot serve the special event traffic effectively. Hence, police officers manually control the right-of-way at most major intersections. Manual control of traffic signals is believed to be extremely effective to handle nonrecurring event traffic. Police officers use their judgment to provide right-of-ways and clear queues. The effectiveness of an officer at directing traffic is a function of training and experience (Parr S, 2014).

2.2: Background

Several research efforts have focused on comparing manual signal control to that of the state-of-the practice traditional automatic signal control methods. Prior to the invention of automated traffic signals, police were the only source of intersection traffic control. Burton Marsh compared the advantages and disadvantages of manual control with automated signal control many decades ago. He summarized the advantages of manual control as: 1) an officer is best at allocating time appropriately at any given instance; and 2) an officer can give priority to emergency and public transit vehicles. Furthermore, he indicated that an officer can handle varying left turn volumes better than any other signal control system and can use common sense judgement on a moment's notice (Marsh B, 1930). Marsh identified the primary disadvantages of manual control as: 1) an officer cannot coordinate his actions with officers at neighboring intersections very effectively; and 2) officers are subject to being asked directions by the public which can distract him from traffic control and also add delays to waiting vehicles when he is providing directions. Marsh also indicated that officers can become complacent over time, which can compromise efficiency (Marsh B, 1930).

Marsh also summarized the advantages and disadvantages of automated signal control. He found that the advantages of automated signal control are that signals are easier to locate and understand; they give pedestrians a clear and defined time to cross; and they are more efficient at allocating right-of-ways for complicated intersections (Marsh B, 1930). The disadvantages of automated signal control are that, the time allotted for each movement remains constant; signals have a hard time dealing with heavy traffic volumes; and signals cannot act spontaneously like police officers (Marsh B, 1930).

While some of Marsh's finding are now outdated, some still apply. Signals rarely operate effectively in oversaturated conditions, and while sensing systems can vary green time allotment, cycle lengths usually remain constant. Further, while there have been many advances in traffic signal systems over the years, the characteristics of police officers manually operating traffic signals has changed little, if at all.

In 1961, the Northwestern University Traffic Institute issued their second edition of "Signals and Gestures for Directing Traffic," which employs traffic engineering concepts to assist in the effectiveness of manual traffic control. This publication states that manual control should be employed only when an intersection is oversaturated for its current control technique (e.g. signal control and stop control). It suggests that officers should try to maximize saturation flow rate by holding a movement's initial arrival until a group of vehicles are formed. Right-of-way should be provided to a movement with a group of vehicles, and it should keep those moving until vehicles depart one right after another. This article instructs officers to balance delays between movements based on volume. Important consideration should be given to spillovers. It suggests to clear queues such that they do not propagate into neighboring intersections. Also, it states that officers should never waste green time. If traffic is not moving at the saturation flow rate, officers are instructed to switch immediately to a different movement or approach (NUTI, 1961).

Nan Ding evaluated the manual multi-modal signal control performance of traffic control agencies. They compared the performance of experienced traffic control agents (TCAs) with optimal traffic signal control. An experiment using the manual intersection control simulator (MIC-Sim) was conducted. MIC-Sim has three components in the setup: 1) a human; 2) a human-traffic control interface; and 3) a commercial traffic simulator. During the experiment, TCAs observed traffic conditions, such as number of vehicles in queue, and manually controlled the traffic by clicking the corresponding traffic movement phases in the control panel displayed on the screen. For the same traffic volume, an online optimization tool was used to control traffic. A comparison of the two scenarios in terms of delay and throughput showed that optimal control outperformed manual control with a 29.2% reduction in delay and increased throughput (Nan Ding, 2013).

Lassacher, et al. (2009) presented a variety of traffic management strategies to manage congestion resulting from football games at Montana State University. For the game day they studied, only one intersection required manual control. Police officers provided right-of-way at the intersection of 11th Avenue and College Street, which is typically an all way stop controlled intersection under normal conditions. A simulation model of this intersection was created to compare manual operation with All Way Stop Control. The findings of this research showed that game traffic had benefited greatly from manual control, but the LOS and delay at that intersection still remained poor. Southbound traffic, which is primarily game traffic, experienced reduced control delay.

All other approaches experienced increased control delay due to manual operation (Lassacher s, 2009).

(Parr S. 2014) analyzed and modelled manual traffic control for signalized intersections. Traffic data was extracted from video feeds for Louisiana State University home games in Baton Rouge, Louisiana. This research developed a field logit model programmed based on field observations to serve as the signal controller for the simulation model of study intersections. This logit model was developed based on the weights given by traffic officers controlling the traffic in the field and basically mirrored the manual operation of intersections in the simulation model. All of the intersections of this study area were operated by push-button or clicker type manual control. The researchers compared the clicker control with actuated signal control by comparing various parameters such as average delay, average number of stops, average speed, average stopped delay, total delay, and total travel time. The findings of this research indicated that actuated signal control outperformed the manual control in every single metric. Manual control experienced a substantial decrease in saturation flow as phase length progressed due to random arrivals. The inability to skip phases in clicker control was identified as another reason for the poor performance of manual control.

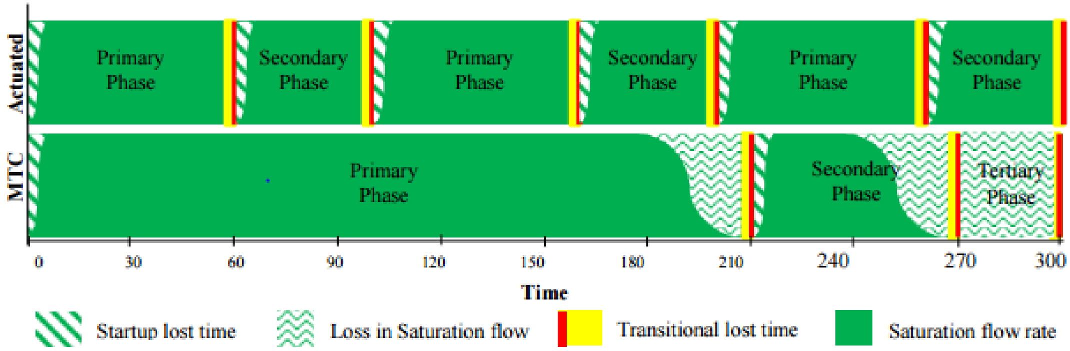

Figure 2-1: Saturation and Lost Time Diagram (Parr S. 2014)

Figure 2-1 shows how the decrease in saturation flow and inability to skip phases has a drastic impact on the vehicle throughput of the intersection when compared to actuated signal control (Parr S. 2014)

2.3: Webster's Equation

In 1958, Webster derived an equation to determine the relationship between cycle length and critical traffic volume while considering signal phasing, loss time, and minimum (saturation flow) headway (Webster, 1958). Webster's equation for the maximum sum of critical volume that can be accommodated for a cycle length is as follows

$$V_c = \frac{1}{h}\left[3600 - N \times t_L \times \left(\frac{3600}{C}\right)\right] \qquad \text{(Webster 1958)}$$

Where:

V_c is the critical volume

h is the headway

N is the total number phases in each cycle

t_L is the total loss time in each phase

C is the total cycle length

It can be observed that cycle length and critical volume are directly proportional to one another. An increase in cycle length will increase critical volume (essentially capacity), however, longer cycle lengths results in diminishing returns with regard to increased capacity.

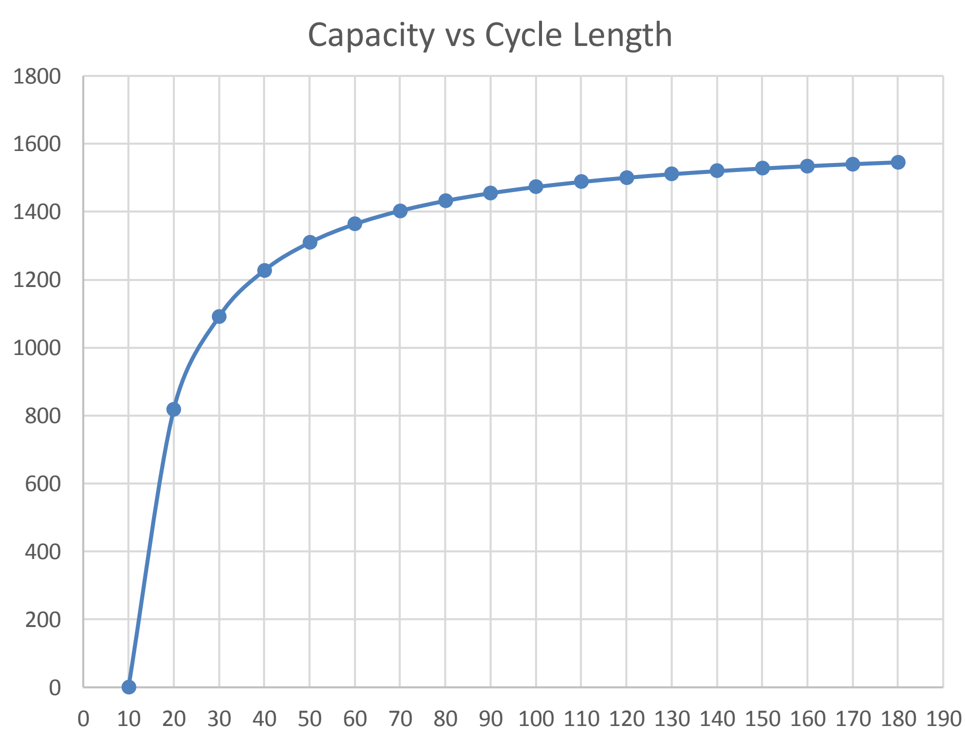

Figure 2-2: Capacity Vs Cycle Length for a Two Phase Signal

Figure 2-2 depicts the relationship between capacity and cycle length for a simple two phase signal by solving Webster's equation for various cycle lengths. In Figure 2-2, capacity is plotted on the vertical axis and cycle length on the horizontal axis. For short cycle lengths up to 30 seconds, the relationship between capacity and cycle length is nearly linear with a steep upward slope. There is a continuous and significant change is slope between 30 and 60 seconds. The slope flattens considerably for cycle lengths greater than 60 seconds. The graph shows that the incremental increase in capacity for cycle lengths greater than 100 seconds is very small. Longer vs shorter cycle lengths is a debatable choice. Longer cycle lengths result in an increased capacity but also result in higher delays for movements that are not served. Shorter cycle lengths favor reduced delay on all approaches, but result in reduced capacity due to more loss time relative to cycle length. If volumes exceed capacity, cycle slips will occur and queues will increase rapidly causing increased delays.

2.4: Chapter Summary

Manual operation is one of the oldest and widely adopted intersection control method during special events. Manual control has both advantages and disadvantages. One advantage is that Officers can adopt to the existing situations and can make spontaneous decisions regarding right-of-way. This would benefit traffic during oversaturated conditions. However if officers are not using the green time wisely this might result in poor performance of manual control. Push button-control cannot skip phases and results in poor performance due to serving all of the default phases which may or may not have demand. Optimized timings. Upon comparing manual control with optimized signal control, optimized control was proven to outperform the manual control.

CHAPTER 3: DATA COLLECTION

3.1: Conditions and Equipment

The Clemson University athletic department requested that Dr. Sarasua and his students analyze the traffic operations during home football games. Dr. Sarasua planned and supervised the data collection efforts during the 2014 and 2015 football seasons. The Clemson University campus and surrounding area is comprised of several critical intersections and required several data collection personnel to successfully capture game day traffic. The Clemson University ITE student chapter helped with the data collection and made it all possible. Sixteen critical intersections in and around the Clemson campus were identified as shown in Figure 3-1.

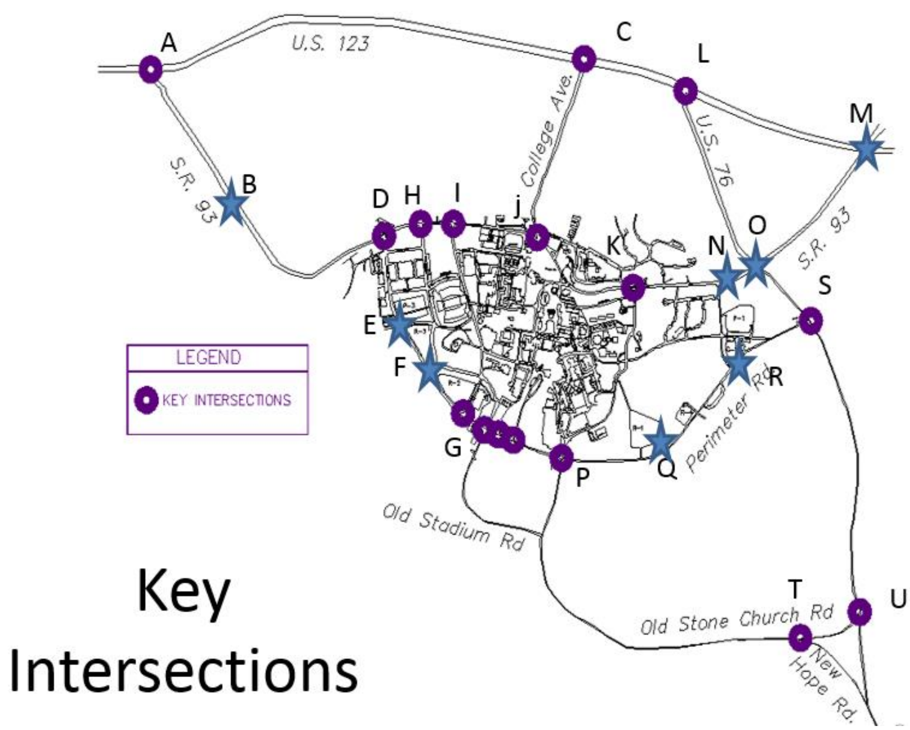

Figure 3-1: Key Intersections for Data Collection

This research is a subset of the whole project, in which the manual operation of traffic signals was compared to the optimized signal timings.

Three intersections out of the sixteen were selected for this thesis research. They were chosen because of their traffic characteristics, geometry, and types of manual control used. Typically there are two types of manual intersection controls. In the first type of manual control, one or more police officers stand in the middle of an intersection and provide right-of-way hand gestures. The second method is done using a push button to provide right-of-way. Push button operations can change phases but cannot skip the default phasing sequence. This research analyzed both types of manual intersection controls. The College Avenue – US 123, and US 76-Perimeter Rd intersections were controlled by police officers standing in the middle of the intersection while the US 123-US 76 intersection was controlled by push button. Although different types of controls were used at the intersections, the data collection methods were the same for both control types. One person was assigned to each intersection to collect the data. The volunteers who worked on this project were debriefed about the data collection process during the weekly ITE meetings before game day. Clear instructions of the volunteers' duties, and equipment setup procedures were given during the meeting. The 2014 Louisville game was an afternoon start; the game started at 3:30 PM. The data collection efforts that began before the game started at 11:00 AM and continued until 2:00 PM. The data collection for after the Louisville game started at 7:00 PM and continued until 9:30 PM. During 2015 football season data was collected for Notre Dame game. This data was used to model US 123- College Avenue intersection. Notre Dame game was a late start, the game started at 8:00 PM. The data collection efforts for the Notre Dame after game scenario started at 12:00 AM. Typical data collected at the intersections was video, queue data, lane geometry, and incidents/noteworthy activities, if any. The primary purpose of the video recording was to collect volume and right-of-way timing data. Queue data was collected to account for additional demand beyond what the actual traffic volumes indicated. On game days, traffic typically used different lane geometry than then normal, therefore, lane geometry at these two intersections was collected. For video recording, action cameras (Vivitar, Anart, and GoPro) were used. Figure 3-2 shows one of the cameras used to collect volume data.

Figure 3-2: Vivitar Camera and Weather proof Case

Each camera has a battery life of roughly 90 minutes. The cameras depend on external SD cards for memory. Each camera was equipped with either a 16 Gigabyte or a 32 Gigabyte SD card. Tripods were used to mount cameras at two of the intersections and a pole mount was used at US 76-Perimeter Rd. Each camera was placed in a weather proof casing. Tripod-mounted camera setups were easy to set up because the volunteer could clearly see what the camera was recording and decide if the camera was facing the correct view (Figure 3-3). A pole mounted camera required the use of wireless communication to monitor the view of the camera.

Figure 3-3: Tripod Setup at College Avenue-123 Intersection

Once the cameras were set up, the volunteers went on to record the queue data at intersections. For the Louisville game, in order to facilitate queue data recording, paint markings were made at 100 feet stations from the stop line approaching the intersections. Flags were posted every 500 feet point from the stop line. For the Notre Dame game, Google Earth images were used to record queues. Queue length information was marked on Google Earth images by identifying the nearest landmarks. This resulted in more accurate queue data, since, the queues can be marked at any point, unlike the previous method in which the volunteers had to estimate the length if the queues were at a point other than the 100 feet markings. The latter method was proven to be easier and more accurate than the first method that was used to collect the queue data. Queue lengths at every 5 minute intervals were recorded on the sheets. If different lanes of an approach had different queues, volunteers were asked to document the queue differences. If an intersection had more than one approach dealing with the game-related traffic, queues were recorded alternately at every other five minutes on each approach. A sample queue and geometry data sheets are shown in Figures 3-4 to 3-7.

Game Day Data Collection

Game ______________________________ Date ________________________

Before After (Circle 1)

Student _______________________________ Cell __________________________________

Location ____

Camera _______________________ # __________ Mount____________________ # ________

Time Started Video ________________________ Time Ended Video ________________________

Geometry: Use this space to sketch intersection geometry. Show arrows to indicate particular movements. Please show the camera location on your diagram

Comments/Notes/Observations (Use back if necessary): Include time(s)

Figure 3-4: Data Collection Sheet 1

Time	Queue Length(Feet)
:00	
:05	
:10	
:15	
:20	
:25	
:30	
:35	
:40	
:45	
:50	
:55	
:00	
:00	
:05	
:10	
:15	
:20	
:25	
:30	
:35	
:40	
:45	
:50	
:55	
:00	

Figure 3-5: Queue Data Recording Sheet Used for Louisville Game

:00	A	:00	AA
:05	B	:05	BB
:10	C	:10	CC
:15	D	:15	DD
:20	E	:20	EE
:25	F	:25	FF
:30	G	:30	GG
:35	H	:35	HH
:40	I	:40	II
:45	J	:45	JJ
:50	K	:50	KK
:55	L	:55	LL
:60	M	:60	MM
:00	N	:00	NN
:05	O	:05	OO
:10	P	:10	PP
:15	Q	:15	QQ
:20	R	:20	RR
:25	S	:25	SS
:30	T	:30	TT
:35	U	:35	UU
:40	V	:40	VV
:45	W	:45	WW
:50	X	:50	XX
:55	Y	:55	YY
:60	Z	:60	ZZ

Figure 3-6: Queue Data Recording Sheet Used for Notre Dame Game

Figure 3-7: Google Maps image used to collect Northbound Queue data at US 123-College Avenue Intersection for Notre Dame after Game

Volunteers were first asked to fill in their personal information, the camera used, the video start time, and the intersection geometry on the Data Collection Sheet 1. The queue data recording time was written next to the time column on the sheet, and the queue length, which precisely represented the point at which vehicles were backed up corresponding to the time, was written in the queue length column. Volunteers used the 100 feet paint markings on the road to determine the length of the queues. For Notre dame game queue data was marked on the google maps images. The queue data recording time was written next to the time column on the sheet. Alphabet letters corresponding to the times were written on the maps at a point which precisely represented the location at which vehicles were backed up corresponding to the time

3.2: Data Processing

The raw data had to be processed to be used in the simulation models. Video feeds at the intersections captured the video of vehicles that were passing through the intersection. Jamar boards were used to manually extract video for this purpose. ITE volunteers were assigned to do this job.

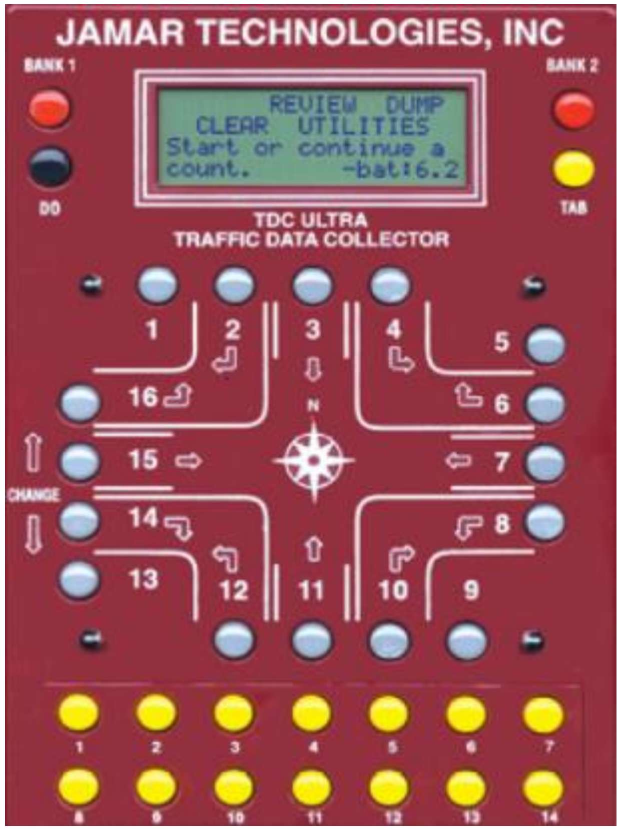

Figure 3-8: JAMAR Board

Each intersection was assigned a unique code to be used on the JAMAR boards so that the data did not get mixed up. Counts were extracted from the JAMAR boards in Microsoft Excel sheets. The counts obtained were stored in five minute intervals. Upon comparing the data obtained from the intersections, a peak 30 minute interval was observed. Within that peak 30 minute period, a peak 15 minute period was chosen to use for generating peak hour volumes. For the Louisville game, the peak 15 minute period was observed to be 12:20 to 12:35 PM. For Notre Dame game the peak 15 minute period was observed to be 12:50 AM to 1:05 AM. Count volumes do not denote the demand volume at intersections that are oversaturated. Many more vehicles are sitting in queues waiting for their turn. Hence, the count volumes had to be adjusted for queues to obtain approach demand volumes. This adjustment for queues was done by converting the queue lengths recorded into the number of vehicles waiting in queue. The length of the queue at any given time was divided by 27 (spacing) to get the number of vehicles waiting in queue at the same time. It was observed that queues experienced an increasing trend during the peak 15 minute period. The rate of increase of queues for every approach was plotted. The vehicles waiting in queue at each approach were distributed to each movement depending on the weightage of that movement. Weightage for each movement of an approach was given based on the observed trends in the videos. The peak 15 minute increase rate was added to the peak 15 minute count volumes, and the demand volumes were obtained.

Start Time	End Time	From South			
12:05 AM	12:10 AM	Right	Thru	Left	Peds
12:10 AM	12:15 AM	17	0	0	0
12:15 AM	12:20 AM	31	15	22	0
12:20 AM	12:25 AM	64	16	17	0
12:25 AM	12:30 AM	36	0	0	0
12:30 AM	12:35 AM	34	7	8	0
12:35 AM	12:40 AM	26	10	10	0
12:40 AM	12:45 AM	54	19	16	0
12:45 AM	12:50 AM	43	14	14	0
12:50 AM	12:55 AM	61	11	9	0
12:55 AM	1:00 AM	78	20	8	0
1:00 AM	1:05 AM	59	27	14	0
1:05 AM	1:10 AM	19	6	7	0
1:10 AM	1:15 AM	74	18	9	0
1:15 AM	1:20 AM	28	22	9	0
1:20 AM	1:25 AM	43	10	1	0
1:25 AM	1:30 AM	56	0	0	0
1:30 AM	1:35 AM	53	50	23	0
1:35 AM	1:40 AM	36	8	4	0
1:40 AM	1:45 AM	45	21	8	0
1:45 AM	1:50 AM	47	21	16	0
1:50 AM	1:55 AM	42	0	0	0
1:55 AM	2:00 AM	44	39	23	0
2:00 AM	2:05 AM	3	0	10	0
2:05 AM	2:10 AM	47	47	16	0

Legend

(highlighted) = Peak 30 minute period

Table 3-1: Northbound Count Volumes for Notre Dame after Game at College Avenue- US 123 Intersection

As an example, the weightage of the northbound right movement is given by dividing the NBR volume by the total approach volume.

The weightage of all other movements at other approaches are found out similarly. These weightages are used to distribute the queue volumes at an approach to movements at that respective approach. The queue data for the College Avenue- US 123 intersection after the Notre Dame game is as follows.

NB			
Start Time	End Time	Queue length (ft)	Queue Volumes
12:05 AM	12:10 AM	No Data	No Data
12:10 AM	12:15 AM	No Data	No Data
12:15 AM	12:20 AM	No Data	No Data
12:20 AM	12:25 AM	No Data	No Data
12:25 AM	12:30 AM	2850	106
12:30 AM	12:35 AM	2850	106
12:35 AM	12:40 AM	2850	106
12:40 AM	12:45 AM	2850	106
12:45 AM	12:50 AM	2850	106
12:50 AM	12:55 AM	2060	76
12:55 AM	1:00 AM	1965	73
1:00 AM	1:05 AM	2850	106
1:05 AM	1:10 AM	2850	106
1:10 AM	1:15 AM	2850	106
1:15 AM	1:20 AM	2850	106
1:20 AM	1:25 AM	2550	94
1:25 AM	1:30 AM	2550	94
1:30 AM	1:35 AM	2850	106
1:35 AM	1:40 AM	2550	94

Table 3-2: Queue Data for Notre Dame after game at NB College Avenue- US 123 Intersection

The queue data is plotted to observe the trends. The increase of queues at peak 15 minute period is observed. This number is added to count volumes to obtain the approach demand volumes.

The value chosen for the NB approach is 33 vehicles per 5 minutes per lane. The queues are increasing at a rate of 33 vehicles per 5 minutes per lane. These vehicles are distributed to each movement of the Northbound approach based on the weightage factors previously calculated. Using the count volumes, queue adjustment volumes and weightage factors the approach demand volumes for the US 123-College Avenue intersection northbound during peak 30 minute period are as follows

Start Time	End Time	Righ AD	Thru AD	Left AD
12:50 AM	12:55 AM	82	19	14
12:55 AM	1:00 AM	99	28	13
1:00 AM	1:05 AM	80	35	19
1:05 AM	1:10 AM	40	14	12
1:10 AM	1:15 AM	74	18	9
1:15 AM	1:20 AM	49	30	14

Table 3-3: Approach Demand Volumes for Notre Dame after Game at College Avenue-US 123 Intersection NB

The next step of data processing is right-of-way/signal timing acquisition. Right-of-way timings at College Avenue-US 123 and US 76-US 123 are obtained from videos. Average right-of-way timings during the peak 30 minute period were used for this purpose.

Equivalent Signal timings at College Avenue-US 123 intersection		
Movement	**Green Time**	**Loss Time**
EBT&EBL	58	7
EBT,WBT&WBR	119	7
Pedestrians	23	N/A
NBT,NBR,NBL	169	7
SBR&SBL	85	7
Pedestrians	27	N/A

Table 3-4: Equivalent Signal Timing at College Avenue-123 Intersection

The equivalent signal timings obtained by this manner are used for simulation purposes.

ROW for a movement or an approach was considered to have started when the first car crosses the stop bar of the respective approach. The ROW for a movement or an approach is considered to have ended when the last car leaves the stop bar of the respective approach. The time elapsed between the end of the ROW of a movement/approach and start of ROW of following movement/approach was considered as loss time.

3.3: Chapter Summary

This chapter explains in detail the data collection tools and methods used for this research. Video recording technique used to collect the intersection count volumes and queue sheets technique used to collect the queue data are explained in detail in this chapter. Also the data processing task was explained in detail. Detailed explanation is given on how approach demand volumes were obtained from count volumes and queue data. This chapter also covers the acquisition of equivalent signal timings at intersections from the videos. The following chapter explains how a simulation model is created and how this data is used in that model.

CHAPTER 4: SIMULATION MODEL DEVELOPMENT

After attaining all the necessary data from the field, the next step is to create a simulation model. A simulation model is employed primarily for three cases: The first case is to evaluate the current operations (i.e. To evaluate how police officers are handling the intersections.); The second case is to obtain optimized signal timings for the approach demand volumes during game times; The final case is to compare the operation of traffic officers against the optimized signal timings. A computer optimization software was used to facilitate optimization of signal timing based on the demand volumes.

The computer optimization software package used for this research was Synchro 9.0 and SimTraffic 9.0 (Trafficware, version 9). Synchro was chosen as the optimization software because it combines the intersection analysis and optimization capabilities with a simulation capability and is capable of doing network level analysis of several intersectoins. The SimTraffic package creates an animated model for the data input in Synchro which is useful to calibrate the model by comparing queues developed in SimTraffic to the queue data obtained from field.

4.1: Model Development

Model development began by acquiring a high resolution Google Maps image of College Avenue-US 123 and the US 123-US 76 intersections. The image used was large enough to accompany the longest queue observed on field during the data collection. The background picture used in Synchro is shown in the figure below.

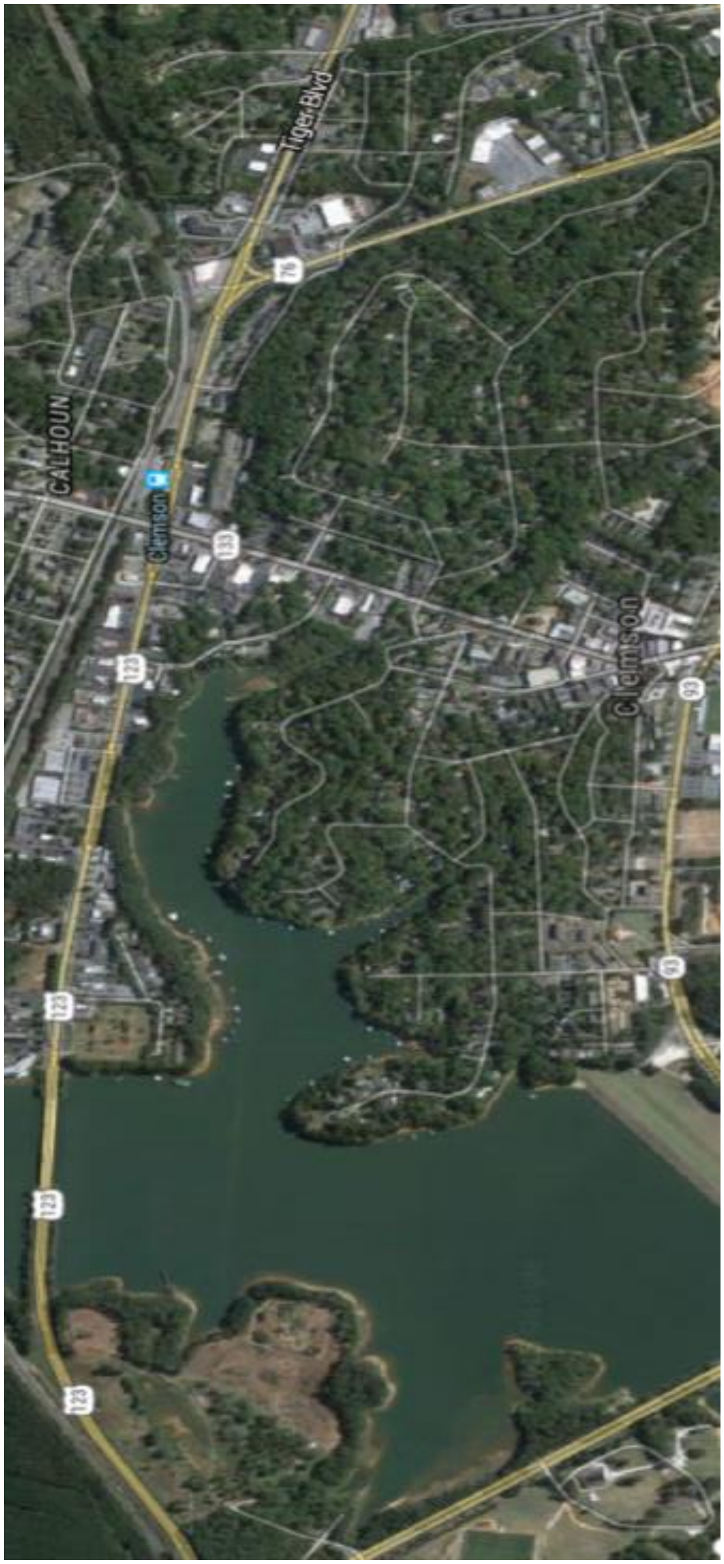

Figure 4-1: Google Maps Image Used for Synchro Background

This image was uploaded as Synchro background using the "Select Background" feature from Synchro 9.0. This feature enables one to select image backgrounds in JPEG format. The selected image can be scaled in Synchro using the Set Bitmap Scale and Offset feature.

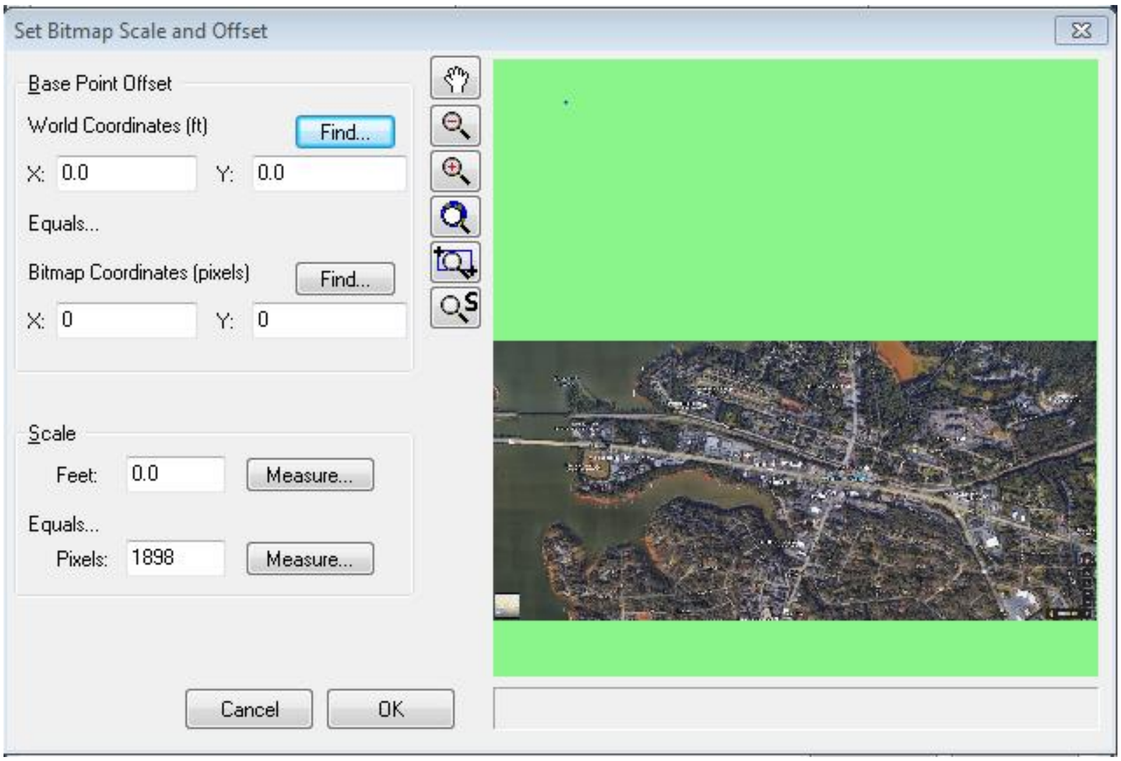

Figure 4-2: Scaling Background in Synchro

The scaling of the background in Synchro was done in the following manner for this research. Before obtaining the image from Google Maps, the distance between the two landmarks was measured and noted. For this background, the distance between the center of College Avenue- US 123 intersection and the center of US 123-US 76 intersection was measured and noted using the distance measuring feature in Google Maps to be 2100 feet. This value was entered in for the feet value in scale tab. After entering the value, the measure button was selected and the two corresponding points in the image, which are 2100 feet apart, were selected. Finally, the image Google Maps image was imported into Synchro and used as a background reference to the model. The drawing served as a very good reference for the placement of intersections, the orientation of roads, and the length of each segment. The Synchro network, which is a series of nodes and links that represents road segments and intersections, are drawn corresponding to the Google Maps image. Figure 4-3 illustrates the College Avenue- US 123 intersection model created in Synchro.

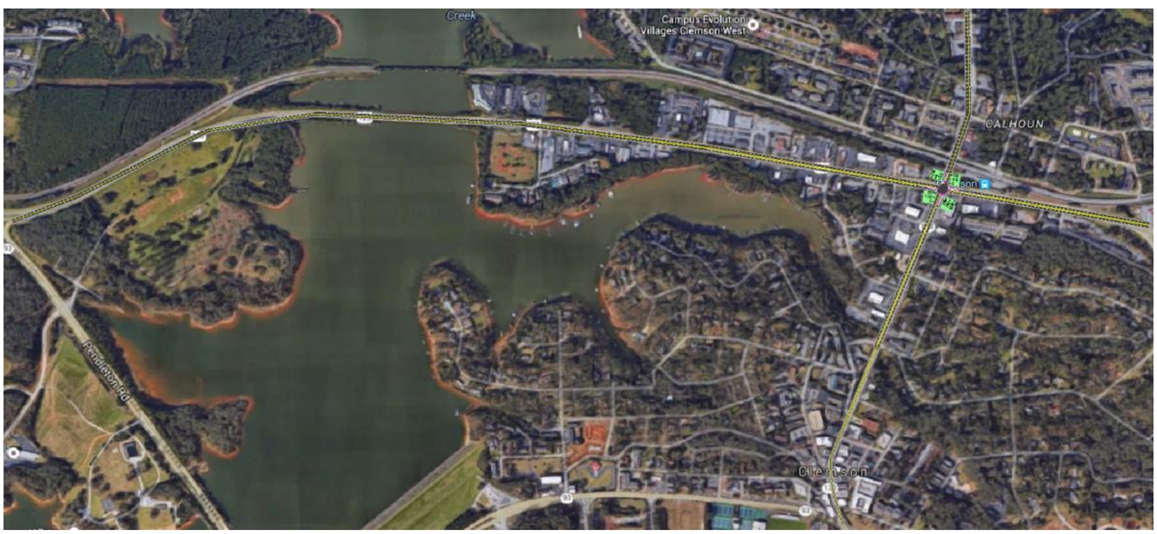

Figure 4-3: Synchro network Model

After the roads and intersections were accurately developed in Synchro, detailed information corresponding to each roadway segment and intersection was entered. Information, such as speed limit, lane width, link distance, and right turn and left turn lanes storage lengths were inputted for links. Information regarding physical location of intersections, signal timings, and volumes was inputted at intersection nodes

LANE SETTINGS	WBL	WBT	WBR
Lanes and Sharing (#RL)			
Traffic Volume (vph)	0	676	204
Future Volume (vph)	0	676	204
Street Name			
Link Distance (ft)	—	2106	—
Link Speed (mph)	—	15	—
Set Arterial Name and Speed	—	WB	—
Travel Time (s)	—	95.7	—
Ideal Satd. Flow (vphpl)	1900	1900	1900
Lane Width (ft)	12	12	12
Grade (%)	—	0	—
Area Type CBD	—	☐	—
Storage Length (ft)	380	—	161
Storage Lanes (#)	1	—	1
Right Turn Channelized	—	—	None
Curb Radius (ft)	—	—	—
Add Lanes (#)	—	—	—
Lane Utilization Factor	1.00	0.95	1.00
Right Turn Factor	1.000	1.000	0.850
Left Turn Factor (prot)	1.000	1.000	1.000
Saturated Flow Rate (prot)	1863	3539	1583
Left Turn Factor (perm)	1.000	1.000	1.000
Right Ped Bike Factor	1.000	1.000	1.000
Left Ped Factor	1.000	1.000	1.000
Saturated Flow Rate (perm)	1863	3539	1583
Right Turn on Red?	—	—	☑
Saturated Flow Rate (RTOR)	0	0	53
Link Is Hidden	—	☐	—
Hide Name in Node Title	—	☐	—

Figure 4-4: Synchro Link Input Window for Westbound at College Avenue-US 123

NODE SETTINGS	
Node #	6
Zone:	
X East (ft):	9991
Y North (ft):	-1872
Z Elevation (ft):	0
Description	
Control Type	Pretimed
Cycle Length (s):	509.0
Lock Timings:	☑
Optimize Cycle Length:	Optimize
Optimize Splits:	Optimize
Actuated Cycle(s):	509.0
Natural Cycle(s):	150.0
Max v/c Ratio:	1.39
Intersection Delay (s):	181.7
Intersection LOS:	F
ICU:	1.29
ICU LOS:	H
Offset (s) :	65.0
Referenced to:	Begin of Green
Reference Phase:	6 - Unassigned
Master Intersection:	☐
Yield Point:	Single
Mandatory Stop On Yellow:	☐

Figure 4-5: Synchro Node Input Window for College Avenue-US 123 Intersection

Eight different models were created for comparison purposes. Two models represent the existing conditions at College Avenue-US 123 and US 123-US 76 intersections for Notre Dame after game and Louisville before game respectively, and two other models represent the optimized models for existing conditions at the same intersections. The other two models represent the alternative phasing proposed by this research at College Avenue-US 123 intersection. Two more models were created to model US 76-Perimeter road intersection for Notre Dame after game, manual control and optimized control scenario. Optimizing was performed using the optimize cycle lengths and optimize splits features of Synchro 9.0.

4.2: Model Calibration

After entering all the data and before using the model to analyze and obtain quantitative results of the measure of effectiveness (MOE's), the model was calibrated. This was done by calibrating simulated queues to modeled queues. SimTraffic was used to observe the queue lengths generated by the model, and those queues were compared to the queue lengths measured in the field during the data collection. When the queue lengths generated by the model were roughly equal to the queue lengths obtained from field data, the model was considered to be calibrated. Since traffic patterns followed different trends for different games, it was not necessary to precisely calibrate the model. The volume and queue data used for this modelling represents the "worst-case" scenario accurately. The figure below depicts the maximum queue lengths generated by SimTraffic for the inputted values. The queue lengths generated by SimTraffic were compared to maximum queue lengths recorded in the field to validate the calibration of the model.

Model Calibration Validation for College Avenue-US 123 Intersection SYNCHRO			
Approach	***Queue Length from SimTraffic(ft)***	***Queue length Observed on field(ft)***	***Difference (%)***
US 123 EB at College Avenue	7286	8554	15
College Avenue NB at US 123	2992	2850	-5

Table 4-1: Model Calibration Validation for College Avenue-US 123 Intersection SYNCHRO

Similarly model calibration was done US 123-US 76 intersection.

VISSIM is used for microscopic simulation which makes it ideal for simulating oversaturated conditions. The same six models were created in VISSIM to obtain the measures of effectiveness for various scenarios. The model was first created by uploading a background image and scaling it. Various links and connectors were drawn to successfully create the intersections. The below figure shows the VISSIM simulation of the US 123-College Avenue intersection.

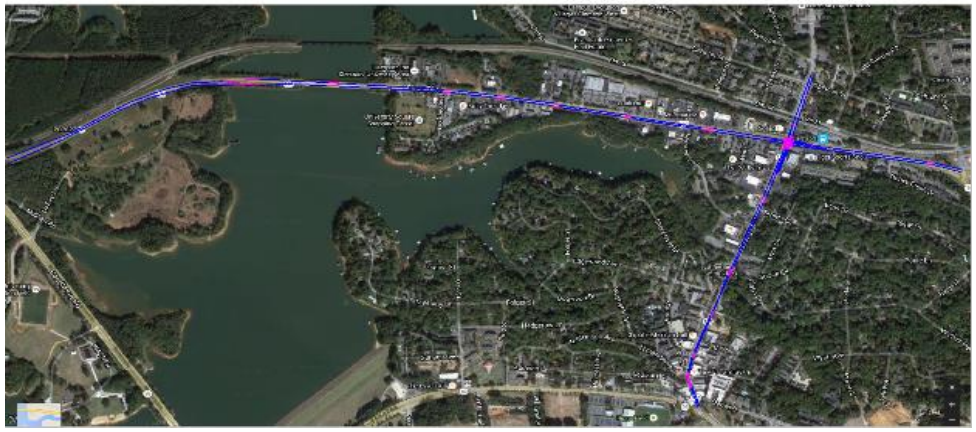

Figure 4-6: VISSIM model of College Avenue-US 123 Intersection

Model calibration in VISSIM was done in the same manner. The model was inputted with vehicle compositions and demand volumes. Routing decisions were placed at each approach, and the total flow for each movement was used to assign turning movement percentages on each approach. Signal timings, speed limits, and low speed zones were created at sharp turns to slow down the vehicle over a short distance. Reduced speed areas were given immediately downstream of the intersections to account for obstructions from neighboring intersections. Once all of the inputs were given, a 5 minute warm-up period was used at the beginning of the simulation. The simulation was run for 60 minutes and the queue formation was observed. Model calibrations were validated by comparing the queues.

Model Calibration Validation for College Avenue-US 123 Intersection VISSIM			
Approach	Queue Length from SimTraffic(ft)	Queue length Observed on field(ft)	Difference (%)
US 123 EB at College Avenue	8606	8554	-1
College Avenue NB at US 123	2375	2850	17

Table 4-2: Model Calibration Validation for College Avenue-US 123 Intersection in VISSIM

Since the football game traffic varies from game to game a threshold of +/- 20% was chosen for model calibration. As presented, the difference between the model and field data is always less than +/- 20%, hence the model was considered calibrated.

CHAPTER 5: RESEARCH FINDINGS AND SIMULATION MODEL ANALYSIS RESULTS

In this thesis, the manual operation of intersections is studied using Synchro 9 and VISSIM 5.4 to analyze the performance of police officers. Three major intersections, during two different games, which used two different techniques of manual control, were selected for this purpose. College Avenue-US 123 and US 76-Perimeter Road intersections were controlled by police officers standing in the middle of the intersection. These two intersections were analyzed for Notre Dame after game scenario. US 123-US 76 intersection was controlled using push button. This intersection was analyzed for Louisville before game scenario. The findings of this research are as follows.

5.1: US 123-US 76 Intersection

This intersection is one of the first intersections that traffic coming on US 123 south has to pass by after entering the Clemson city limit. It is to be noted that this intersection was controlled by push button. The average equivalent cycle length used by police officers at this intersection was 174 seconds. For the same volume using the "optimize cycle length and optimize splits features of Synchro 9, the optimized cycle length was obtained as 65 seconds.

Signal phasings' and timings used in VISSIM model are shown in figure 5-1 and 5-2:

Figure 5-1: Manual Signal Operation Timings at US 76-US 123 Intersection

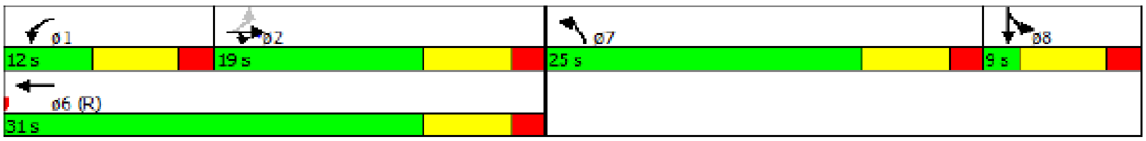

Figure 5-2: Optimized Signal Timings Operation Timings at US 76-US 123 Intersection

It can be observed that the police officers were allotting more green time for eastbound and westbound. Northbound Left movement was allotted relatively less time, and this resulted in increased delays.

Using the VISSIM 5.4 simulation package, the intersection was modeled to get delays for the push-button control and optimized control. Various parameters, such as turning movements, signal timings, and vehicle speeds used in the VISSIM model are exactly same as the ones used in the SYNCHRO model. The average delay per vehicle for all the movements were compared using VISSIM. Total delay of a movement for peak five minute volumes is also calculated to normalize the data for comparison purposes. The findings from VISSIM simulation are as follows. Westbound approach has the highest demand for the before game scenario. It is noteworthy that the optimized Westbound through delay is less than manual control.

US 76-US 123 Intersection												
	Eastbound				Westbound				Northbound		Southbound	
Type of Control	EBT		EBR		WBL		WBT		NBL		SB All	
Turning Movement	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay
Manual Operation	19	836	1	27	71	639	6	606	73	2117	63	63
Optimization Software	24	1056	1	27	26	234	14	1414	16	464	17	17
Improvement %	-26	-26	0	0	63	63	-133	-133	78	78	73	73

Table 5-1: Average Delay per Vehicle Comparison between Push-button Operation and Optimized Operation at US 123-US 76 intersection

Research findings show that the optimized timings reduce Average delay per vehicle on Northbound left approach by 78% and on Southbound by 73%. Westbound experienced an increase in delays as a result of optimized timings. Westbound approach saw noticeable reduction in delays from the optimized timings. This is particularly noteworthy because the Westbound volume is by far the largest and most critical at this intersection.

5.2: College Avenue-US 123 Intersection

After the game, all of the attendees trying to leave at the same time overwhelms the transportation network. The College Avenue-US 123 intersection was analyzed with the data from Clemson Vs Notre Dame game during the 2015 season. This game attracted a sellout crowd. Typically after games, the northbound and eastbound approaches at this intersection are the most heavily affected by game related traffic. One important observation to be made is that College Avenue was closed after the game at SR 93 to help reduce northbound traffic on College Avenue. From the videos taken, it was observed that the drivers still managed to cut through neighborhoods and enter College Avenue.

This resulted in heavier than expected traffic on northbound approach to the intersection. Also, it was observed that police officers are rationing relatively more time to NB than EB.

The average equivalent cycle length used by police officers at this intersection was 509 seconds. For the same volumes using the "optimize cycle length and optimize splits features of Synchro 9, the optimized cycle length was obtained as 205 seconds.

Signal phasings' and timings used are shown in figure 5-3 and 5-4

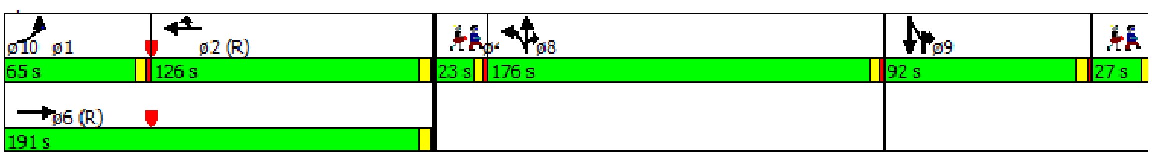

Figure 5-3: Manual Signal Operation Timings at College Avenue-US 123 Intersection

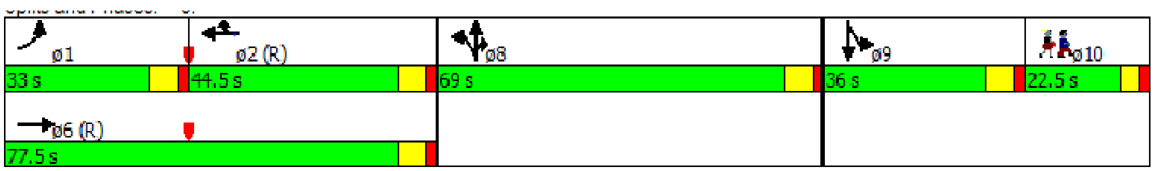

Figure 5-4: Optimized Signal Operation Timings at College Avenue-US 123 Intersection

Using the VISSIM 5.4 simulation package, the intersection was modeled to get delays for the manual control and optimized control. Average delays per vehicle and total delays for different movements were obtained from VISSIM.

College Avenue-US 123 intersection																		
	Eastbound				Northbound						Westbound				Southbound			
	EBT		EBL		NBL		NBT		NBR		WBT		WBR		SBL		SBR	
	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay
Manual	599	93444	763	21364	243	4617	247	8645	194	19206	258	17544	235	4465	244	6344	133	3724
Optimized	232	36192	308	8624	194	3686	210	7350	180	17820	139	9452	100	1900	174	4524	51	1428
Improvement%	61	61	60	60	20	20	15	15	7	7	46	46	57	57	29	29	62	62

Table 5-2: Average Delay per Vehicle and Total Delay Comparison between Manual Operation and Optimized Operation at College Avenue-US 123 Intersection

The results from VISSIM indicate that the optimized timing results in fewer delays on all approaches and all turning movements.

Upon observing the traffic operation at this intersection, a few observations were made regarding the phasing. Current phasing serves eastbound thru and eastbound lefts on an average for 65 seconds and then switches to eastbound thru and westbound thru for 126 seconds. During the second phase eastbound left turns were running out of space and were backing into the thru lanes, thus affecting the flow rate of the eastbound thru movement. For this reason this thesis proposes an alternate phasing at this intersection. The phasing followed by officers and the phasing proposed by this thesis is shown below. By restarting phase 1 (shown as phase 3 in Figure 5-6), the left-turn lane queue can dissipate which will significantly increase the flow rate of the EB through movement.

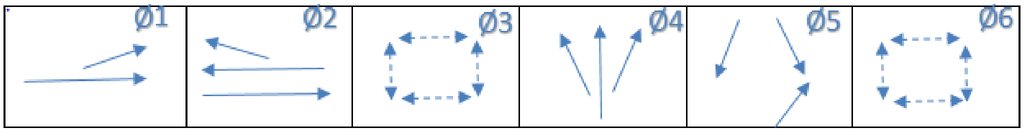

Figure 5-5: Phasing Used by Officers at College Avenue-US 123 intersection

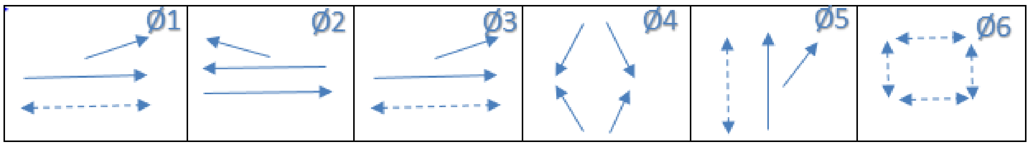

Figure 5-6: Proposed Phasing at College Avenue-US 123 intersection

A SYNCHRO model was created to model the intersection with proposed phasing. A cycle length of 486 seconds, which allots same percentage splits for approaches as the cycle lengths used by the officers, except that eastbound lefts were reserved. This was done to check if the Eastbound left turn blockage had any influence on the flow of eastbound thru movement.

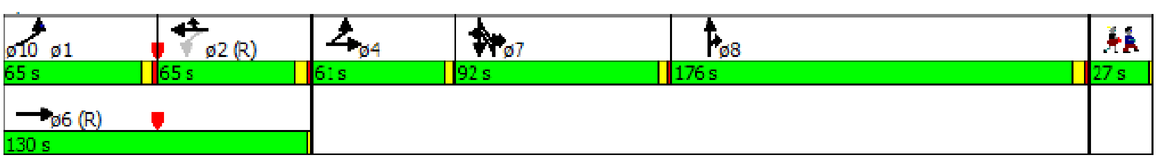

Figure 5-7: Proposed Phase Splits at College Avenue-US 123

This signal timing is compared to the timings officers adopted for the game, and the results are as follows.

The model is created in VISSIM, and the average delay per vehicle for different movements are obtained as shown in table 5-3.

College Avenue-US 123 intersection																		
	Eastbound				Northbound						Westbound				Southbound			
	EBT		EBL		NBL		NBT		NBR		WBT		WBR		SBL		SBR	
	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay
Manual	599	93444	763	21364	243	4617	247	8645	194	19206	258	17544	235	4465	244	6344	133	3724
Proposed	336	52416	331	9268	382	7258	206	7210	162	16038	747	50796	658	12502	219	5694	115	3220
Improvement%	44	44	57	57	-57	-57	17	17	16	16	-190	-190	-180	-180	10	10	14	14

Table 5-3: Average Delay per Vehicle Comparison between Existing Timings and Proposed Timings

From the VISSIM model it can be observed that the delays experienced by eastbound thru and eastbound left were noticeably reduced. Proposed phasing resulted in a slight increase of delays for northbound traffic. This could be countered by strictly enforcing the closure of College Avenue after the game. This results in reduced demand on northbound lanes. It can be noticed that while delays on westbound lanes are increased, the westbound thru total delay is still lower than the Eastbound thru movement total delay and hence it is considered reasonable to give less preference to this approach.

The optimized cycle length of 225 seconds for the proposed phasing obtained from SYNCHRO is used to see if it results in improved delays. The findings state that reduced cycle lengths resulted in improved delays.

College Avenue-US 123 intersection																		
	Eastbound				Northbound						Westbound				Southbound			
	EBT		EBL		NBL		NBT		NBR		WBT		WBR		SBL		SBR	
Type of Control	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay
Manual	599	93444	763	21364	243	4617	247	8645	194	19206	258	17544	235	4465	244	6344	133	3724
Optimized	232	36192	308	8624	194	3686	210	7350	180	17820	139	9452	100	1900	174	4524	51	1428
Proposed(Optimized)	103	16068	125	3500	206	3914	287	10045	212	20988	206	14008	121	2299	56	1456	21	62

Table 5-4: Total Delay Comparison between, Manual, Optimized and Proposed Timings

It can be observed that proposed phasing with optimal timing resulted in less delays on eastbound traffic. Westbound approach experienced more delay. The reasons for this would be cutting down green time for westbound thru movement and allotting it to eastbound left.

5.3: US 76-Perimeter Road Intersection

This intersection lies on the east side of the Clemson campus. Perimeter road is heavily affected by game traffic coming from parking lots C1, C2, C5, and R3. US 76 is loaded with traffic coming off from the SC 93 right turn ramp. This results in oversaturated conditions at Perimeter-US 76 intersection. The current geometry at this intersection is Perimeter east bound is contraflowed after games. This gives two lanes for eastbound traffic. Upon approaching the intersection, two left turn lanes and one right turn lane is provided. Eastbound right turn has an acceleration lane and right turns are run continuously. Right turners turn in the acceleration lane and merge in to the US 76 South.

In order to serve the left turners, north and southbound has to be stopped. The southbound approach has two thru lanes and one left turn lane. The left turn lane is closed by officers and only two thru lanes are open for traffic. Northbound has two thru lanes and one left turn lane. The left turn lane is blocked by the officers and only two thru lanes are open. Upon watching the recorded videos, it was observed that on an average eastbound left turns were given right-of-way for 152 seconds. The saturation flow for two left turn lanes is observed only during the start of the phase and as the phase progresses, left turners are only using one left turn lane. After looking at the videos at this intersection it was observed that the two left turn lanes from perimeter road were not running at full capacity during its green phase, hence this thesis proposes three left turn lanes on eastbound and cutting down the right of way time for eastbound. The left most lane will turn into the median between north and southbound and will be coned from making right turns on to the US 93 ramp. The other two left turn lanes will turn into US 76 NB and can go thru or turn right at the ramp. Two of the three left turn lanes are storage lanes and are 340 feet long each, the third left turn lane is continuous. Upon adapting three lanes, 40 cars can be stored in these three lanes and as soon as officers provide right of way for eastbound lefts, all of these vehicles could be cleared off at a saturation rate of flow. With one extra lane, the right of way timing for the eastbound left could be reduced without any effect on the capacity. Southbound thru traffic will merge into one thru lane instead of using two thru lanes and as a result the eastbound right turners can enter their own lane on US 76. Since the eastbound right turn volume is proportionately equal to southbound thru volume, this change is expected help eastbound right turn movement.

Figure 5-8: Proposed three left turn lanes at Perimeter US 76 Intersection

Figure 5-9: Proposed Southbound merge at Perimeter-US 76 Intersection

The signal timings used for manual and optimized scenario are shown in the figures 5-10 and 5-11.

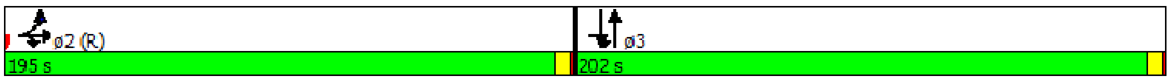

Figure 5-10: Manual Signal Operation Timings at US 76-Perimeter Road Intersection

Figure 5-11: Optimized Signal Timings at US 76-Perimter Road Intersection

Average delay per vehicle for existing scenario, and optimized timings for existing scenario is shown in table 5-5:

Two Left Turn Lanes on EB												
Average Delay Per Vehicle												
		NBT		EBL		EBR		SBT		SBT(From US 93 Ramp)	
Control Type	Cycle Length	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay
Manual (Two Left Turn Lanes on EB)	397	54	2430	420	18480	390	37830	121	4840	214	15836
Optimized (Two Left Turn Lanes on EB)	130	18	810	397	17468	387	37539	35	1400	41	3034

Table 5-5: Average Delay per Vehicle Comparison between Manual Operation and Optimized Operation at US 76-Perimeter Road Intersection

Upon implementing the above made recommendations, average delay per vehicle, obtained from VISSIM simulation are shown in table 5-6.

Average Delay Per Vehicle											
		NBT		EBL		EBR		SBT		SBT(From US 93 Ramp)	
Control Type	Cycle Length	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay
Manual (Two Left Turn Lanes on EB)	397	54	2430	420	18480	390	37830	121	4840	214	15836
Manual (Three Left Turn Lanes on EB)	397	57	2565	264	11616	199	19303	285	11400	479	35446
Optimized (Two Left Turn Lanes on EB)	130	18	810	397	17468	387	37539	35	1400	41	3034
Optimized (Three Left Turn Lanes on EB)	130	17	765	158	6952	110	10670	157	6280	293	21682

Table 5-6: Average Delay and Total Delay comparison between two left turn lanes and three left turn lanes on Eastbound with Southbound Thru merge

Simulation results indicates that merging two thru lanes on Southbound results in increased delay on the Southbound approach, especially on the vehicles coming down the ramp from SC 93. Hence another model is designed to study the effect of three left turn lanes on Eastbound without merging Southbound thru traffic. The resulting delays are shown in table 5-7. Three left turn lanes on Eastbound approach resulted in decreased delays for Eastbound left and Eastbound right movements. Also with added capacity from third lane on Eastbound, the approach requires less right-of-way timing and this could benefit the southbound approach.

Average Delay Per Vehicle										
	NBT		EBL		EBR		SBT		SBT(From US 93 Ramp)	
Control Type	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay	Avg Delay	Total Delay
Manual (Two Left Turn Lanes on EB)	54	2430	420	18480	390	37830	121	4840	214	15836
Manual (Three Left Turn Lanes on EB)	59	2655	345	15180	299	29003	116	4640	220	16280
Optimized (Two Left Turn Lanes on EB)	18	810	397	17468	387	37539	35	1400	41	3034
Optimized (Three Left Turn Lanes on EB)	18	810	292	12848	274	26578	33	1320	40	2960

Table 5-7: Average Delay per Vehicle Comparison between Two Left Turn Lanes and Three Left turn lanes on EB without Southbound Merge at US 76-Perimeter Road Intersection

5.4: Chapter Summary

Upon analyzing all the results, a few general observations were made.

- Officers are using extremely long cycle lengths in severely oversaturated conditions resulting in increased delays
- When intersections are significantly oversaturated, officers tend to misjudge how long vehicles are in queue, which leads to some approaches receiving significantly more delay than others
- Officers tend to misinterpret the change in flow rates, they only notice that the queues are backed up, hence they prolong the right-of-way even after a reduction in rate of flow below the saturation flow rate. This reduced rate of flow occurs

even in saturated conditions for a number of reasons. One example is when an auxiliary lane queue clears, the lane will not operate the saturation flow rate even though adjacent lane is over saturated.

- On average, officers typically have greater loss time than traffic signals during a phase change. Thus, shortening the cycle length will result in more cycles (and phases) per hour which in turn will result in a greater hourly loss time. But in severely oversaturated conditions, the greater proportion of loss time is offset by a reduced rate of flow below sometimes well below the saturation flow.
- In less severely saturated conditions officers perform relatively well—especially if they can accurately judge queue dissipation.

CHAPTER 6: CONCLUSIONS

The overall goal of this thesis was to evaluate how traffic officers control traffic at Clemson football games. One of the objectives of this thesis was to evaluate how traffic officers control intersections in varying levels of oversaturated conditions. Three different intersections were analyzed in this research. Two of the three intersections analyzed were heavily oversaturated while the US 76-US 123 intersection was at or near a saturated condition during the period of highest demand. All three intersections were under saturation when data collection began but traffic increased quickly. One finding of this research was that when an intersection was under saturated or not overly saturated, officers could see the ends of the queues and could balance delays when changing ROW. For the push-button controlled US 76-US 123 intersection, the analysis showed that officers performed well on the two major approaches at this intersection, in fact, better than the optimized timings. The northbound left movement at this intersection experienced a slight increase in delay during manual operation. During heavily over saturated conditions, queues tended to back-up for as far as the officer could see. In these cases officers tended to run extremely long phases in an effort to clear the queues, however this routinely resulted in unbalanced delays on other approaches. While unbalanced delays are sometimes necessary for prioritizing critical movements where demand is highest—it can be difficult for an officer to tell which movement needs the greatest priority if all of the movements/approaches have extremely long queues.

One other objective of this research was to evaluate how officers balance delay among different approaches. When officers cannot see the ends of the queues, they tend to misjudge how long vehicles are waiting in a queue leading to substantially unbalance delays. This is clearly evident from the results at the College Avenue-US 123 intersection. The eastbound thru which has relatively more demand volume than the Northbound right turn movement, is routinely given less right-of-way. Both these movements have queues backed up for extreme lengths, hence officers were not able to interpret the real demand and provide adequate time corresponding to the demand.

Another objective of this research was to evaluate how officers manage queues and promote quicker queue dissipation, one way officers manage queues is by serving a movement for a longer phase period to try to clear the queues. Cycle lengths in excess of several hundreds of seconds is used for this purpose. While the analysis of all three intersections, showed that longer cycle lengths are resulting in increased delay, optimized cycle lengths resulted in reduced delay in every single scenario except at the less saturated US 123-US 76 intersection.

The final objective of this research was to develop recommendations on how officers can potentially improve traffic operation and comment on the transferability of these recommendations to other planned events besides Clemson football. Based the findings of this thesis, the following recommendations are suggested:

- Officers should try to be cognizant of the rate of flow. An obvious reduction of rate of flow may indicate that a phase change may be appropriate.

- Officers should try to reduce delay on approaches dealing with game related traffic of highest demand even if this results in increased delay on other approaches.
- Communication between officers at neighboring intersections could help them better understand the queue situation on different approaches and provide better system level operation.

These recommendations are pretty generic and are supported by findings in the literature. Thus, they should be transferable to other locations and events where manual traffic control is chosen to manage oversaturated conditions.

CHAPTER 7: REFERENCES

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