ASSESSING THE IMPACT OF SCHOOL BUS TRAFFIC USING MODELING SOFTWARE AND AUTOMATED TRAFFIC SIGNAL PERFORMANCE MEASURES

by

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ABSTRACT

ANDREI MARIUS DUMITRU. Assessing the Impact of School Bus Traffic Using Modeling Software and Automated Traffic Signal Performance Measures (Under the direction of DR. SRINIVAS S. PULUGURTHA)

Some of the least studied vehicle types in the urban and suburban traffic environment are school buses. Their dynamic deficiencies, as well as the two additional rules that govern their functionality versus other vehicles (no right-turn-on-red and stop at every railroad crossing), makes them a delay-inducing traffic participant. This thesis presents modeling and analysis of school bus traffic influence over a coordinated network of traffic signals. A comparison was made in a chosen specific set of measures of effectiveness: total vehicle delay and queue length. The financial impact was also analyzed using emissions as a measure of effectiveness. The real-world network was modeled, and analysis was performed with a state-of-the-art traffic microsimulation computer software, VISSIM. The effects were measured via both the analysis tools present in the software as well as through a third-party performance measurement software that relies on arrival data.

This research positions itself as an alternative to a previously performed Traffic Impact Analysis (TIA) that looked at a new high school opening using Synchro software which does not explicitly account for school buses behavior. The results confirm that there exists a quantifiable performance decrease for the signalized corridor. This was validated through analyzing simulation outputs and usage of advanced signal performance metrics.

ACKNOWLEDGMENTS

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LIST OF ABBREVIATIONS

AAHSTO	American Association of State Highway and Transportation Officials
API	Application Programming Interface
ASC/3	Advanced System Controllers series 3
AADT	Average Annual Daily Traffic
ATSPM	Automated Traffic Signal Performance Measurements
AVL	Automatic Vehicle Location
CALTRANS	California Department of Transportation
CID	Controller Interface Network
DOT	Department of Transportation
FHWA	Federal Highways Administration
FTP	File Transfer Protocol
GUI	Graphical user interface
HGV	Heavy Goods Vehicle
HIL	Hardware-in-the-loop
Hz	Hertz (the unit for frequency)
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
ISO	International Organization for Standardization

LOS	Level of Service
MOE	Measure of Effectiveness
NEMA	National Electrical Manufacturers Association
NCDOT	North Carolina Department of Transportation
NTCIP	National Transportation Communications for ITS Protocol
OS	Operating System
RTOR	Right-turn-on-red
SIL	Software-in-the-loop
SNMP	Simple Network Management Protocol
TCP/IP	Transmission Control Protocol/Internet Protocol
TIA	Traffic Impact Analysis
TMC	Traffic Management Center / Turning movement counts
UDP	User Datagram Protocol
VISSIM	Traffic in Towns Simulation (Verkehr In Stadten SIMulationsmodell)

CHAPTER 1: INTRODUCTION

This first chapter initially goes over the rationale that led to choosing this study's topic and what the research sets as an exploration goal. Finally, it ends with a breakdown of the thesis organization.

1.1 Motivation

Traffic congestion is an ever-increasing issue in most of the urban areas in the United States (U.S). With the rapid growth in population, the land use and traffic patterns are starting to change. Traffic Engineers everywhere are facing the day to day challenge of providing more reliable and efficient traffic flow for in a rapidly changing environment. New housing, medical, educational and commercial developments rely on Traffic Impact Analysis (TIA) studies in the form of a consultant prepared analysis report, that evaluates the traffic impact it would create in a specific region. These are detailed documents that provide insights and forecasts pertaining to the influence of the proposed development in a selected region. The latter is always performed with the aid of traffic microsimulation software suites. Typically, this means they are performed with Trafficware's Synchro software. The analysis is usually performed from the point of view of Level of Service (LOS) deterioration, and the effects are studied through a microsimulation in SimTraffic.

The TIA depends on the historically studied trip percentages and is employed for the following purposes: to analyze the current conditions, determine the growth in demand as a result of the project, estimate the degree of influence over the surrounding transportation facilities and propose mitigation procedures that guarantee the reduction of the negative effect of the project in order to maintain a specific LOS (NCHRP 758). A large portion of this analysis as it pertains to the urban and suburban environment is the determination of delays the development produces at a specific location. Consultants usually perform capacity analysis in order to measure vehicle delay. The LOS is determined as a function of control delay using the data's output and following the Highway Capacity Manual (HCM) 2010 methodology. A proposed set of mitigation measures needs to be implemented if the LOS decays under any circumstances, as it offers a method of relief.

This research looks at the effect of a school (West Cabarrus High School) addition in a well delimited Traffic Analysis Zone (TAZ) located in the western part of the City of Concord, North Carolina, and its traffic impact on the nearby arterial corridor that is used by school buses and regular traffic participants alike. The researcher's opinion is that some of the inefficiencies of the traffic system stem from not being able to discern between different vehicle characteristics and properties. All model simulations need to parametrize the traffic participants, a fact that is not achieved by TIA studies.

1.2 Purpose of the Research

The overall goal of this research is to assess the impact of additional school bus traffic on the George W. Liles Pkwy corridor and quantify it in terms of performance decrease as well as an increase in environmental costs. A set of performance measures had to be chosen and, subsequently, see how they were employed in order to achieve this goal. In lieu of a limited scope and scale TIA that a consultant offered when judging the impact of a school opening, even a limited experimental and a theoretical study is preferred that due to the aforementioned study not taking a look at the corridor but merely at the intersection, developing a more detailed microsimulation model is preferable and will lead to a better understanding of the actual influence incurred by this area.

This research presents modeling and analysis performed with a calibrated model developed in microsimulation software. This model is governed by a sophisticated traffic signal controller emulator that runs a mirror image of the traffic signal controller software from the field controllers. The obtained output data is then compiled and analyzed with the internal software tools. This research also takes the resulting traffic signal controller output and runs through a state-of-the-art traffic performance data analysis tool where the data is compared to the current conditions.

1.3 Thesis Organization

The thesis is split into six chapters and one appendix. Following this one, Chapter 2 presents the literature review that was conducted in the following areas that were identified as key towards understanding this paper: traffic modeling software and more specifically microsimulation, measures of efficiency (MOEs), the development of automated traffic signal performance measures (ATSPMs) as well as ways of integrating traffic signal control into a microsimulation model.

Chapter 3 provides a detailed explanation of the study area and looks at the tools that are used to perform this experimental work, such as the microsimulation environment and the implementation of traffic signal controller. Subsequently, it discusses the methodology used to perform this research. It also dives into the preliminary model construction, the simulation model development, and parametrization.

Chapter 4 goes over the calibration methodology and the data collection process that was performed in the field plus using intelligent transportation systems (ITS) technologies, in order to capture the needed data, so the exact field conditions are represented.

Chapter 5 presents the results obtained from multiple simulation runs and analyzes the obtained results. It also looks at the results obtained with the additional third-party signal performance metrics software.

Chapter 6 presents conclusions obtained after performing this research, some of the observed limitations of the study and recommendations for in case a more detailed analysis is pursued.

The Appendix presents the data that was not included in chapters 3 and from the data collection process, as obtained from the field detectors via the approach volume from the as ATSPM system. outputs organized per intersection per time of day.

CHAPTER 2: LITERATURE REVIEW

This chapter presents the discoveries from the literature review that was performed in the initial part of this study. This was concentrated in four distinct areas: traffic simulation software/tools, measures of effectiveness, signal performance measurements and traffic signal control implementation into microsimulations. Before selecting, it is important to know what the characteristics of specific simulation software packages were. There is a vast amount of literature written on this topic. In order to understand what microsimulation modeling software was more advanced than Synchro, a detailed look was taken at the options.

2.1 Traffic Simulation Tools

Vehicular traffic simulation is the process of mathematical modeling performed, with the assistance of computer software, of the transportation systems such as freeways and highways, arterials, roundabouts, parking lots, etc. (Fellendorf and Vortisch 2010) There are three major categories of traffic simulation tools.

The first one is the macroscopic category. This group does not deal with individual vehicles; it does instead model the traffic flow using the triple concept of aggregate speed, flow, and density (Boxill and Lu, 2000). Some examples of software suites are: TRANSIT - 7F and KRONOS. The second one is the microsimulation software. This class tracks the individual movements of vehicles, such as lane changes as they are governed by the behavior model of the individual driver. Behaviors are represented by specific and different lane changing, lateral spacing, signal control models as well as car-following models. Examples in this group are VISSIM, CORSIM, AIMSUN, SUMO, and PARAMICS. The third group is mesoscopic software. In this case, even though a look is not taken at the individual vehicles, the parameters that govern them are the same ones as above: speed, flow, and density. These fill the gap between the aggregate level approach mentioned above and the individual interactions of the microscopic ones by keeping the behavior characteristics at a low level detail while describing the traffic units at a high level (Burghout et al. 2005). Examples in this category are DYNASMART and DynaMIT.

For the purposes of this research, a microsimulation modeling tool was used to create a model that, once refined, reflected accurate field observed conditions.

2.2 Microsimulation Modeling Software

In recent times, traffic modeling software suites have been developed to conduct a microsimulation analysis of transportation facilities. Microscopic simulation tools attempt to replicate the behavior of the individual drivers and vehicles within a given network. Some of the most used and well-known software packages capable of it are CORSIM, SimTraffic, and VISSIM.

COSRSIM, an abbreviation from "corridor simulation" is an all-inclusive microscopic traffic simulation environment that can model streets, freeways, and integrated networks with a full array of traffic control devices such as stop and yield signs, traffic signals as well as ramp metering. It is capable of simulating traffic and traffic control systems using commonly accepted vehicle and driver behavior models. CORSIM includes two of the most widely used traffic simulation models: one for surface streets called NETSIM, and one for freeways named FRESIM (FHWA, 2016).

SimTraffic is a core component of the Synchro/ SimTraffic software package used by consultants and agencies alike across the country. Due to the comfortable visual interface, it is relatively easy-to-use traffic simulation tool designed for use by field traffic engineers primarily as a complementary package to the Synchro signal-timing optimization software. Significant disadvantages of SimTraffic are the lack of Application Programming Interface (API) functionality as well as supporting detailed output of vehicle-state variable information and automated statistical analysis capabilities of other codes. In contrast, SimTraffic has the firmest state variable standard update intervals of all models surveyed, standing at a tenth of a second. Although their validity has not yet been researched, it advertises many improvements over the CORSIM models for representing real-world traffic conditions. SimTraffic appears to model most of the behaviors necessary for collecting stand-in measures, but at a lesser resolution level than VISSIM (Fellendorf and Vortisch 2010).

Verkehr In Stadten SIMulationsmodell (VISSIM), the German translation for "Traffic in Towns Simulation" is a microscopic and multi-modal software tool used by consultants, agencies and researchers, whose goal is modeling transit and traffic flow in urban areas as well as interurban freeways as personal motorized private transport, public transport in road, rail form, goods transport as well as pedestrian and cyclists. The traffic flow model in VISSIM is a discrete, stochastic, time step based microscopic model, with driver-vehicle-units as single entities; the aforementioned model contains a psycho-physical car-following model for longitudinal vehicle movement and a rule-based algorithm for lateral movements (Fellendorf and Vortisch 2010). This software package can be used for capacity analysis as well as testing of traffic signal control systems. Various design alternatives available in VISSIM include roundabouts, unsignalized and signalized intersections, and grade-separated interchanges.

It can be used to design, test and evaluate various scenarios. Furthermore, it can be used to analyze toll plaza facilities, perform traffic impacts analysis and test ramp metering operations and interchange design.

2.3 Measures of Effectiveness

The Federal Highway Administration (FHWA) defines performance measurements as the use of statistical evidence to determine progress toward specifically defined organizational objectives. This can refer to evidence of actual facts, such as measurement of pavement surface smoothness as well as measurement of user perception that would generally be gauged through a customer satisfaction survey (FHWA, 2019).

An exemplification of these measures would be the number of vehicles using a specific stretch of road for a specific period of time. Performance measures, also called measures of effectiveness (MOEs), can also measure transportation network user's satisfaction with a given road facility. The concept of Level of Service (LOS) is aimed specifically at assessing a qualitative image of the performance. The Highway Capacity Manual (HCM) defines performance measures as a qualitative characterization of some aspect of the service provided to a specific road user group (HCM 2010). With the exception of the volume-to-capacity (V/C) ratio, the LOS is used to expose the relative difference for each of the MOEs. In order to assess the efficiency of signal timing, one could use the LOS.

Some of the MOEs that are commonly used by transportation agencies to assess the performance of road segments are traffic volume (in AADT, peak-hour or peak-period form), vehicle miles traveled (volumes times length), travel time (distance divided by speed), speed (distance divided by time), density (vehicles per lane per period), and occupancy (persons per vehicle).

For a cluster of signalized intersections that are running coordination, MOEs are cycle length, green time and capacity, counts and volumes, V/C ratio, percent arrivals on green, arrival type, and maximum vehicle delay. Table 1 shows a breakdown of MOEs for freeway and coordinated signalized intersections.

TABLE 1: Facility performance MOEs

Freeway / Highway	**Coordinated Signalized Intersections**
Lane miles by volume	V/C ratio
Average speed by facility/lane type	Cycle length
Passenger miles/vehicle miles traveled	Degree of intersection saturation
Hours per day operating with congestion	Platoon or flow profile
Change in peak period VMT	Estimated queue length
Change from baseline in peak hour volumes	Maximum vehicle delay

When conducting a signalized network traffic analysis, the MOEs for consideration can be classified into two main categories. The first one is the environmental category, which includes measures such as fuel consumption, noise emission, vehicle operating costs, personal time, carbon dioxide emission, etc. The second category refers to universally recognized traffic operations such as traffic volume, mean speed, travel time, delay, queue length, number of stops, time-space-diagram outputs, V/C ratio, and density.

2.4 Microsimulation Signal Control

According to Fellendorf and Vortisch (2010), there are multiple ways to model signal control in microsimulations. The first category is driven internally from the software. This includes fixed or pre-timed signal plans, ring and barrier actuated, and macro language logic defined. The second category includes external drivers. This category interfaces with external modules such as the Split Cycle Offset Optimization Technique (SCOOT) and Sydney Coordinated Adaptive Traffic System (SCATS) adaptive algorithms, external signal controller firmware such as Econolite ASC/3 and Intelight D4, and finally external hardware such as National Electric Mechanical Association (NEMA) TS1 and TS2 controllers or California Department of Transportation (CALTRANS) 2070 controllers. As of this moment, the three most used methods of modeling traffic signal operations in microscopic simulation models are the proprietary simulation model's controller emulator, hardware-in-the-loop (HIL) simulation, and software-in-the-loop (SIL) simulation.

Every traffic simulation software typically has its own approach to performing traffic control. VISSIM comes bundled in the U.S. with one such emulator that is called the Ring and Barrier Controller (RBC). This follows the NEMA standard specification for pre-timed, semi-actuated and fully-actuated operation, and in more ways than one is an upgrade to the standard NEMA controller, supporting 16 signal groups with 32 vehicle detectors, 16 pedestrian detectors as well as transit system priority functionality (Fellendorf and Vortisch 2010). This acquires the status of the detectors and changes the status of the signal heads in real time. Even though it can be parametrized very closely to real-life conditions, it lacks a multitude of control operations as well as the sophistication of the coordination parametrization. Conversely, this does have several advantages, such as ease of configuration of the signal controller and timings and simulation speed since it is an embedded tool.

Another method used to involve external traffic signal control in a simulation is to include the real hardware and connect it to the software simulation via a Controller Interface Device (CID), as seen in Figure 1. This is constituted from a hardware component assembly: one piece would be an adapter harness that on one side plugs to the connector at the back of a 2070 or NEMA Controller and the other an embedded board that interfaces the discrete logic levels of control pins on the controller to the computer executing the model simulation. Thus, the logic of the simulation program is performed in the actual controller. This acquires the detector input data as a discrete signal that are transferred to the controller in real time (Urbanik et al. 2010)

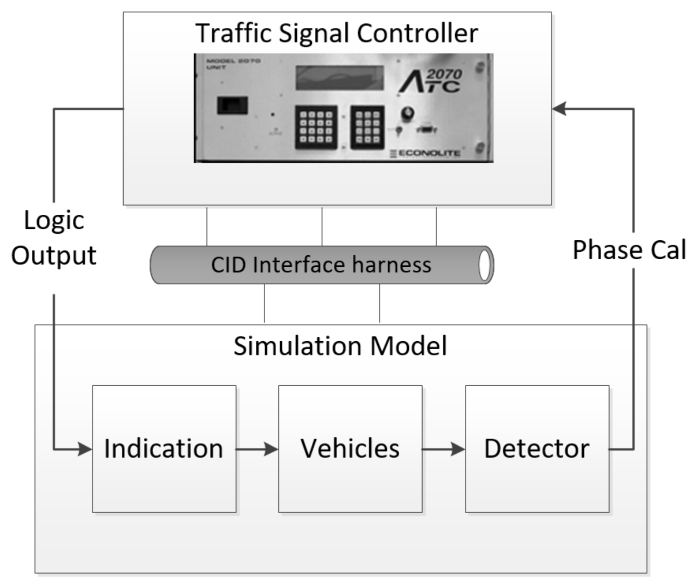

FIGURE 1: CID interface for HIL

VISSIM constitutes basically an abstraction of what happens in the field and its core advantages are dependability and the fact that when testing basic traffic control functions, it is advantageous to use a simpler approach. There are several downsides to the utilization of HIL solutions: primarily the introduction of latency due to the time needed to process the data, time needed to propagate the data, and time needed to transmit the data. Since this is over a serial interface, the data transmission is limited to the serial bus data transmission rate, which for the current setup is no more than 19,200 bits per second.

Due to the fact that HIL simulation is quite expensive from both time budget and financial resource perspectives, more recently a better solution can be found in the SIL applications developed for the VISSIM simulation software. This setup is comprised of a virtual controller as well as the simulation model running on the same computer.

There are multiple alternatives that rely on this API interface offered by VISSIM. This enables users to develop and integrate their own or existing external applications to control a simulation. Many major signal controllers' manufacturers use this avenue to test their newest controller technology. The most known is the Econolite ASC/3 module. Developed initially in a project by researchers at the University of Idaho, it enables users to simulate the exact field options, as it relies on the same code like the one from the hardware deployments (Urbanik et al. 2010)

ASC/3 SIL essentially runs a virtualized controller emulation of the code as the one found in the field controllers and performs identically to it. This application provides many opportunities for evaluating and analyzing traffic control strategies that could be performed within a simulation environment. Once all the tests have been done in the simulation, the control strategies can be easily transferred to the field controllers by uploading the database file created during the simulation. This relieves some of the required effort and time, as well as costs that could be induced if the changes and testing are performed on a field controller. But, by far, the biggest advantage of the ASC/3 SIL is that it can run faster than the real time during simulation, which significantly cuts down on the time needed to test a scenario in VISSIM.

The ASC/3 SIL is a system that has multiple core components. The first one is a baseline data manager, otherwise called a Database Editor, Traffic Control Kernel, Controller Front Panel Simulator, and VISSIM Dynamic Link Library (DLL) Interface components. The first one is an application that handles the controller timing data input into the simulated controllers while in the Operating System (OS) environment. Its role is to present the user with an easier method for data entry than using the controller's physical front panel numerical keypad and data entry screens. The database file for the ASC/3 SIL is identical to the one from an actual ASC/3-LX controller. The Traffic Control Kernel is the virtual ASC/3 core software that operates under the OS. It incorporates all internal processing that occurs between the initially assigned field inputs passed from VISSIM and ensuing acquisition of actuated field outputs that are passed to VISSIM. This way one can ensure a high-level consistency in traffic control operation between the simulated ASC/3 SIL running under VISSIM and the physical controller. Lastly, Controller Front Panel Simulator is a Graphical User Interface (GUI) designed to simulate the 16 lines by 40 characters display and keypad found on the ASC/3-LX physical controller. This GUI permits the display of status and data along with the changing of all user data settings within the simulated ASC/3 controllers running under VISSIM, as seen in figure 2. Any changes made to the controller settings are stored in the simulated controller's database (Urbanik et al. 2010).

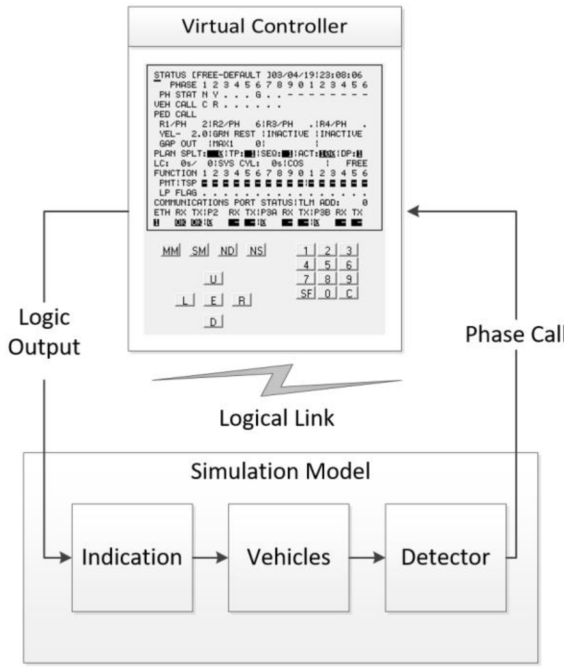

FIGURE 2: SIL interface

VISSIM has its own programming language with a graphical flowchart for defining custom signal operations and logic. It also offers another method of programming traffic signal control. This is called Vehicle Actuated Programming (VAP) and technically is template interfacing system where two files work in conjunction to enable a specific control set. The VAP control logic is described in a text file (*.VAP) using a simple programming language, while the VAP signal data set (*.PUA) contains the signal data. There is a third file with a *.DLL extension that interlinks the signal control. It is a structured programming language like C populated with specific functions relevant for researchers and traffic engineers alike. Some of these functions are available to collect detector pulses, occupancy rates, and the presence of vehicles. Furthermore, the display of signal groups and stages can be accessed. An actuated logic can be defined based on signal groups or based on stages and inter-stages to reflect national standards of signalization.

2.5 Automated Traffic Signals Performance Measures (ATSPMs)

Signal performance measures (SPM) are metrics created by third-party software relying on data retrieved from traffic signal devices. They depend on a communication link with the traffic controller, data obtained from the vehicle detectors and controller status. Since faster processors were integrated and the addition of Linux operating system (OS) on recent Advanced Traffic Controller (ATC), 2070 and NEMA controllers, they all provide the ability to log every controller event at high resolution, that is every tenth of a second. This is in comparison with the standard data collection method of a standard central system, that occurs every third of a second, as seen illustrated in Figure 3.

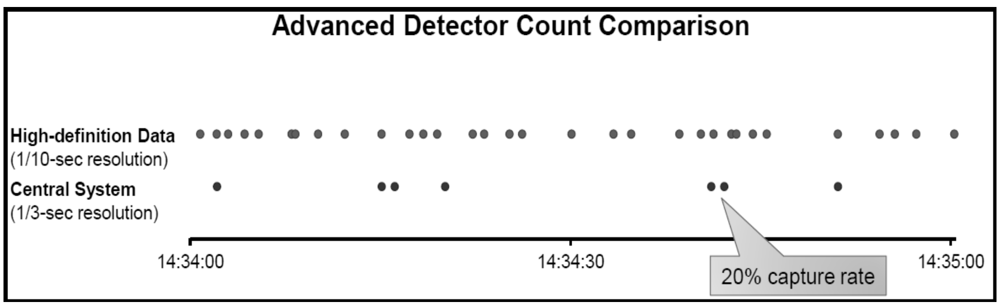

FIGURE 3: High definition logging vs standard [Sturdevant et al. 2012]

Traffic signal performance measures upgrade a system’s management potential by providing high-resolution data. They support maintenance and operations in order to improve safety and reduce congestion. ATSPM is FHWA’s terminology used to describe them. It is a set of metrics created to combine high-resolution data from traffic signal controllers and detectors along with data analysis techniques in order to provide graphical data outputs. ATSPMs can offer real-time and historical functionality at signalized intersections. They also allow traffic engineers to measure what was previously only attainable through modeling in simulation software. Concurrently, accurate decisionmaking about signal performance and timing helps signal management personnel identify vehicle and pedestrian detector malfunctions. ATSPMs are a cost-effective solution that can also measure vehicle delay as well as the volume, speed and travel time of vehicles, depending on the ITS technologies employed.

The logs contain events such as decision points packaged along with inputs and outputs as seen by the traffic signal controller. These event definitions have been standardized across manufacturers. Every controller event is logged with an intersection identifier, a timestamp, an event code (which is a standardized number for the type of event that occurred and provides specific detail for the event -which phase or detector channel triggered an event, which timing plan is starting, or what the split time for a phase is) and a parameter number.

Since traffic signal controllers are limited to an instantaneous shot of what just last happened, such as “car on loop detector sensor”, “pedestrian push button activation”, there always existed a need for collecting and using these logs in order to understand better traffic signal controller behavior for signal timing programming works from a traffic engineer’s perspective. This constitutes an evolution of what a central or Advanced Traffic Management System (ATMS) system always gave practitioners. It is a combination of detector data that relies on arrival data in combination with signal phase data. The operating mode can be seen illustrated as in Figure 4.

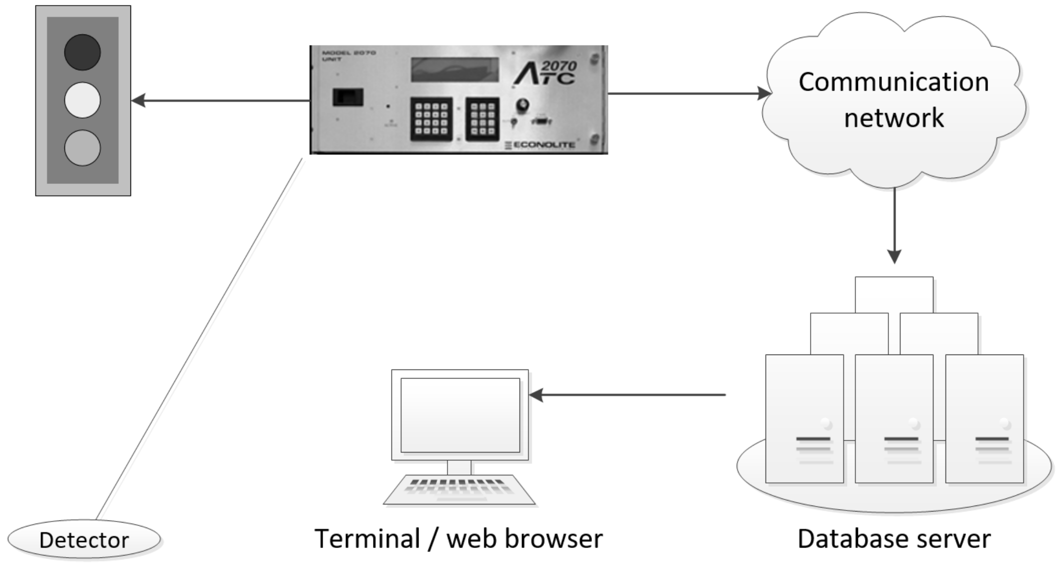

FIGURE 4: ATSPM system architecture

ATSPMs are a concept started in a collaborative effort in 2005 by Purdue University and the Indiana Department of Transportation (DOT). The goal was to develop new performance measures for traffic signals. The research was finalized in 2012 with a document named “Indiana Traffic Signal Hi Resolution Data Logger Enumerations” (Sturdevant et al. 2012). Immediately afterward this led the big names in the traffic signal controller manufacturing industry, such as Econolite, Trafficware, and Intelight, to implement the new standardized messages. Utah DOT took upon the task of developing an SPM software tool that automates the production of many of these metrics and translates it into a graphical output. An exemplification of an event log can be seen in Figure 5. The figure shows the contents of a *.DAT file with all the information collected by the traffic signal controller for a specific time period and a resultant metric in graphical format.

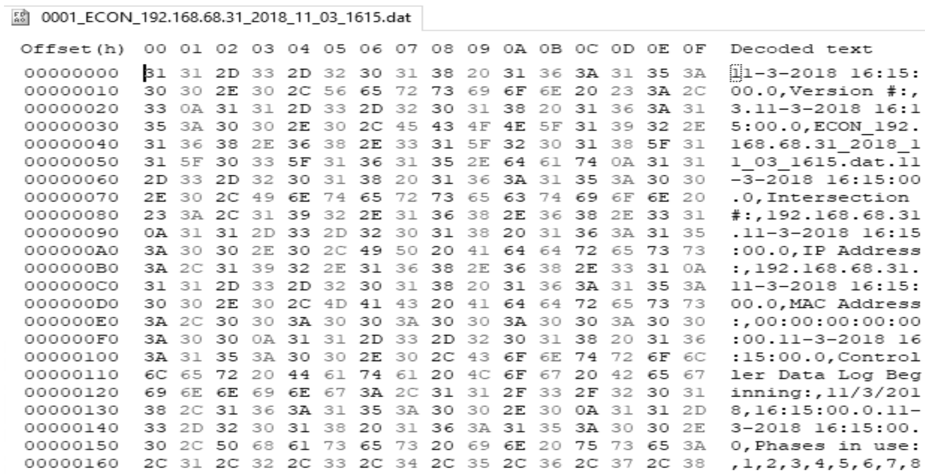

FIGURE 5: DAT file log example

There is a multitude of useful information that can be acquired via ATSPMs. According to Day et al. (2014), the following data output has been identified as attainable:

- Volume counts: an immensely important metric where advanced (upstream) of the intersection detection exists
- Phase time reallocation: as the majority of modern signals are actuated, any unused time from one phase can be given to the next or coordinated phase
- Emergency preemption data: the number of times the signal was preempted by an emergency vehicle
- Coordination improved because of timing changes: metrics such as arrivals on green versus arrival on red
- Max recall enabled: if a detector is broken or disconnected then the phase associated with it uses its maximum allocated time
- Ped push button is not working correctly: multiple consecutive actuations
- Vehicle platoon arriving patterns: the function of coordination offset parameter; closely bunched up arrivals on green in a phase are desirable

- Approach speed is slower: how does the speed differ in specific times of the day versus the traffic volume
- Time of day coordination patterns to serve direction specific: when coordinated phases begin and end as a function of morning/evening peak
- Approach delay: the core metric for obtaining the LOS at a signalized intersection. This relies on the advanced detectors sensing cars as they arrive in relation to when the signal turns green.

2.6 Bus and School Bus-related Microsimulation

Very few studies have looked at the role of buses, much fewer school buses, as standalone traffic entities. Most of them had to do with either the implementation or studying the integration of Transit Signal Priority for Bus Rapid Transit (BRT) systems. An example is a study performed by Yang et al. (2013) that looks at the implementation of a BRT line in the downtown area of Yingtan, a city located in the northeast of Jiangxi province, China. The research looks at the methods of prioritizing bus movements through three signalized intersections. The authors chose to calibrate their VISSIM model via observation of field travel speed versus the one from the simulation. The result was the proposal of two priority strategies that improved the BRT line efficiency from a stop delay point of view. The study has a couple of glaring omissions, chief among them not considering the effect on traffic signal coordination.

Zhang et al. (2012) researched bus calibration parameters in a different microsimulation environment (AIMSUN) using the Gipps safety distance car-following model. This study looked at the influence of bus signal priority strategies on the bus and overall traffic emissions. Based on information gathered from iBus’s database, the largest

Automatic Vehicle Location (AVL) system implemented by Siemens in London, U.K., the researchers focused on calibrating the dynamic characteristics of the busses: acceleration, deceleration and speed acceptance. In the end, it was found that actual bus acceleration rates differed significantly from the model default values, also causing a significant difference in emissions. One of the downsides is that inaccuracy of GPS speed recording data created a data set of unrealistic data.

Rahman et al. (2018) used probe data in corroboration with HERE maps data for calibration of bus speed acceptance to estimate that the heavy goods vehicle (HGV) and school bus speeds are very similar, thus creating a common speed distribution. The researchers also created an arterial speed distribution for the aforementioned classes of vehicles, where the standard deviation between them and regular passenger cars was calculated to be 5.31 mph. A noteworthy method was used for calibration: with the aid of multiple data collection points clustered per approach, the researchers verified the type and speed of the vehicle through the network.

While there has been previous research on the applicability of microsimulation software to solve the transportation problem, literature documents no efforts on school bus analysis by incorporating the following parametrization concepts: size, the power to weight ratio and power curve.

2.7 Summary of Literature Review and Limitations of Past Research

In the literature review, a brief description of traffic simulation tools, and more specifically microsimulation was presented. This was followed by an explanation of MOEs and their role in quantifying the level of service. Afterward, the evolution of the MOEs for traffic signals, ATSPMs was explained. ATSPMs are detection and traffic signal phasing metric outputs that can give practitioners a good understanding of the status of a signal or signal system. A review was also conducted to see if any studies dealt with school buses or at least transit ones in the past.

The findings gathered from the literature review indicate that not many researchers focused on the impact of buses, particularly school buses, on the performance of the transportation system. The few that touch upon it tangentially concentrate on the analysis of prioritizations methods for transit and BRT. The design and operational characteristics of school buses differ from transit buses. Additionally, their functionality is governed by additional enforcing rules such as no right-turn-on-red and stop at every railroad crossing. Such an analysis can only be performed by developing a dedicated well calibrated microsimulation model, that studies them specifically.

Furthermore, not many researchers explored and compared outputs from microsimulation driven analysis with signal performance measures or, for that matter, incorporated data collected from ATSPM to develop calibrated microsimulation models. This thesis contributes to the body of knowledge in a two-fold manner: first, by assessing the impact of school buses using microsimulation modeling software using accurately parametrized entities; secondly, it improves the analysis methodology by expanding upon the using the embedded VISSIM analysis using ATSPM-based performance measure metrics.

CHAPTER 3: SIMULATION MODEL DEVELOPMENT

In order to accurately evaluate the impact of school buses, a detailed and properly calibrated model was needed. This chapter goes over the process of building a microsimulation model of the signalized intersection corridor comprised of eight intersections. At the beginning of this chapter, the study area and its characteristics are presented. Subsequently, the details of the setup process are detailed: initial model buildout, traffic signal settings, virtual controller setup and communication, coordination, and analysis area. The model buildout follows the methodology detailed in the flowchart in Figure 6. A summary of the built model can be found at the end.

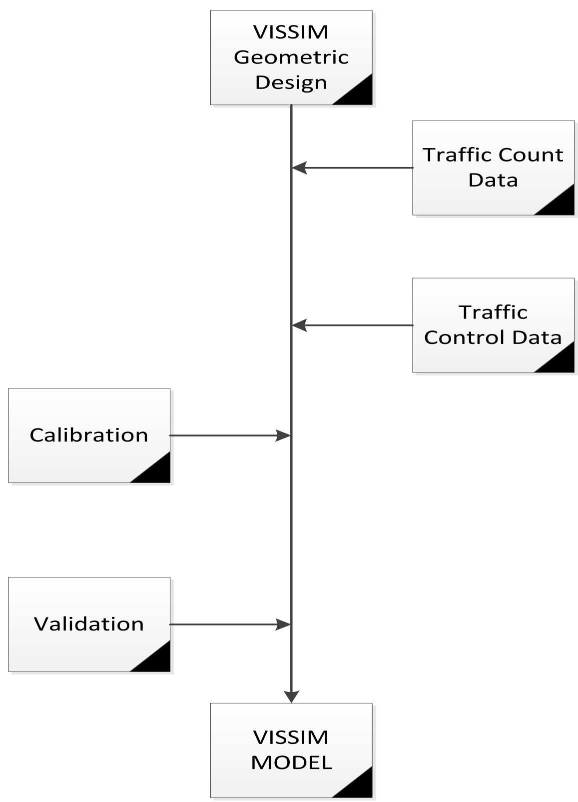

FIGURE 6: Model development flowchart

3.1. Study Area

The study area, in this case, was the George W. Liles Pkwy, located on the western side of the City of Concord, Cabarrus County, N.C. Interstate 85 (I-85) acts as the border-line between City of Concord and City of Kannapolis. This is a four-lane major arterial corridor with an average annual daily traffic (AADT) of more than 30,000 vehicles. This more than two-mile traffic signal coordinated section stretches from Glen Afton Blvd, in Kannapolis to the North to Weddington Rd in the South, in Concord. Figure 7 depicts the chosen area and where the eight intersections are located on the corridor alongside with their state signal identification number and name. Table 2 confers the full list of intersections.

TABLE 2: Intersection listing

State ID	Intersection name
1951	Kannapolis Pkwy / Glen Afton Blvd
1713	Kannapolis Pkwy / I- 85 SB Ramp
1712	George W. Liles Pkwy / I-85 NB ramp
2127	George W. Liles Pkwy / Village Dr
1499	George W. Liles Pkwy / Poplar Tent Rd
2153	George W. Liles Pkwy / Poplar Crossing Loop Rd
2203	George W. Liles Pkwy / Laurel View Dr
1500	George W. Liles Pkwy / Weddington Rd

This is a mixed arterial corridor with two major intersections with over 25000 AADT (Poplar Tent Rd / Weddington Rd), two I-85 Freeway ramp intersections (1712- George Liles Pkwy / I-85 NB Ramp and 1713- Kannapolis Hwy / I-85 SB Ramp) that are major feeders of traffic, a major shopping center intersection (1951 – Kannapolis Hwy / Glen Afton Blvd.) as well as couple of small ones placed at the entry of residential neighborhoods (George W. Liles Pkwy / Poplar Crossing Loop Rd and George W. Liles

Pkwy / Laurel View Dr.) that were not significant traffic generators. Due to the diverse build of this corridor, the current delay varies from one intersection to another and have a different LOS currently, ranging from LOS A to LOS D.

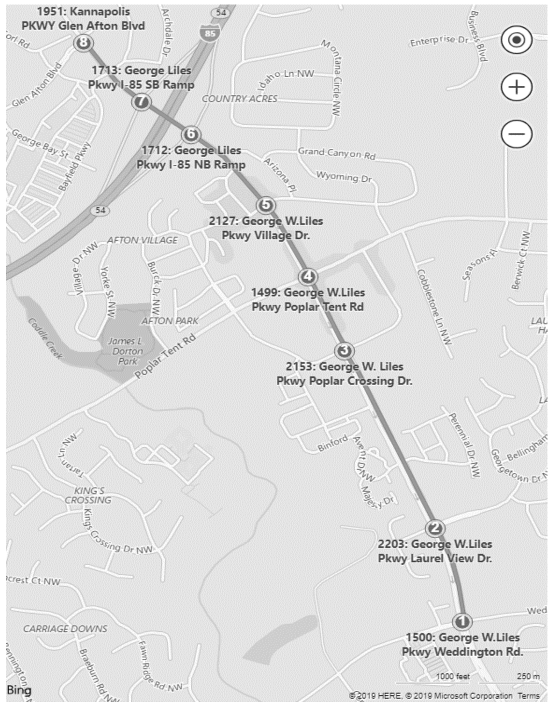

FIGURE 7: Research study area/corridor

3.2. Chosen Tools

In order to perform the analysis, the following set of tools was employed. VISSIM was used to create the simulation model geometric design. For replicating the traffic signal behavior, the SIL implementation was used. City of Concord's Econolite Centracs ATMS was used to transfer the traffic signal controller data such as detector configuration and perform validation of the operation for coordination patterns. Finally, in the data analysis procedure where the outputs had to be compared, a prototype ATSPM solution was used alongside the internal analysis tools that VISSIM provides.

Afterward, the traffic signal control part had to be modeled using data from the signal plans. Instead of using the editor part of VISSIM, the virtual traffic controllers were integrated into Centracs. In order to be able to make sure that the same data is parametrized, the ATMS was used for downloading the configuration and performing a database configuration check. The added advantage was that coordination transitions can be monitored using the ATMS.

3.2.1. VISSIM

A large portion of the process presented in this thesis involved the construction of a simulated network in VISSIM that reflected as closely as possible the field conditions experienced during the data collection period. VISSIM is used to model personal motorized private transport, public transport in road and rail form, goods transport as well as pedestrian and cyclists. Its main differentiating characteristics are that it is a behavior-based simulation program that has a user-configurable time-step (PTV AG, 2018). It was chosen due to available embedded multiple analysis tools, where possible outputs include:

- MOEs such as volume, mean speed, travel time, delay, queue length, number of stops, and time-space-diagrams
- vehicle emissions in terms of as carbon monoxide, dioxide, nitrates, and nitrites
- signal control data such as minimum, maximum and average green time per signal group/phase, waiting time after detector calls and display of dynamic signal timing plans.

3.2.2. ATSPM

Some of the analysis was performed using the ATSPM software. This measures the performance of a network with a function of metrics that rely on arrivals. This process relies on detection and signal phase and timing logs that the virtual controller stores locally for every 15 minutes of activity. These logs are combined into a hexadecimally encoded file with *.DAT extension. The log files that were a result of the VISSIM simulation were uploaded in the ATSPM software.

Out of all possible types of metrics that the ATSPM solution can output, the Purdue Coordination diagram was chosen for this study. This is a two-dimensional graphical output, where the time of day is represented on the X-axis and the time in the signal cycle is shown on the Y-axis, that visually shows the quality of progression through an intersection or along a signalized arterial corridor (Day et al. 2014). It can graphically represent vehicles arrivals per the corresponding instance in the signal cycle, thus allowing a visual confirmation if vehicles arrived on green or red.

3.2.3. ASC/3 Software-in-the-Loop simulation environment

Since all of the intersections located on this corridor are running ASC/3 software, the ASC/3 SIL interface was chosen to perform a simulation with. In order to simulate the behavior for each traffic signal controller, a SIL instance was used for each intersection, for a total of eight. As stated above when comparing the types of controller emulation, this solution was preferable due to not tying in multiple hardware resources as well as having the capability to perform multiple simulation steps per second.

However, there were configuration steps needed to be performed, for each of them to understand that it was a single entity. Due to the simulation running on a single very high-performance computer workstation, a solution needed to be employed to deceive the system into believing it was dealing with more. The employed solution involved each virtual controller needing to be parametrized with its own (User Datagram Protocol) UDP port, referencing the same (Internet Protocol) IP address, as seen exemplified in Figure 8.

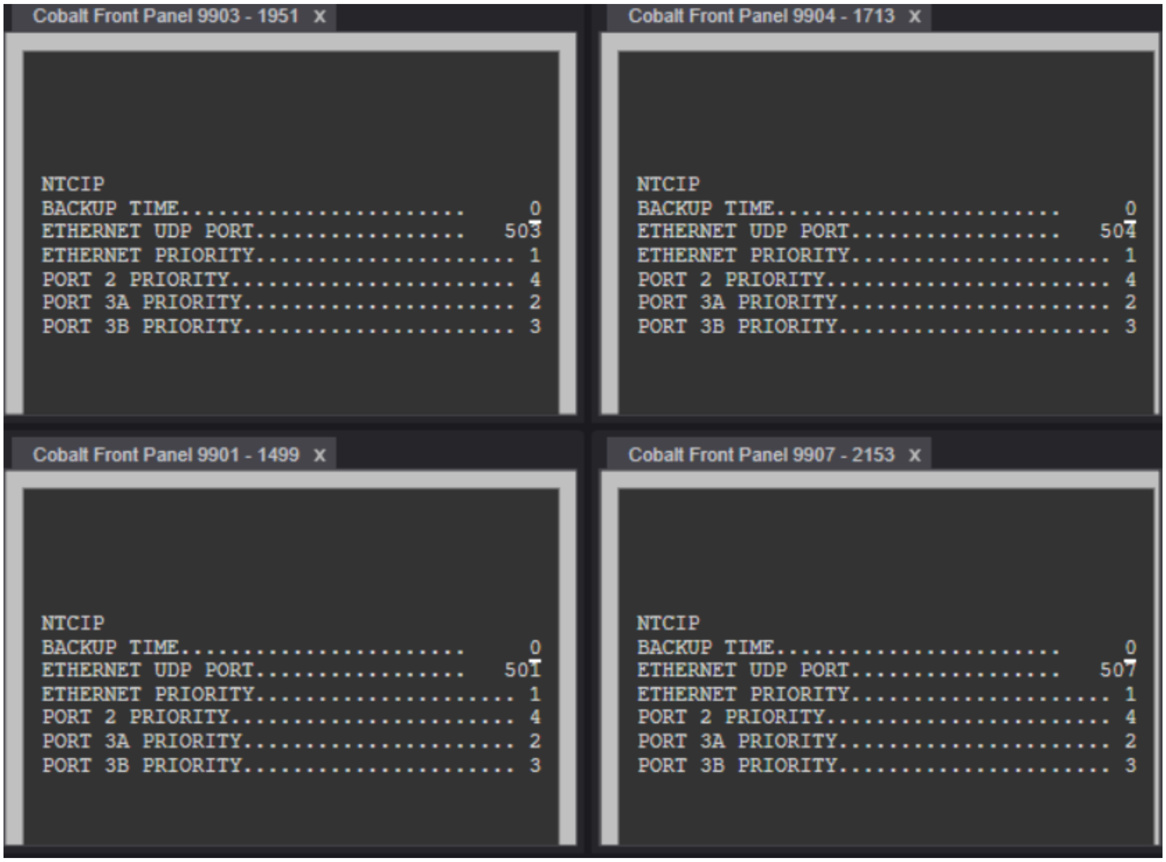

FIGURE 8: Virtual controller parametrization

It meant that the communication with the entire network of virtual controllers was performed in parallel. This was validated by employing a software package that captured packets to confirm the process. Figure 9 illustrates a sequence of data packages being transferred to and from one of the virtual controllers.

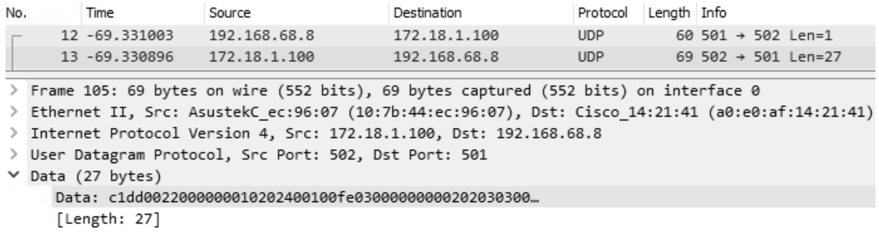

FIGURE 9: UDP packages transfer functionality

3.2.4. Advanced Traffic Management Software

Once communication was established with the virtual controller SIL instance, the signal programming and coordination were integrated with the aid of the City of Concord's ATMS software, Centracs. A separate signal cluster was created for these eight virtual entities. This was partly done to be able to easily transfer the actual intersections configurations, bypassing the manual entry via the aforementioned Signal Editor component of ASC/3 SIL. Performing this action considerably reduced the chances of programming data input error. This alternative was also chosen due to the embedded ATMS compiler that offered a validity check for the data downloaded into the SIL instance.

This method of integration also offered a chance to visually check the coordination transitions and actions that happened in synchronization such as detection actuations. It also offered the possibility of validating the virtual control by assigning vehicle calls and checking the functionality of the traffic signal from a centralized location. Figure 10 shows the virtual controller front panel instances as visualized from the ATMS.

FIGURE 10: Virtual controllers integrated in ATMS

3.3. Methodology

For the purposes of this experiment, the George W. Liles Pkwy corridor was built using VISSIM version 10.00-14. Initially, the geometric model had to be developed using the modeling software. The virtual controllers had to be created and their instances deployed. They were configured to acquire detection data from their instances in VISSIM and communicate with the ATMS. All had the same IP address as the simulation workstation. In order to ensure communication was established the UDP port was the distinguishing parameter. This communication uses the National Transportation Communications (NTCIP) protocol which is a joint AASHTO, ITE and NEMA created family of standards. For this specific task, NTCIP 1202 was employed. This makes use of the Simple Network Management Protocol (SNMP) at the application level and UDP at the transport level. UDP implementation instead of TCP/IP is intended to reduce the number of retransmissions since traffic signal controller communication is a real time application (NTCIP, 2016).

Afterward, the general functionality and detection part had to be modeled using data from the signal plans. Instead of using the editor part of the virtual controller, functional configuration of the virtual traffic controllers was performed via the Centracs ATMS. This was used for downloading the configuration and performing a database configuration check in order to be able to make sure that the same data is used in the model. The added advantage is that coordination transitions can be monitored using the ATMS.

Since this study dealt with new school buses influence, a preliminary forecast of the expected numbers had to be performed. West Cabarrus High School is intended to be the largest one in the county, a fact illustrated by the building plans that call for a three-story structure capable of housing almost 2000 students. While the districts have not been yet fully determined, a preliminary discussion with the Cabarrus County Schools district planners about the possible number of buses indicated that the expected number is in between 15 and 20. This research used a median estimate of 17 new school buses.

3.3.1. Geometric design

There were two practical alternatives available for creating the geometrical design of the network: either create it from scratch or import an existing layout from another simulation software, such as Trafficware's Synchro suite. Even though the first option was not appealing considering the number of man-hours it would have required simply to create the network geometry, this step was chosen in the absence of an existing corridor model as well as for ensuring a current and accurate representation of the current condition. In order to complete this part of the process, the following actions needed to be performed:

- insert links and connectors for all approaches and intersection movements
- check the number of lanes on each approach and each turning movement
- create turn radii to follow actual travel paths
- insert vehicle inputs
- check routing decisions to ensure there are no broken connections
- set desired speed decisions to the observed speeds
- install and position reduced speed areas on intersection turning movements,
- deploy stop signs for right-turn-on-red (RTOR) instances, where the signal displayed a red ball instead of an arrow
- employ yield setups that ensure proper right-of-way is applied.

Figure 11 shows an example of an intersection layout, namely George W. Liles Pkwy / Poplar Tent Rd, created in VISSIM displaying the links, connectors, reduced speed areas alongside with the detection and visual representation of the signal heads. Network geometry data, including the number of lanes, lane widths, and traffic signal configuration were retrieved from traffic signal plans and schematics provided by the City of Concord DOT. With the geometry and simulation elements set, the next step was to adjust the signal timings and volumes to match the morning (AM) and evening (PM) peak periods.

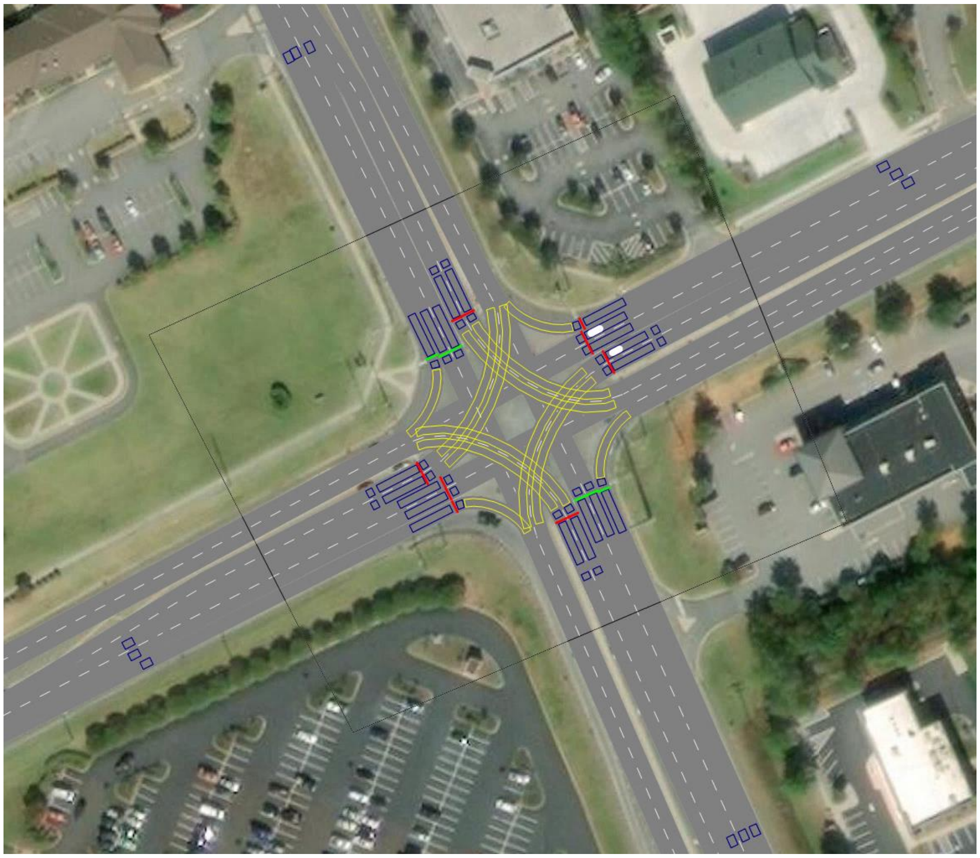

FIGURE 11: Intersection layout

3.3.2. Vehicle Composition

Four vehicle types were chosen for the model. Due to VISSIM being primarily developed in Europe, the default vehicle fleet was not applicable to this model. The default settings for passenger cars were changed to reflect common vehicles in the area, with an accent on pickup trucks and large sport utility vehicles (SUV). The default 33.5 ft EU-04 and 28.9 ft EU-05 HGV were not selected for use in the model. In their place, a field measured the composition of 45 ft length WB-40, 55 ft WB-50, and 73 ft WB-67 were chosen to accurately represent the traffic encountered in this corridor. These changes can be seen reflected in Figure 12.

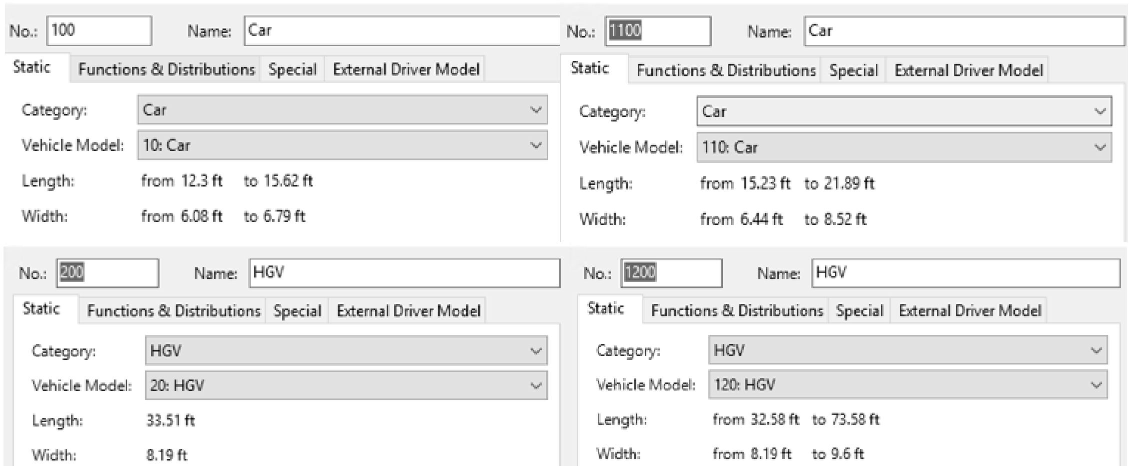

FIGURE 12: Vehicle composition adjustment

3.3.3. Traffic Signal Control Parametrization

Adding traffic control devices was a two-step process. First, signal controllers had to be created and specific timing for the signal group phases are entered. Afterward, signal heads were placed at the intersections and the applicable signal controller number and signal group phase was assigned to that specific head. The cars that were turning right on red were not affected by the signal head placement. This behavior was modeled with stop control signs with the RTOR option turned on.

Vehicle detectors were set to communicate with the appropriate signal controller, and they were labeled according to the nomenclature established by the signal plans. The detectors were named according to the NEMA phase that they were calling with a nomenclature that called for a leading signal ID number: Phase 8 from Signal 1 was named 1951_Phase8. The type of detector was kept in line with the field ones, as advance detectors were set for a pulse while the stop bar ones were set for presence.

The phase sequence page was checked as well as the timing plans and phase compatibility. Detector logging was enabled in order to produce viable outputs later used in the ATSPM instance, as seen in Figure 13.

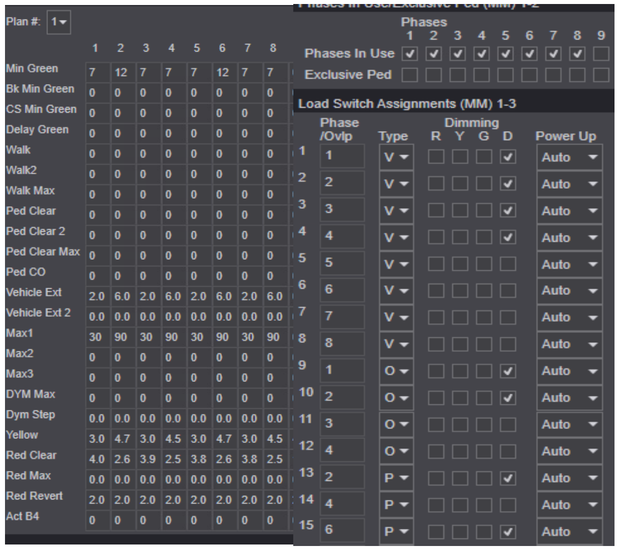

FIGURE 13: Signal controller parametrization example

3.3.4. Vehicle Inputs

Before calibrating the model, vehicular volumes had to be input. Normally, a Poisson distribution is used for the times when a vehicle enters the network. The user can choose whether these arrival times will be determined entirely before the start of the simulation, to allow for the exact number of vehicles. Typically, in microsimulations, origin to destination (O-D) matrices are most commonly used. In this case, an approximation of the volumes was the basis for this model. Instead of using dynamic assignment, the latest (field collected) data volumes with turning movement count data was used with the static decision tool in VISSIM. The procedure that was used to create routing decisions was similar to the one employed for creating connectors. For each link entering an intersection, the permitted movements (right-turn, left-turn, and through movement) had to be defined at that intersection for approaching vehicles.

Hourly volume counts collected with the ATSPM system were used. This data was generated with the advanced detectors placed upstream of the stop line on the main approaches for every intersection. Turning movement count (TMC) ratios were kept the same throughout the corridor.

The two most important intersections on the corridor, George W. Liles Pkwy / Poplar Tent Rd and George W. Liles Pkwy / Weddington Rd, had more advanced video detection systems, capable of emulating areas for performing turning movement counts, as seen in Figure 14.

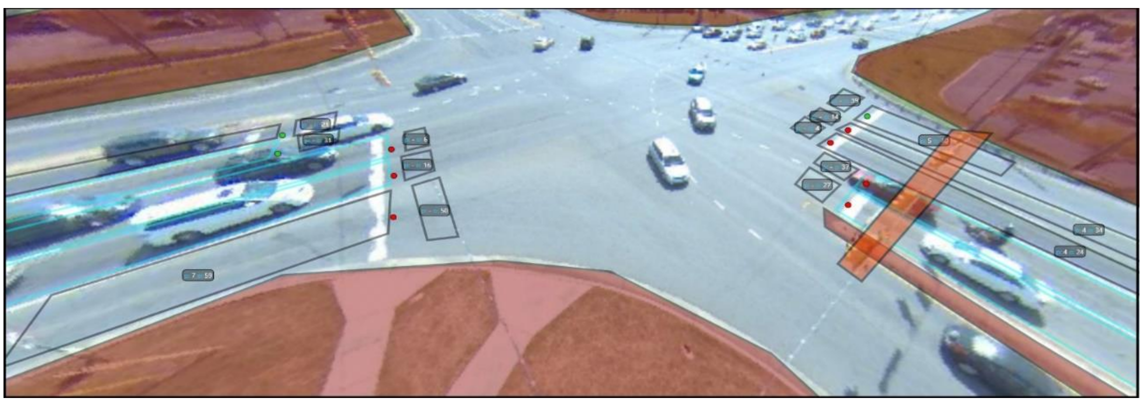

FIGURE 14: Video detection areas

As the majority of the intersections offered just presence style stop-bar detection for the side street, as opposed to advance detectors which run in pulse mode, getting an accurate volume was nearly impossible. This data then was approximated to the nearest 5% for the other six intersections. The collected hourly traffic volume data for these intersections can be seen in the Excel tables compiled in Appendix A. The results of the turning movement counts, made possible by the video detection system at the two major intersections were compiled in figures 15 and 16.

Study Name 1499 - Weddington School Effect
Start Date Wednesday, February 13, 2019 6:30 AM
End Date Wednesday, February 13, 2019 6:00 PM
Site Code

Report Summary

		Southbound						Westbound						Northbound						Eastbound						
Time Period	Class.	R	T	L	U	I	O	R	T	L	U	I	O	R	T	L	U	I	O	R	T	L	U	I	O	Total
Peak 1	Lights	471	1441	524	0	2436	2185	360	476	187	0	1023	1525	467	1439	491	0	2397	1829	201	534	386	1	1122	1439	6978
Specified Period	%	100%	99%	98%	0%	99%	99%	98%	98%	98%	0%	98%	98%	99%	99%	99%	0%	99%	99%	100%	98%	100%	100%	99%	99%	99%
6:30 AM - 9:30 AM	School Buses	0	2	4	0	6	4	2	11	3	0	16	16	5	2	0	0	7	5	0	7	0	0	7	11	36
One Hour Peak	%	0%	0%	1%	0%	0%	0%	1%	2%	2%	0%	2%	1%	1%	0%	0%	0%	0%	0%	0%	1%	0%	0%	1%	1%	1%
8:15 AM - 9:15 AM	Trucks	2	16	6	0	24	23	5	1	1	0	7	9	1	18	4	0	23	17	0	2	0	0	2	7	56
	%	0%	1%	1%	0%	1%	1%	1%	0%	1%	0%	1%	1%	0%	1%	1%	0%	1%	1%	0%	0%	0%	0%	0%	0%	1%
	Total	**473**	**1459**	**534**	**0**	**2466**	**2212**	**367**	**488**	**191**	**0**	**1046**	**1550**	**473**	**1459**	**495**	**0**	**2427**	**1851**	**201**	**543**	**386**	**1**	**1131**	**1457**	**7070**
	PHF	0.8	0.89	0.77	0	0.84	0.86	0.82	0.76	0.72	0	0.82	0.78	0.88	0.81	0.81	0	0.84	0.89	0.68	0.77	0.75	0.25	0.78	0.91	0.9
	Approach %					35%	31%					15%	22%					34%	26%					16%	21%	
Peak 2	Lights	218	2205	338	0	2761	3099	481	1382	297	0	2160	2086	361	2306	412	0	3079	2819	317	1387	312	0	2016	2012	10016
Specified Period	%	99%	98%	96%	0%	98%	99%	98%	99%	97%	0%	99%	99%	98%	99%	99%	0%	99%	98%	99%	99%	98%	0%	99%	99%	99%
2:00 PM - 6:00 PM	School Buses	2	4	4	0	10	7	4	8	9	0	21	14	5	2	0	0	7	13	0	5	1	0	6	10	44
One Hour Peak	%	1%	0%	1%	0%	0%	0%	1%	1%	3%	0%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
5:00 PM - 6:00 PM	Trucks	0	31	9	0	40	33	4	2	0	0	6	17	1	25	3	0	29	35	4	7	4	0	15	5	90
	%	0%	1%	3%	0%	1%	1%	1%	0%	0%	0%	0%	1%	0%	1%	1%	0%	1%	1%	1%	1%	1%	0%	1%	0%	1%
	Total	**220**	**2240**	**351**	**0**	**2811**	**3139**	**489**	**1392**	**306**	**0**	**2187**	**2117**	**367**	**2333**	**415**	**0**	**3115**	**2867**	**321**	**1399**	**317**	**0**	**2037**	**2027**	**10150**
	PHF	0.9	0.91	0.92	0	0.95	0.91	0.89	0.88	0.86	0	0.91	0.93	0.62	0.9	0.86	0	0.87	0.93	0.97	0.88	0.98	0	0.96	0.94	0.94
	Approach %					28%	31%					22%	21%					31%	28%					20%	20%	

FIGURE 15: George W. Liles Pkwy – Poplar Tent Rd. traffic volume data

Study Name 1500 - Weddington School Effect
Start Date Wednesday, Febraury 13, 2019 6:30 AM
End Date Wednesday, February 13, 2019 6:00 PM
Site Code

Report Summary

		Southbound						Westbound						Northbound						Eastbound						
Time Period	Class.	R	T	L	U	I	O	R	T	L	U	I	O	R	T	L	U	I	O	R	T	L	U	I	O	Total
Peak 1	Lights	151	441	324	0	916	1210	360	169	62	0	591	565	61	634	100	0	795	557	54	180	216	1	451	421	2753
Specified Period	%	99%	96%	97%	0%	97%	98%	98%	98%	94%	0%	98%	96%	91%	97%	96%	0%	96%	96%	100%	97%	100%	100%	99%	98%	97%
6:30 AM - 9:30 AM	Buses	0	1	4	0	5	4	2	3	3	0	8	12	5	2	0	0	7	4	0	3	0	0	3	3	23
One Hour Peak	%	0%	0%	1%	0%	1%	0%	1%	2%	5%	0%	1%	2%	7%	0%	0%	0%	1%	1%	0%	2%	0%	0%	1%	1%	1%
8:15 AM - 9:15 AM	Trucks	2	16	6	0	24	23	5	1	1	0	7	9	1	18	4	0	23	17	0	2	0	0	2	7	56
	%	1%	3%	2%	0%	3%	2%	1%	1%	2%	0%	1%	2%	1%	3%	4%	0%	3%	3%	0%	1%	0%	0%	0%	2%	2%
	Total	**153**	**458**	**334**	**0**	**945**	**1237**	**367**	**173**	**66**	**0**	**606**	**586**	**67**	**654**	**104**	**0**	**825**	**578**	**54**	**185**	**216**	**1**	**456**	**431**	**2832**
	PHF	0.8	0.89	0.77	0	0.84	0.86	0.82	0.76	0.72	0	0.82	0.78	0.88	0.81	0.81	0	0.84	0.89	0.68	0.77	0.75	0.25	0.78	0.91	0.9
	Approach %					33%	44%					21%	21%					29%	20%					16%	15%	
Peak 2	Lights	218	702	338	0	1258	1110	318	182	67	0	567	610	59	542	62	0	663	839	70	213	250	0	533	462	3021
Specified Period	%	99%	97%	96%	0%	97%	98%	98%	96%	88%	0%	96%	96%	91%	98%	95%	0%	97%	96%	95%	97%	98%	0%	97%	97%	97%
2:00 PM - 6:00 PM	Buses	2	4	4	0	10	7	4	8	9	0	21	14	5	2	0	0	7	13	0	5	1	0	6	10	44
One Hour Peak	%	1%	1%	1%	0%	1%	1%	1%	4%	12%	0%	4%	2%	8%	0%	0%	0%	1%	1%	0%	2%	0%	0%	1%	2%	1%
5:00 PM - 6:00 PM	Trucks	0	21	9	0	30	16	4	0	0	0	4	11	1	8	3	0	12	25	4	1	4	0	9	3	55
	%	0%	3%	3%	0%	2%	1%	1%	0%	0%	0%	1%	2%	2%	1%	5%	0%	2%	3%	5%	0%	2%	0%	2%	1%	2%
	Total	**220**	**727**	**351**	**0**	**1298**	**1133**	**326**	**190**	**76**	**0**	**592**	**635**	**65**	**552**	**65**	**0**	**682**	**877**	**74**	**219**	**255**	**0**	**548**	**475**	**3120**
	PHF	0.9	0.91	0.92	0	0.95	0.91	0.89	0.88	0.86	0	0.91	0.93	0.62	0.9	0.86	0	0.87	0.93	0.97	0.88	0.98	0	0.96	0.94	0.94
	Approach %					42%	36%					19%	20%					22%	28%					18%	15%	

FIGURE 16: George W. Liles Pkwy – Weddington Rd. traffic volume data

3.3.5. Traffic Signal Coordination

According to FHWA's Traffic Signal Timing manual, traffic signal coordination, in essence, constrains the local traffic signal controller to a timing plan that achieves the operational objective of corridor progression, thus resulting in fewer stops along the corridor. There are three foundational parameters that characterize a coordinated signal system: cycle length, offset and split. The first one constrains the time required for complete sequence of indications, the second one defines the time relationship between coordinated phases as consecutive intersections, while the third one defines the time allocated for each phase (NCHRP 812, 2015).

As mentioned initially, this is a functionally coordinated arterial corridor. There are multiple coordination plans running through the day to reflect the changing traffic patterns: morning peak, evening peak, and midday peak. Thus, parametrizing the model to reflect the above patterns was an important item that needed to be performed on the simulated corridor. As seen in the attached ATSPM output image in Figure 17 from the George W Liles Pkwy / Poplar Tent Rd intersection, the corridor runs multiple coordination patterns throughout the analyzed time frames. The morning school bus peak was exclusively in coordination plan 2, while the afternoon peak occurs starting in plan 12 and ending in plan 15. All of them have the same cycle time of 140 seconds, with the key differentiator being the offset, which prioritizes directional progression. Not all coordination plans can be observed throughout the whole corridor as some intersections display specific signal timing characteristics.

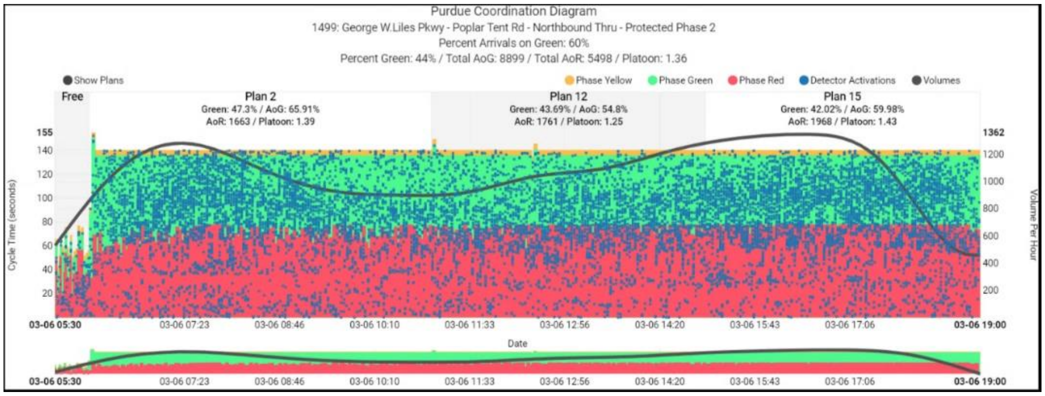

FIGURE 17: George W. Liles Pkwy / Poplar Tent Rd coordination patterns

After all the inputs had been calibrated, the model was run under various conditions to ensure it would stay at equilibrium for the entire duration of the School morning and evening peaks simulation. This was determined by analyzing the number of vehicles in the network, using numerous data collection points through the network.

3.3.6. Emissions Comparison Setup

The fully calibrated and validated VISSIM model was used to estimate vehicle emissions in two categories: Nitrous oxides (NOx) and Carbon Monoxide (CO). Node evaluations in VISSIM produce values that are average values over an area, which is defined by the selected nodes. Specific areas were demarcated by nodes drawn around the intersections of the eight intersections. Seven school bus morning and evening peak hour simulation runs were conducted for each site location for both conditions during both the peak periods.

CHAPTER 4: MODEL CALIBRATION

Chapter 4 presents the model calibration stage, the process by which the input parameter values of a simulation model are adjusted until they accurately replicate the observed and in this case field-measured traffic conditions. This followed the calibration model methodology created by the FHWA in the following two documents: Traffic Analysis Toolbox Volume III and Volume XIV, as seen in Figure 18.

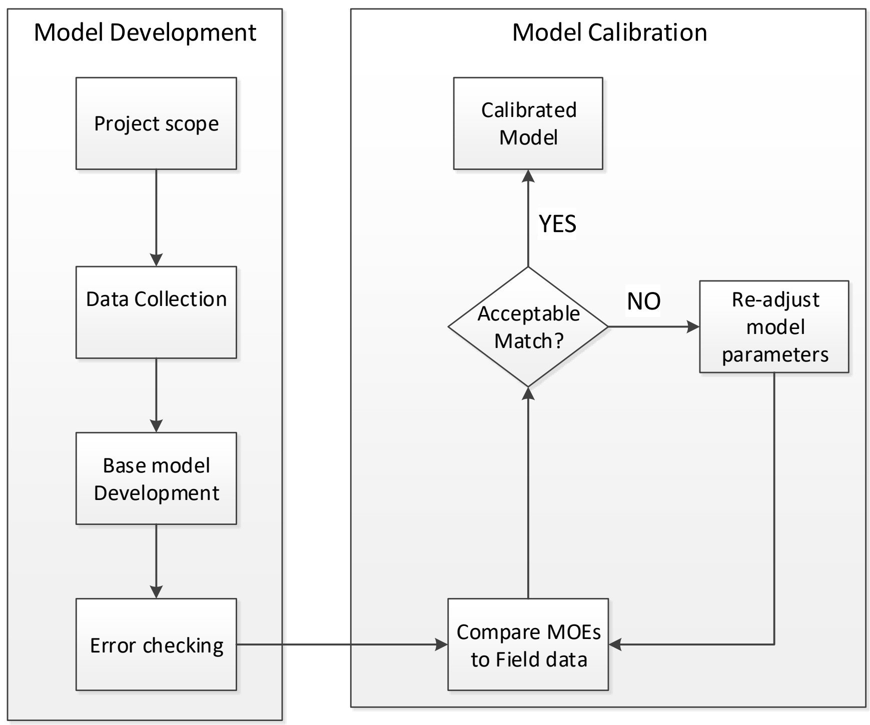

FIGURE 18: Calibration procedure

4.1. Calibration Parameters

In order to properly calibrate the model, one has to tweak each of these factors: driver behavior, control devices or demand modeling. Driver behavior is a critical characteristic that can be simulated in VISSIM. This is broken down into multiple categories: lane-changing model, lateral placement model, reaction to signal control and car-following model, as seen in Figure 19.

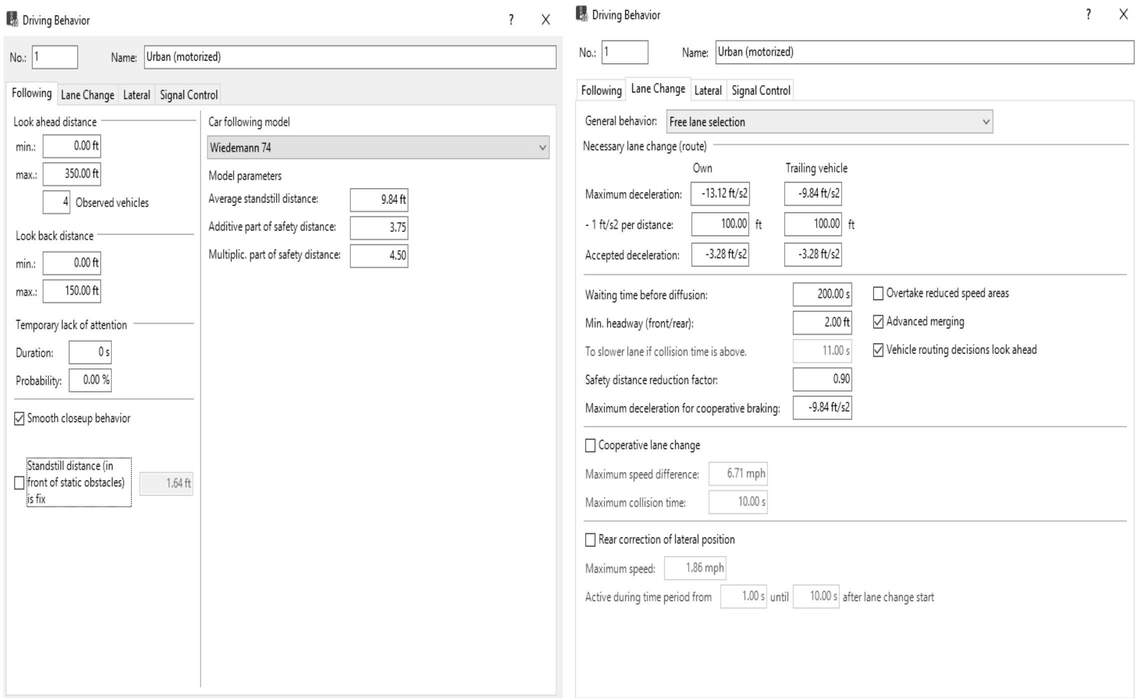

FIGURE 19: Wiedemann 74 adjusted driver behavior parameters

VISSIM employs two adjustable versions of the Wiedemann car-following and lane-changing behavior models. One pertains to freeways (Wiedemann 99) and the other urban roads (Wiedemann 74). They were both built by Professor Rainer Wiedemann, one in 1974 and one in 1999. Since this was an exercise involving an arterial corridor, the latter was used. Besides the recommended three main tunable parameters, parameters in this "psycho-physical" model, an additional 3 of them were identified as important ones and had to be changed. These were: minimum headway (front/rear), safety distance reduction factor, and maximum deceleration. The new chosen values of the calibration parameters are summarized in Table 3.

TABLE 3: Driver behavior calibration parameters

Parameter	Default	New Value
Average standstill distance	6.56 ft	7.84 ft
Additive part of safety distance	2 ft	3.75ft
Multiplicative part of safety distance	3 ft	4.5ft
Minimum headway (front/rear)	1.64 ft	2ft
Safety distance reduction factor	0.6 ft	0.9 ft
Maximum deceleration	13.12 ft/s^2	15 ft/s^2

Initial calibration was based on peak school bus traffic times divided into two slots: school morning peak containing the 6 to 9 AM time interval, one that coincides with the morning peak period, and school evening peak, 2 to 6 PM, one that captures a large amount of the evening peak period. Turning movement counts and vehicle classification were used, where available. Mainline traffic volumes were obtained from the ATSPM deployment via the advanced detectors. Entering traffic demand, speed decisions, priority rules, and reduced speed areas was performed in such manner as to match an exact field representation.

In order to represent the school bus characteristics, the PTV provided AASHTO 40 and 45 V3D models were loaded. This introduced scaled vehicular entities into the model. Appropriate dynamic and power characteristics were applied based on the Cummins ISB diesel engine specifications and power curve, as this is the most encountered type in Cabarrus County as well as throughout the state. This was an upgrade and it came in stark contrast to how researchers had to parametrize a specific class of vehicles over the years; namely using a structured text file that needed to be input in a specific format via VISSIM's COM interface.

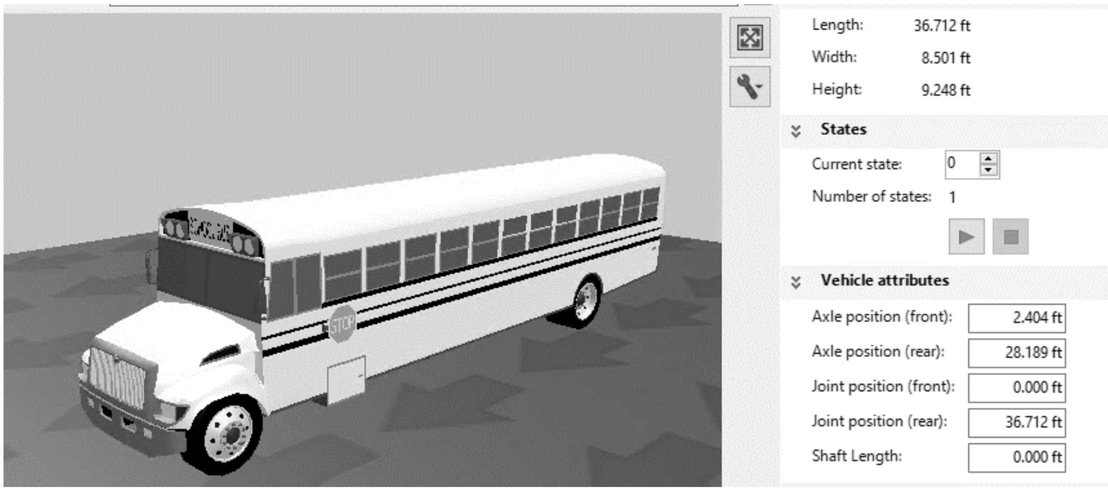

FIGURE 20: Parametrized AASHTO 40 school bus model

Another important calibration step was choosing the right types of speed for the right types of vehicles. This step included the creation of turning speeds with distributions based on field measured. Figure 21 looks at the right and left turning speed distributions as declared.

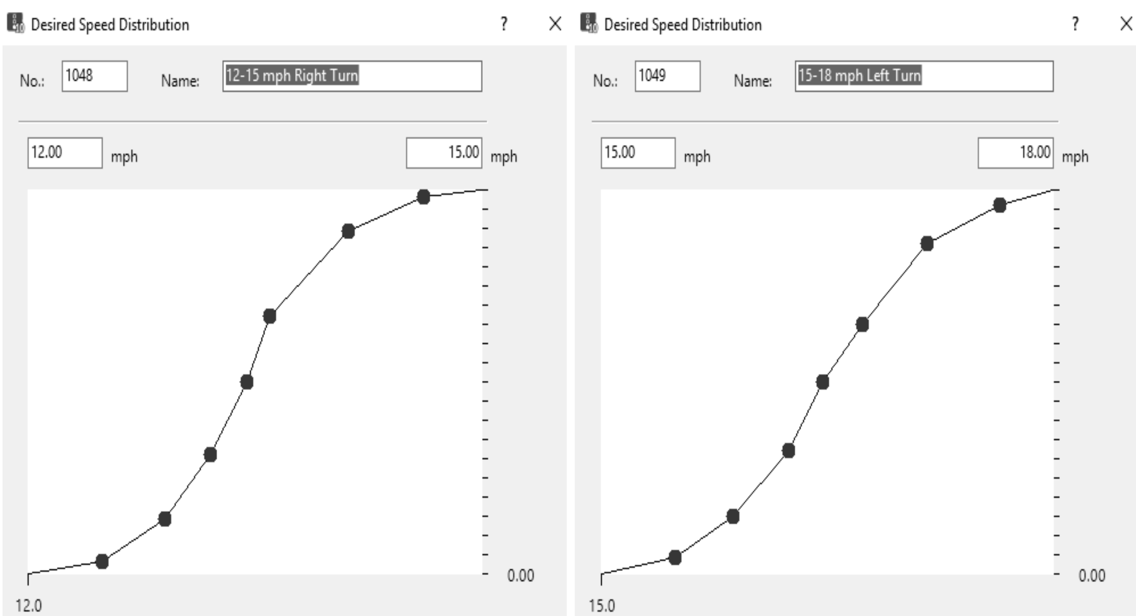

FIGURE 21: Vehicle turning speed distribution

Figure 22 shows the two default speed distributions established for the creation of this model: a 35 mph that applies to school buses and a 45 mph for all other traffic participants.

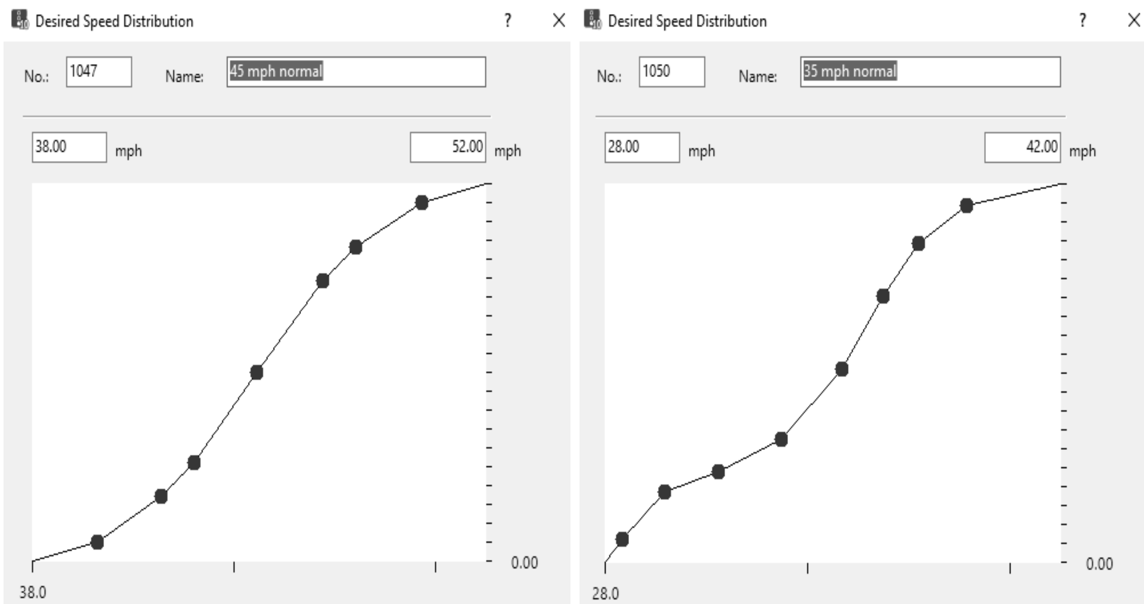

FIGURE 22: Vehicle speed distributions

4.2. Data Collection

The simulation was ready to be started after the modeled network was created. Nonetheless, an unparameterized simulation provides simply a visual representation of the system unless a specific set of outputs were specified. VISSIM is capable of generating output data in the following categories: travel times, delay times, queue lengths, green time distribution, specific vehicle information, etc. Thus, the evaluation was set to generate output data in the aforementioned categories, as seen in Figure 23. Likewise, all the virtual controllers were set for logging detection data for later input into the ATSPM system.

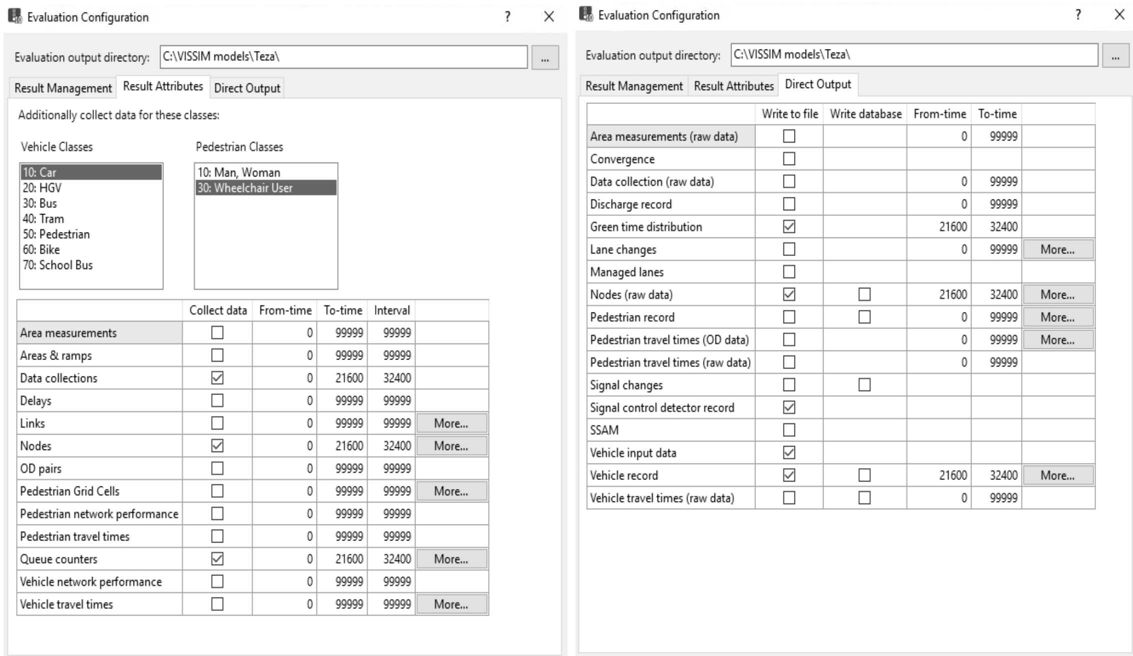

FIGURE 23: VISSIM data collection setup (AM Period)

4.3. Seeding and Initialization

The final step was to determine the seeding period, otherwise called initialization period, since the VISSIM model starts with no vehicles in the network, which was not representative to the either of the periods intended to be analyzed. Thus, a buffer time period had been added onto the beginning of the simulation period in order to allow vehicles to populate the network by the time specified in the data collection periods. Generally, going by the recommendations from the FHWA's Traffic Analysis Toolbox, the chosen network seeding time should be equal to or greater than twice the estimated travel time at free-flow conditions to travel the entire network (VDOT, 2015). However, due to the number of the intersections present in the network and sheer complexity of the model, a seeding time of 30 minutes was chosen.

CHAPTER 5: SIMULATION RESULTS AND ANALYSIS

This chapter covers the obtained results. For the purposes of this evaluation, VISSIM was coded to perform node analysis in the following categories: intersection performance in terms of delay and queue lengths, signal changes, and overall network performance. The results were collected for each scenario and then compared.

5.1. VISSIM Analysis Based Outputs

The obtained results were tabulated, and the outputs were graphed. As previously mentioned, seven runs at different random seed values were executed for each of the school peak time slots: 6:30 AM to 9:30 AM and 2:00 PM to 6:00 PM. The results that are included below rely on the mean value of each and are broken down into two sections: morning school peak and evening school peak results for their respective time slots.

5.1.1. School morning peak period

In this part of the analysis, the results for the morning peak period are presented. The output constitutes of five charts that show the operational impact in three of them and financial costs as estimated through emissions in two of them. Each chart contains all intersections in a whole corridor chart with bars depicting the current simulated conditions labeled “before” and the expected simulated conditions labeled as “after”.

Figure 24 deals with the performance effects in terms of delay per intersection. Noticeable increases can be found across the board, but especially at the two largest intersections on the corridor, George W. Liles Pkwy / Poplar Tent Rd and George W. Liles Pkwy / Weddington Rd. However, measurable impacts are also seen at the two northernmost locations, Kannapolis Pkwy / Glen Afton Blvd and Kannapolis Pkwy / I- 85

SB Ramp. This is consistent with traffic patterns and volumes in the morning peak hour that show southbound traffic through the corridor being the preponderant movement. The results obtained at the latter of the two intersections are the subject of additional findings due to a discovered data collection issue.

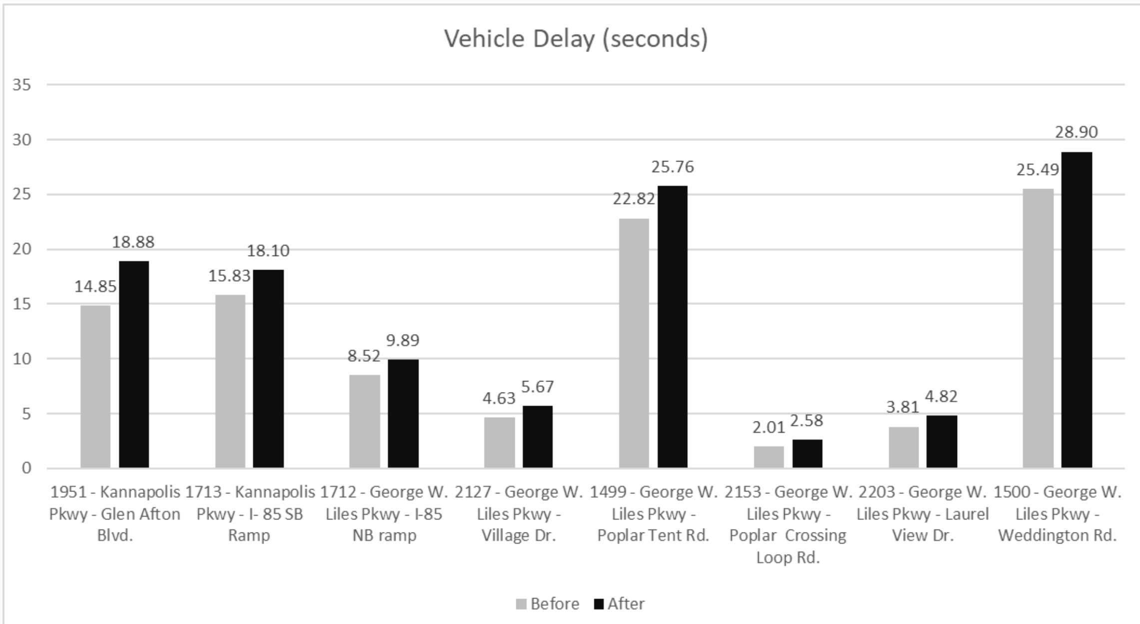

FIGURE 24: Vehicle delay (morning peak)

Figure 25 presents the queue length results. Besides the largest intersection on the corridor, the two northernmost intersections exhibit the highest queueing Figure 26 shows an increase in the number of stops in the preponderant movement. This is consistent with the increase in delay and queueing observed in the previous two outputs

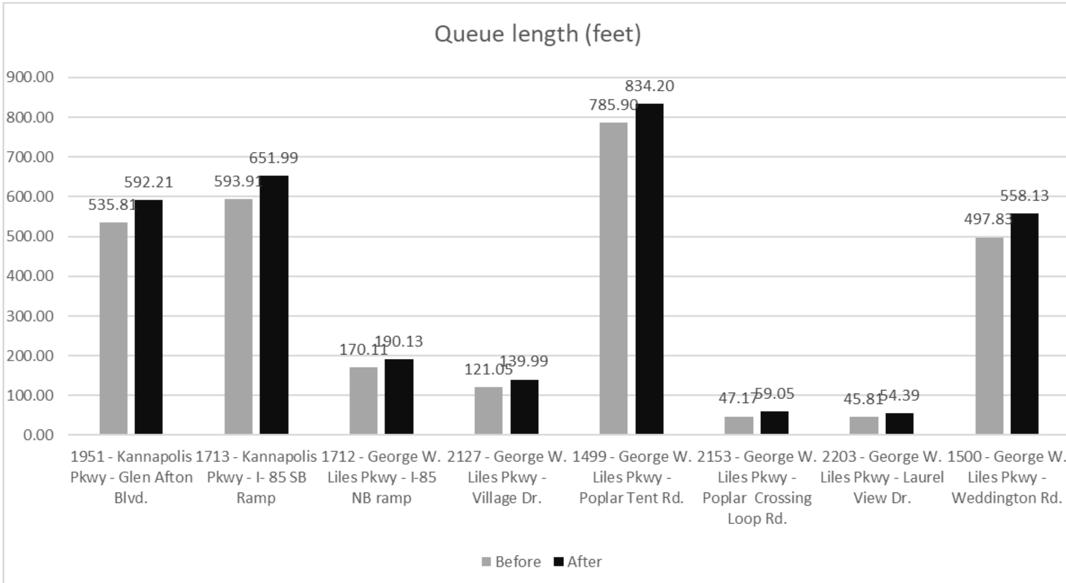

FIGURE 25: Intersection queue length (morning peak)

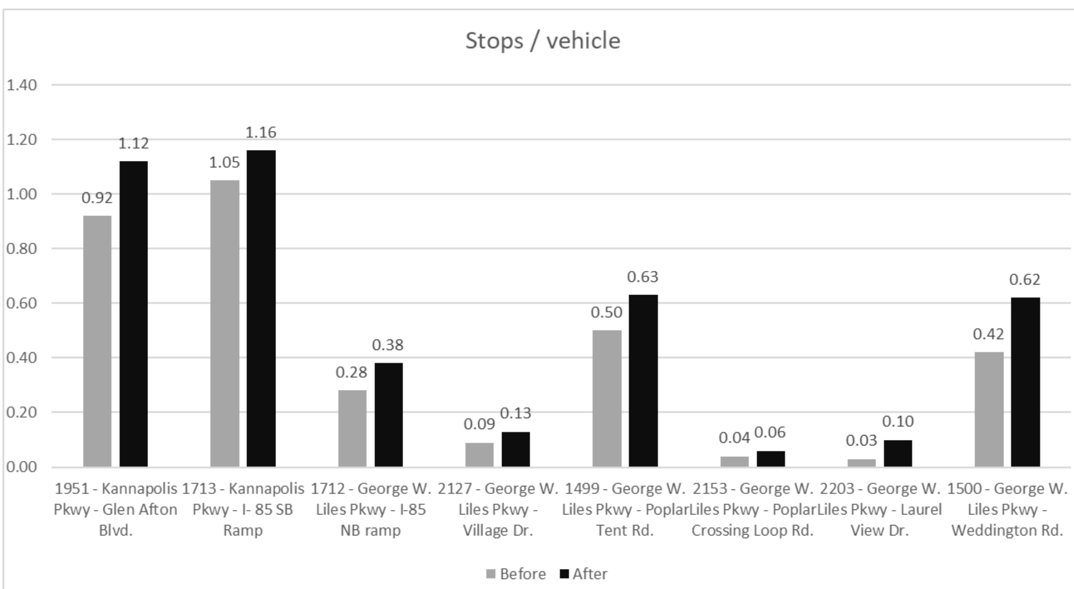

FIGURE 26: Number of stops/vehicle (morning peak)

Figures 27 and 28 show the cost change from an environmental impact point of view. The node analysis by emissions output values indicates that there is an apparent increase in NOx emissions in all the estimation approaches. This could be credited to a combination of factors: a total increase in the number of heavy vehicles with the additional school buses and the fact that diesel engines produce much more NOx than gasoline engines due to their higher operating temperatures.

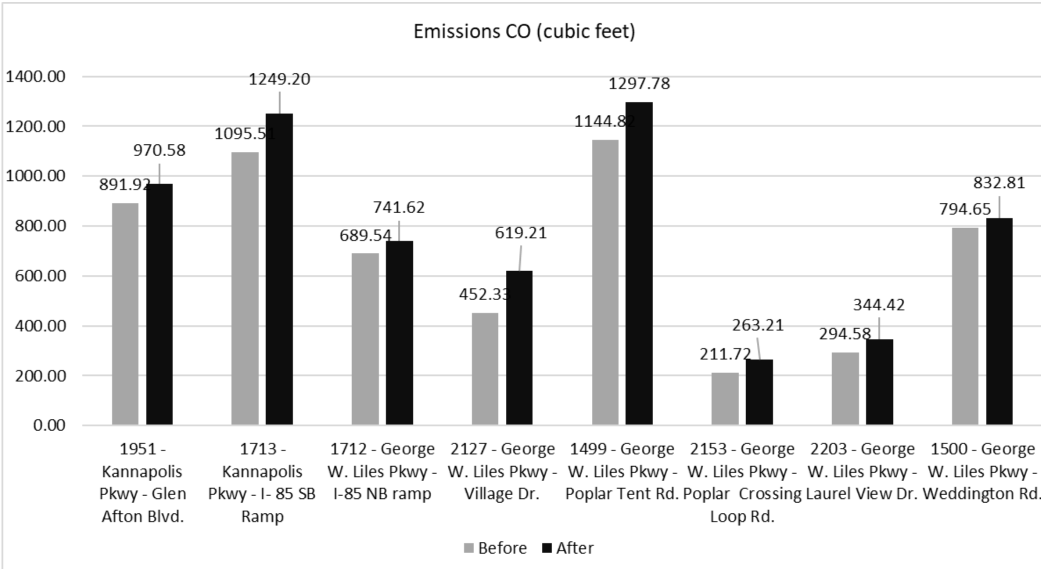

FIGURE 27: Carbon Monoxide emissions (morning peak)

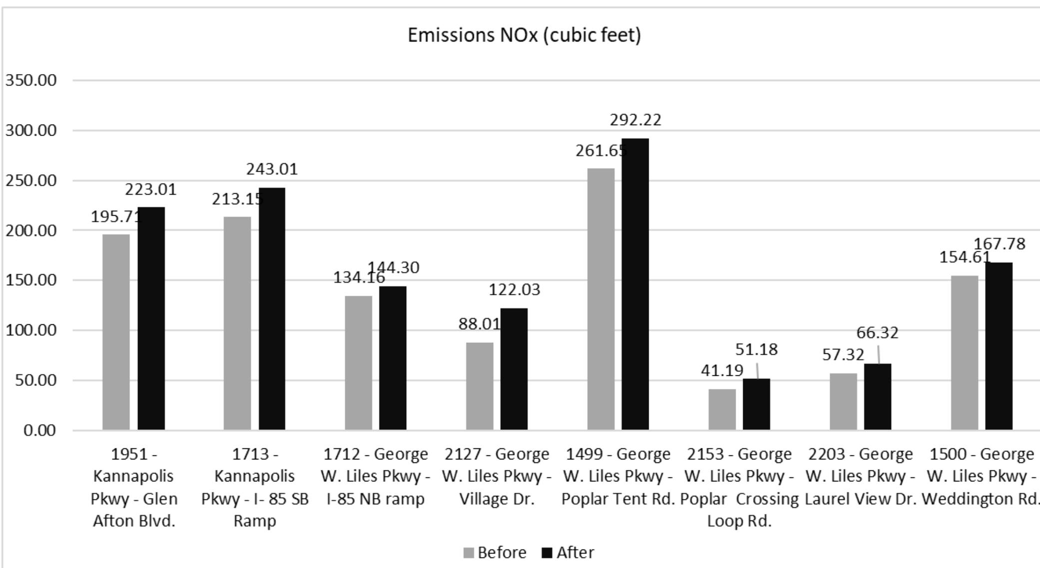

FIGURE 28: Nitrous Oxide emissions (morning peak)

5.1.2. School evening peak period

The second part of the analysis looks at the school evening peak period. Instantly, it can be observed that the vehicle delay quantities shift to higher total numbers with the two major intersections seeing an increase equal in size but less percentual magnitude. Judging by Figure 30 outputs, the evening peak hour patterns favor the northmost intersection where queueing was especially visible during the morning peak period. The coordination plans seem to work better for progression in this timeframe due to a total reduction in the number of stops, as seen in Figure 31.

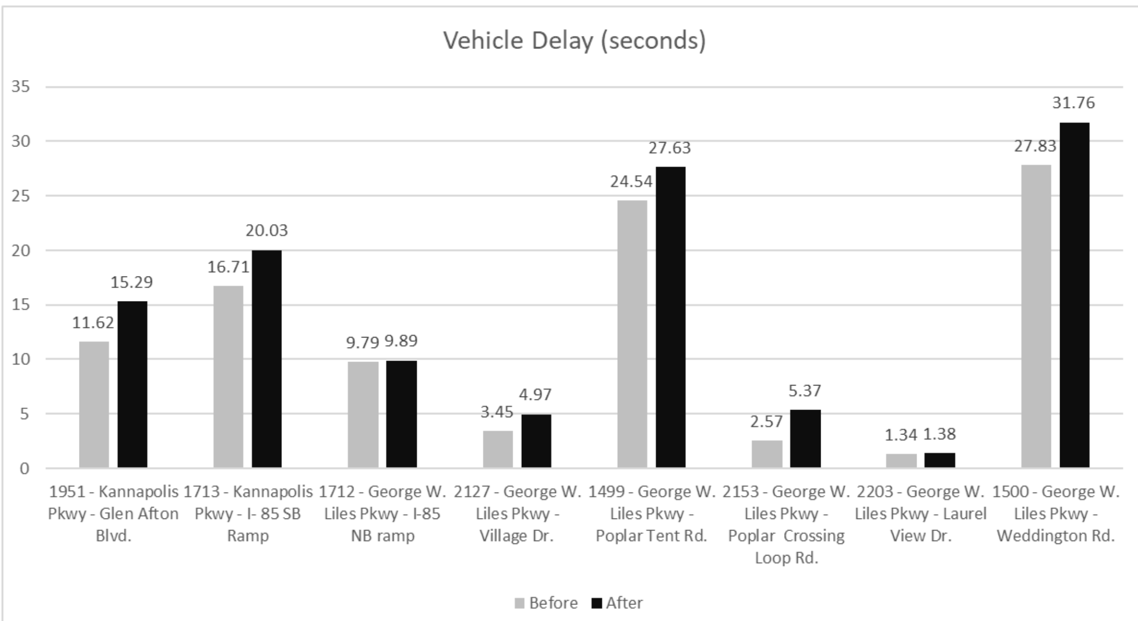

FIGURE 29: Vehicle delay (evening peak)

The increase in emissions is more drastic in the evening peak period due to the additional buses slowing corridor progression of more vehicles. A higher total environmental cost than in the morning peak period can be observed as well when looking at figures 32 and 33.

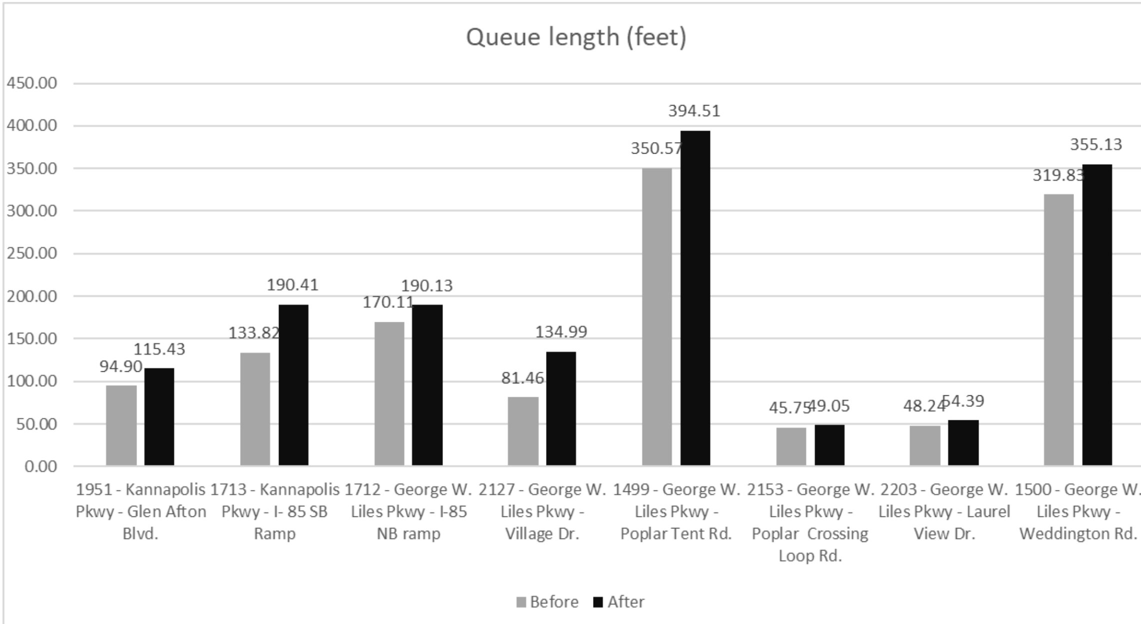

FIGURE 30: Intersection queue length (evening peak)

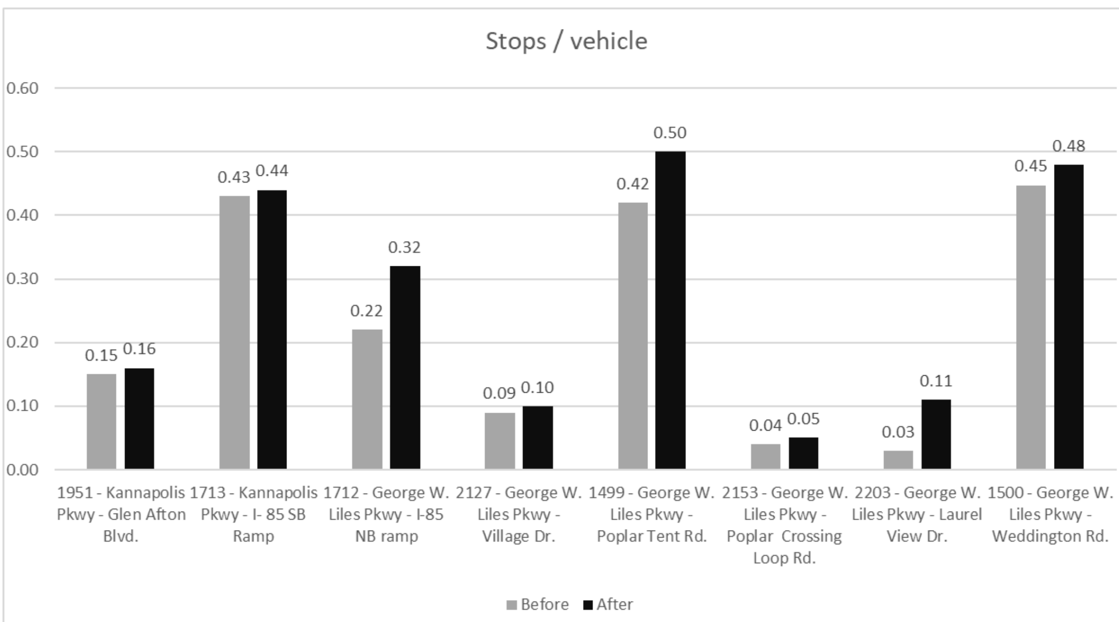

FIGURE 31: Number of stops/vehicle (evening peak)

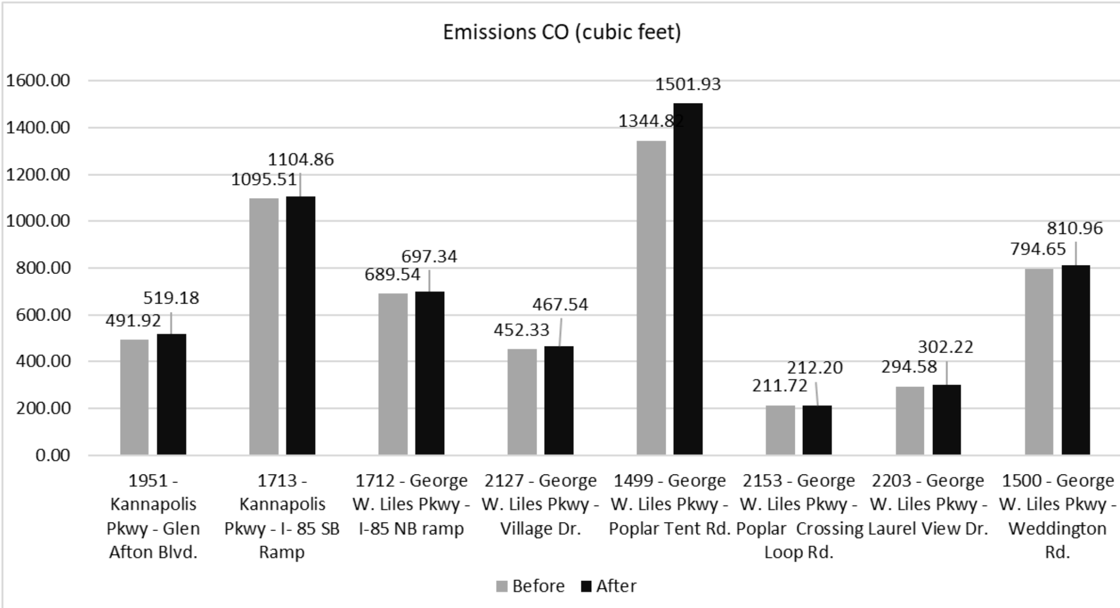

FIGURE 32: Carbon Monoxide emissions (evening peak)

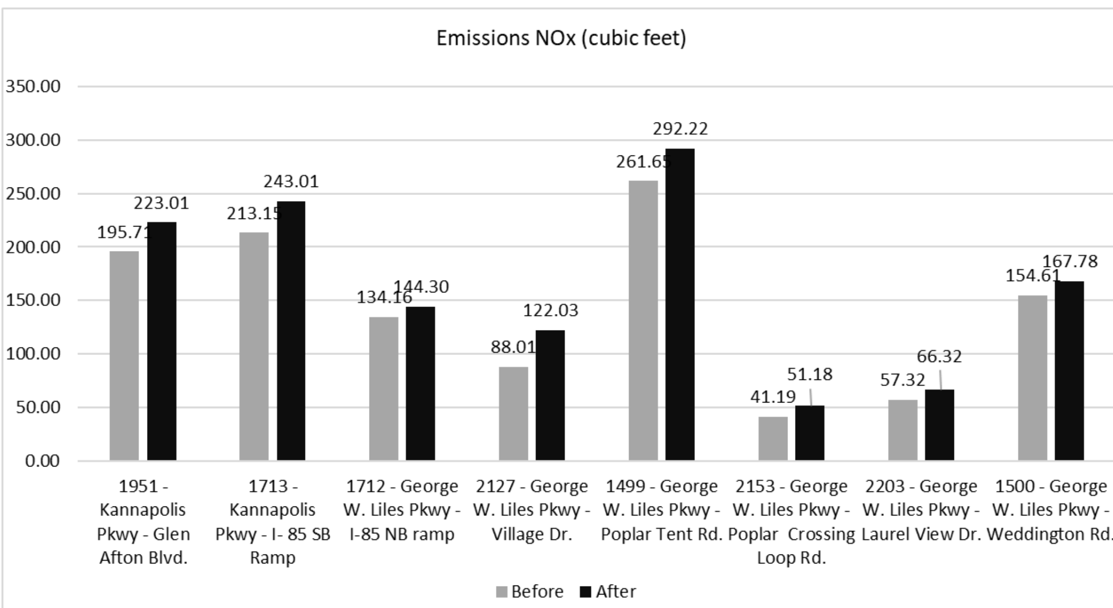

FIGURE 33: Nitrous oxide emissions (evening peak)

5.2. ATSPM Outputs (Purdue Coordination Diagram)

The figures in Appendix B constitute direct outputs from the ATSPM software, representing charts that present the Purdue Coordination Diagrams for each of the coordinated phases (2 and 6) for the eight intersections. The reason for using the Purdue

Coordination Diagram is that it has three embedded metrics, such as percent arrivals on the green, green time and platoon ratio. For the purposes of this research, out of these three metrics, two were used as comparison tools for the traffic signal coordination performance. The percent of arrivals on the green metric is better as the percentage is higher, while the platoon ratio number is better as the number tends to be larger. Table 4 shows the chart taken from the ITE Highway Capacity Manual (HCM) for illustrating the correlation between the arrival type and platoon ratio.

TABLE 4: Platoon ratio (HCM 2010)

Arrival Type	Range of Platoon	Default Value	Progression Quality
1	≤0.50	0.333	Very poor
2	>0.50-0.85	0.667	Unfavorable
3	>0.85-1.15	1.000	Random arrivals
4	>1.15-1.50	1.333	Favorable
5	>1.50-2.00	1.667	Highly favorable
6	>2.00	2.000	Exceptional

The compiled results are structured in the following manner. The tables contain aggregated data from seven runs where the minimum and maximum overall values where removed and the remaining five were averaged. The first table shows the values obtained by inputting the collected data into the ATSPM system. The data is split per intersection, per approach (which corresponds to the coordinated phases 2 and 6) and reflect the current conditions and the expected simulated ones.

The effects are more impactful at the higher demand intersections, George W. Liles Pkwy / Poplar Tent Rd, and George W. Liles Pkwy / Weddington Rd that already possessed a lower performance level. As stated previously in this chapter, the performance decrease is quantifiable across the board. The lower the impact, the further the intersection is from the influence area; bar the freeway ramp signals. This has to do with decay in progression due to the decreased dynamic characteristics of the school buses.

TABLE 5: ATSPM morning peak period results

		NORTHBOUND APPROACH		**SOUTHBOUND APPROACH**	
Intersection		**Arrivals on Green**	**Platoon Ratio**	**Arrivals on Green**	**Platoon Ratio**
1951 - Kannapolis Pkwy / Glen Afton Blvd	Before	77.0%	1.18	75.0%	1.06
	After	75.0%	1.11	72.0%	1.04
1713 - Kannapolis Pkwy / I-85 SB Ramp	Before	59.0%	1.14	81.0%	1.06
	After	58.0%	1.07	81.0%	1.06
1712 - George W. Liles Pkwy / I-85 NB ramp	Before	76.0%	1	75.0%	1.08
	After	75.0%	0.99	74.0%	1.07
2127 - George W. Liles Pkwy / Village Dr	Before	78.0%	1.08	72.0%	0.93
	After	78.0%	1.06	72.0%	0.92
1499 - George W. Liles Pkwy / Poplar Tent Rd	Before	48.0%	1.42	51.0%	1.48
	After	42.0%	1.27	50.0%	1.47
2153 - George W. Liles Pkwy / Poplar Crossing Loop Rd	Before	78.0%	1.09	76.0%	1.13
	After	78.0%	1.09	75.0%	1.08
2203 - George W. Liles Pkwy / Laurel View Dr	Before	80.0%	1.08	81.0%	1.06
	After	79.0%	1.06	80.0%	1.06
1500 - George W. Liles Pkwy / Weddington Rd	Before	47.0%	0.96	80.0%	1.48
	After	46.0%	0.94	78.0%	1.42

The second table shows the values obtained by inputting the school evening peak period collected data into the ATSPM system. The results are conclusive in illustrating a higher decay. Since the evening peak period plans primary goal is to move traffic with a concentration on the southbound approach, any disturbance in the equilibrium have a higher effect for that approach.

TABLE 6: ATSPM evening peak period results

		NORTHBOUND APPROACH		SOUTHBOUND APPROACH	
Intersection		**Arrivals on Green**	**Platoon Ratio**	**Arrivals on Green**	**Platoon Ratio**
1951 - Kannapolis Pkwy / Glen Afton Blvd	Before	75.0%	1.16	66.0%	1.08
	After	74.0%	1.13	66.0%	1.08
1713 - Kannapolis Pkwy / I- 85 SB Ramp	Before	62.0%	1.24	80.0%	1.11
	After	55.0%	1.13	75.0%	1.1
1712 - George W. Liles Pkwy / I-85 NB ramp	Before	67.0%	1.13	71.0%	1.04
	After	60.0%	1.02	67.0%	1.15
2127 - George W. Liles Pkwy / Village Dr	Before	78.0%	1.11	67.0%	1.1
	After	71.0%	1.05	61.0%	1
1499 - George W. Liles Pkwy / Poplar Tent Rd	Before	60.0%	1.36	73.0%	1.52
	After	42.0%	1.31	38.0%	1.08
2153 - George W. Liles Pkwy / Poplar Crossing Loop Rd	Before	75.0%	1.04	72.0%	1.16
	After	72.0%	0.97	68.0%	1.04
2203 - George W. Liles Pkwy / Laurel View Dr	Before	81.0%	1.04	82.0%	1.01
	After	81.0%	0.91	82.0%	0.99
1500 - George W. Liles Pkwy / Weddington Rd	Before	44.0%	1.02	54.0%	1.41
	After	43.0%	1	46.0%	0.96

5.3. Additional Findings

Aside from the ones mentioned above, one of the most important findings when performing this experiment constituted an operational gem. Generally, any research whose output is a future projection is as good as the data that it relies on. When measuring the Southbound movement on the corridor, volumes at the 1713 - Kannapolis Pkwy / I- 85 SB Ramp intersection did not match up with the upstream one, 1951 - Kannapolis Pkwy / Glen Afton Blvd, as exhibited in Figure 34.

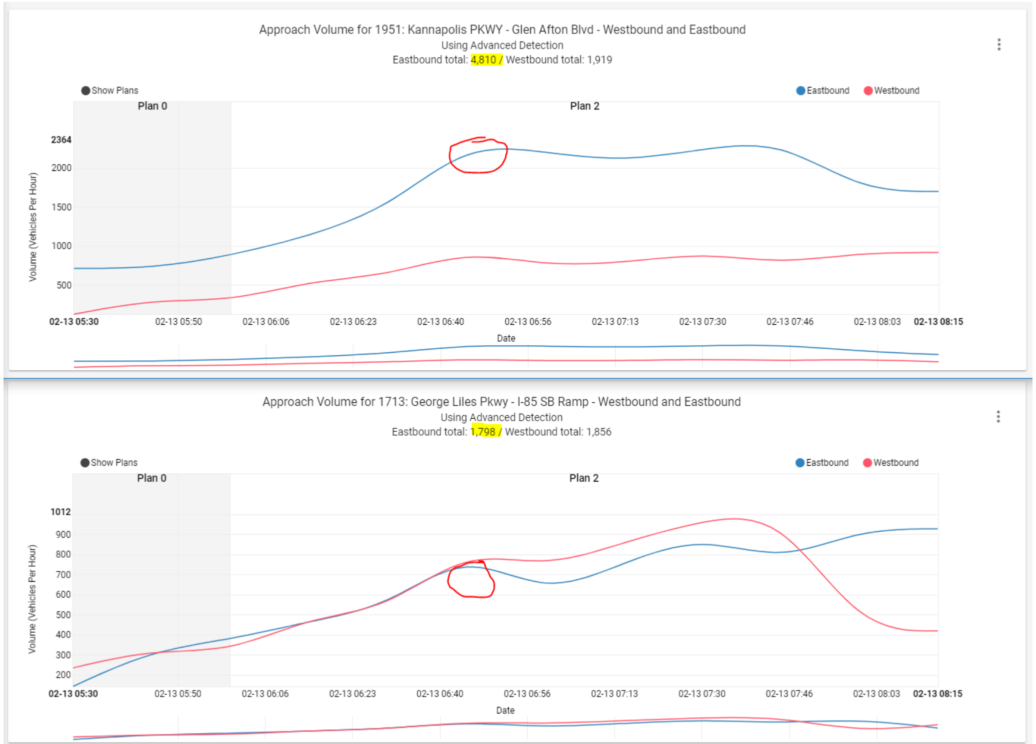

FIGURE 34: Southbound approach volumes mismatch

The amount of missing volume clearly showed a potential detection failure as it was not possible to miss on over 1000 vehicles for that approach, as shown in Figure 35. After investigating the matter further, this issue was clarified. The positioning of the advanced detectors for that approach completely misses out half of the traffic volume for both morning and evening peak periods, as vehicles tend to skew to the right-turn onto the I-85 freeway. This can be seen in the combined image collage from Figure 35 that shows freeway traffic at the ramp intersection and backing up through the Kannapolis Pkwy / Glen Afton Blvd, as well as the aforementioned detector placement.

FIGURE 35: Detection system failure at the I-85 SB Ramp intersection

5.4. Results Summary

Overall, increasing the number of school buses meant the corridor incurred a higher delay as a whole, with an intersection by intersection basis for the exact order of magnitude. The highest delay was observed at the two largest intersections on the corridor, while the highest impact was observed in the evening peak period where a higher overall traffic volume of traffic was observed. The highest change was observed at the two northernmost locations, Kannapolis Pkwy / Glen Afton Blvd and Kannapolis Pkwy / I- 85 SB ramp. A ripple effect was observed through the corridor. While the intersections did not change their LOS, the two major ones have seen an increase in total delay that brought them high to the LOS C range.

CHAPTER 6: CONCLUSIONS

Conclusions are explained in this chapter, as well as additional ideas for expanding future research. The purpose of this analysis was to test and see what impact the addition of another 17 school buses would have over the performance of a traffic signal coordinated arterial corridor. Even though that was the main goal, other research goals were just as important. These were listed below in the order of importance:

- test the configuration of an arterial corridor constituted of eight intersections where each intersection control is managed by an ASC/3 SIL instance which are working properly;
- create the possibility of having the ATMS software manage the virtual controller instances, including manual control and configuration import and export;
- make use of the central ATMS software to manage coordination during the two simulation scenarios; using this approach, hours of manual labor that would have been done in order to transfer settings were avoided by having the information seamlessly transferred from the field devices

The thesis also summarizes the benefits of using microsimulation to test various real-world controllers' strategies through the ASC/3 SIL platform.

6.1 Summary of Findings

The findings from the research are summarized below, in the order of importance**:**

- As expected, the simulation outputs indicated there was a distinguishable increase in delay throughout the entirety of the George W. Liles Pkwy corridor.

- The range of the delay increase spans from tenths of seconds at the smallest intersections to upwards of 3 seconds at the larger ones on the corridor.
- The impact on the two largest intersections by approach volume was easy to observe. The delay impact was upwards of 5% even though the LOS level did not increase.
- The emissions range increase throughout the corridor was in between 2% and 9%. No RTOR rule brings a quantifiable detriment in the case of the emissions.
- These results were validated with VISSIM data output analysis as well as the data ran through the ATSPM solution.
- Extra school buses on this corridor lead to an increase in slower accelerating vehicles. This, in turn, leads to the current signal timing plans needing to be retooled to allow for a larger gap (vehicle extension) among other changes.

From an operations point of view, integrating the ASC/3 SIL controllers in the VISSIM simulation uncovered that traffic signal databases are interchangeable between field and SIL controllers, thus helping to streamline the programming process.

6.2 Study Limitations and Recommendations

Even though the procedure outlined in this thesis was a success in identifying the impacts, conceptually there is still room for improvement. The strength of this analysis relies on the data collected from field detection devices. The ATSPM instance used to perform data collection as well as processing is only as reliable as the data sources allow it to be. The repercussions were made clear with the issue found at the Kannapolis Pkwy / I-85 SB Ramp intersection, where the analysis relied on flawed data.

Moreover, the data used in this research that attempted to capture a specific instance and day were volumes and turning movement counts were available. This meant a certain degree of engineering judgment needed to be applied to estimating specific movements and approaches. Thus, it could be argued that the data set is incomplete due to weighted origin to destination data not present.

Operationally, field observations show that queuing is more localized and dependent on the arrival rate as well as heavily dependent on processing times. For instance, one particular vehicle could require over more than a minute to complete its transaction; during this time multiple vehicles will certainly queue up temporarily until favorable conditions return. This can be pointed out as the main reason why multiple time periods to estimate capacity and queue lengths are generally needed to more accurately find an average value of these constraints in the field, but also when using VISSIM.

Future work should look into collecting field travel time and include it as a validation check in the virtual network in order to potentially increase accuracy. Additional work could also be done to explore using different driving behavior parameters for different segments of the network, due to the diversity of the corridor.

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APPENDIX: COLLECTED DATA

Volume data: 1951 - Kannapolis Pkwy / Glen Afton Blvd.

Time	Eastbound	Westbound
02/13/19 06:00:00.000	1,458	604
02/13/19 07:00:00.000	2,225	807
02/13/19 08:00:00.000	1,551	688
02/13/19 09:00:00.000	1,015	510
02/13/19 10:00:00.000	810	416
02/13/19 11:00:00.000	967	426
02/13/19 12:00:00.000	1,154	503
02/13/19 13:00:00.000	997	607
02/13/19 14:00:00.000	1,157	633
02/13/19 15:00:00.000	1,254	812
02/13/19 16:00:00.000	1,576	1,074
02/13/19 17:00:00.000	1,814	1,135
02/13/19 18:00:00.000	1,896	924
02/13/19 19:00:00.000	616	522

Volume data: 1713 - Kannapolis Pkwy / I- 85 SB Ramp

Time	Southbound	Eastbound	Westbound
02/13/19 06:00:00.000	160	551	539
02/13/19 07:00:00.000	246	752	894
02/13/19 08:00:00.000	177	711	706
02/13/19 09:00:00.000	174	688	657
02/13/19 10:00:00.000	185	637	695
02/13/19 11:00:00.000	239	817	813
02/13/19 12:00:00.000	212	937	1,045
02/13/19 13:00:00.000	244	913	1,035
02/13/19 14:00:00.000	279	913	1,113
02/13/19 15:00:00.000	302	1,182	1,033
02/13/19 16:00:00.000	346	1,371	1,244
02/13/19 17:00:00.000	391	1,520	1,419
02/13/19 18:00:00.000	224	1,281	1,249
02/13/19 19:00:00.000	165	790	856

Volume data: 1712 - George W. Liles Pkwy / I-85 NB ramp

Time	Northbound	Eastbound	Westbound
02/13/19 06:00:00.000	277	579	1,190
02/13/19 07:00:00.000	352	975	1,700
02/13/19 08:00:00.000	315	858	1,449
02/13/19 09:00:00.000	297	651	1,130
02/13/19 10:00:00.000	268	725	968
02/13/19 11:00:00.000	293	877	1,119
02/13/19 12:00:00.000	338	1,000	1,268
02/13/19 13:00:00.000	364	1,006	1,283
02/13/19 14:00:00.000	422	1,110	1,162
02/13/19 15:00:00.000	535	1,154	1,481
02/13/19 16:00:00.000	732	1,287	1,555
02/13/19 17:00:00.000	812	1,434	1,696
02/13/19 18:00:00.000	646	1,196	1,497
02/13/19 19:00:00.000	414	816	951

Volume data: 2127 - Kannapolis Pkwy / Glen Afton Blvd.

Time	Northbound	Southbound
02/13/19 06:00:00.000	1,076	660
02/13/19 07:00:00.000	1,647	1,143
02/13/19 08:00:00.000	1,341	987
02/13/19 09:00:00.000	1,082	753
02/13/19 10:00:00.000	931	739
02/13/19 11:00:00.000	1,067	924
02/13/19 12:00:00.000	1,190	1,092
02/13/19 13:00:00.000	1,172	1,067
02/13/19 14:00:00.000	1,113	1,255
02/13/19 15:00:00.000	1,409	1,321
02/13/19 16:00:00.000	1,536	1,547
02/13/19 17:00:00.000	1,674	1,830
02/13/19 18:00:00.000	1,445	1,461
02/13/19 19:00:00.000	860	985

Volume data: 2153 - George W. Liles Pkwy / Poplar Crossing Loop Rd.

Time	Northbound	Southbound
02/13/19 06:00:00.000	969	530
02/13/19 07:00:00.000	1,674	797
02/13/19 08:00:00.000	1,302	829
02/13/19 09:00:00.000	1,035	662
02/13/19 10:00:00.000	900	650
02/13/19 11:00:00.000	893	759
02/13/19 12:00:00.000	912	869
02/13/19 13:00:00.000	1,049	893
02/13/19 14:00:00.000	1,013	982
02/13/19 15:00:00.000	1,227	1,125
02/13/19 16:00:00.000	1,337	1,378
02/13/19 17:00:00.000	1,379	1,653
02/13/19 18:00:00.000	1,151	1,315
02/13/19 19:00:00.000	730	867

Volume data: 2203 - George W. Liles Pkwy / Laurel View Dr.

Time	Northbound	Southbound
02/13/19 06:00:00.000	715	525
02/13/19 07:00:00.000	1,295	839
02/13/19 08:00:00.000	1,029	752
02/13/19 09:00:00.000	706	566
02/13/19 10:00:00.000	636	597
02/13/19 11:00:00.000	653	697
02/13/19 12:00:00.000	742	767
02/13/19 13:00:00.000	778	799
02/13/19 14:00:00.000	827	893
02/13/19 15:00:00.000	997	1,108
02/13/19 16:00:00.000	1,126	1,323
02/13/19 17:00:00.000	1,150	1,653
02/13/19 18:00:00.000	974	1,245
02/13/19 19:00:00.000	571	729