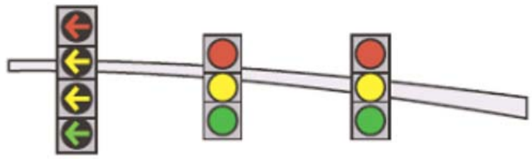
Dynamic Flashing Yellow Arrow (FYA)
A Study on Variable Left-Turn Mode Operational and Safety Impacts
Phase II – Model Expansion and Testing



FLORIDA DEPARTMENT OF TRANSPORTATION
FDOT Contract BDV24-977-10

FINAL REPORT

Submitted to

Research.Center@dot.state.fl.us
Business Systems Coordinator, (850) 414-4614
Florida Department of Transportation Research Center
605 Suwannee Street, MS30
Tallahassee, FL 32399

c/o Richard Morrow, P.E.
District Traffic Operations Engineer

Submitted by

Dr. Essam Radwan, P.E. (PI), Ahmed.Radwan@ucf.edu
Dr. Hatem Abou-Senna, P.E. (Co-PI) habousenna@ucf.edu
Dr. Hesham Eldeeb & Alex Navarro Imagineer1987@knights.ucf.edu

Center for Advanced Transportation Systems Simulation (CATSS)
Department of Civil, Environmental & Construction Engineering (CECE)
University of Central Florida
Orlando, FL 32816-2450
(407) 823-4738

June 2016

DISCLAIMER

CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	Mega grams (or "metric ton")	Mg (or "t")

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Dynamic Flashing Yellow Arrow (FYA) A Study on Variable Left-Turn Mode Operational and Safety Impacts Phase II – Model Expansion and Testing		5. Report Date June 2016 6. Performing Organization Code
7. Author(s) Hatem Abou-Senna, Essam Radwan, Hesham Eldeeb & Alex Navarro		8. Performing Organization Report No.
9. Performing Organization Name and Address Center for Advanced Transportation Systems Simulation (CATSS) Department of Civil, Environmental & Construction Engineering University of Central Florida 4000 Central Florida Blvd. Orlando, FL 32816-2450 (407) 823-4738		10. Work Unit No. (TRAIS) 11. Contract or Grant No. BDV24-977-10
12. Sponsoring Agency Name and Address Florida Department of Transportation Research Center 605 Suwannee Street, MS 30 Tallahassee, FL 32399 (850) 414-4615		13. Type of Report and Period Covered Final Report (May 2014 – June 2016) 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The flashing yellow arrow (FYA) signal display creates an opportunity to enhance the left-turn phase with a variable mode that can be changed on demand. The previously developed decision support system (DSS) in phase I facilitated the selection of the FYA left-turn mode, changing by time of day at intersections. There was a need to continue to refine the interactive framework to improve its service. However, the ultimate objective of the continued research of phase II was to demonstrate the ability to execute the automation of the process. Phase II of the FYA project provided additional intersection data that refined the work that was previously completed. Virtual testing of the DSS was first conducted using VISSIM application programming interface (API) to confirm the validity of the procedure and logic. The DSS was then tested in a field testing environment. A custom communications software was developed to retrieve instantaneous channel input data, synchronize opposing thru green phase, analyze traffic information, provide the algorithm decision, and generate a real-time log recording the events. The proposed algorithm is implemented with the goal of safely optimizing traffic operations with constant analysis in real-time to determine whether it would be optimal to switch the red arrow to a flashing yellow arrow. The algorithm determines the time interval between the successive arrivals of vehicles and computes the corresponding headway for each lane by cycle on a second-by-second basis. The DSS was ultimately tested at two different intersections in Seminole County. The DSS testing confirmed the applicability and validity of the developed DSS as well as the aforementioned procedure, criteria, and logic.

17. Key Word		18. Distribution Statement	
Flashing Yellow Arrow (FYA), Decision Support System (DSS), Left-Turn Mode, Time of Day			
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 98	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

The authors would like to express their sincere appreciation to the Florida Department of Transportation and acknowledge the cooperation and support of Mr. Rick Morrow (District 5) for serving as the Project Manager and providing guidance during the course of this research. The UCF research team would like also to express their deepest gratitude to all Seminole County Traffic Engineering Staff, especially Mr. Chad Dickson for his tremendous help in providing the testing environment in the lab and mapping the loop detector connections to the lab cabinet. The authors are also grateful to Orange County Traffic Engineering Staff for their help and support during the pilot study.

EXECUTIVE SUMMARY

The all-new four-arrow configuration with the flashing yellow arrow (FYA) signal display creates an opportunity to enhance the left-turn signal with a variable mode that can be changed by time of day on demand. Phase I of this project provided the framework and detailed process of developing a decision support system (DSS) with the use of an interactive model. The DSS facilitates the selection of the flashing yellow arrow left-turn mode and changing by time of day at intersections. There was a need to continue to refine the interactive framework to improve its service as a decision support system. The framework already allowed for an interactive evaluation of the permissive left-turn phase and was able to recommend phasing mode by time of day. However, the ultimate objective of the continued research of phase II was to demonstrate the ability to execute the automation of the process in a field testing environment through the use of an active controller.

The University of Central Florida (UCF) research team refined the model estimates and implemented an expanded database. The phase II portion of the flashing yellow arrow project provided additional video data that was extracted on a second-by-second basis. The master database was increased to 38 intersections with locations across the State of Florida. The data extraction process in phase II was completed to match the basic prioritized parameters that were used to refine the developed model in phase I. With an expanded database, the model's coefficient of correlation was improved because of the increased model domain.

With the conclusions drawn from phase I, any data that was included in the analysis for phase II was required to have a balanced number of peak and off-peak conditions. The preliminary analysis of the data pinpointed some of the data sets that had low left-turn volumes and other circumstances that required removal from the data set so as not to affect the modeling process. The final total remaining hours used in the statistical analysis were 1,058 hours. Based on the analysis, the neural networks model provided the highest correlation between the independent variables, with a coefficient of correlation reaching 90%.

The final refined neural network model, along with the decision support system criteria, was first tested in a simulated environment before moving on to the field testing environment. Virtual testing or Software-in-the-Loop-Simulation (SILS) is used to prove or test the software. This is an advanced step compared to the HILS (Hardware-in-the-Loop-Simulation) testing where an actual traffic controller is needed along with a controller interface device (CID). Virtual testing was conducted using the latest version of the microscopic traffic simulation model VISSIM 7.13 along with its application programming interface modules, which included the use of COM (Component Object Module) server as well as the VISVAP (VISSIM Vehicle Actuated Programming) module. These components, unified under the Windows operating environment and integrated with VISSIM, provide the ability to simulate one or more intersections with a unifying controller management interface and the ability to model both standard and custom saturated timing strategies. Virtual testing of the decision support system using VISSIM application programming interface (API) confirmed the applicability and validity of the procedure and logic.

The DSS was then used in the next steps of automating the decision making process for the Traffic Management Center (TMC). The decision support system was ultimately tested at two different intersections in Seminole County. The UCF research team utilized the Seminole County Traffic Engineering Lab, where field data was collected in real-time mode using peer-to-peer logic in order to map the field controller to the lab controller. The intersection vehicle detection system through the loop occupancy and the CCTV cameras were connected to the data logger and the communication software to receive data signaling the traffic flow on a second-by-second basis. The permissive green times and the opposing thru traffic were determined on a cycle-by-cycle basis from the field by the data logger software. The logic was based on modeling the inter-arrival time of vehicles and calculating the minimum headway and gap time per lane for the opposing traffic from the loop detectors data for the first two to three cycles before recommending a decision for the left-turn signal head, either flashing or not, for the next cycle. This iterative process is repeated throughout the day on a cycle-by-cycle basis. The DSS testing confirmed the applicability and validity of the developed DSS as well as the aforementioned procedure, criteria, and logic.

The procedure, criteria, and logic are expected to provide traffic engineers with the tools to utilize the efficiency of the permissive left-turn at peak and off-peak times. In turn, this can reduce the delay at approaches when there are low volumes on the roadways. The FYA 4-section configuration provides the opportunity for a fully adjustable system and provides the TMCs with more tools to operate the intersections as efficiently as possible.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Overview

Spurred by the decision support system (DSS) and the interactive model developed in phase I for the selection of the flashing yellow arrow (FYA) left-turn phasing mode changing by time of day, at intersections, the UCF research team is aiming at refining the model estimates and expanding the database from 13 intersections to 50 intersections for two main reasons: first, to improve the coefficient of correlation through the increase of the model domain which will increase the reliability of the developed model and support the generalization of the methodology, and second, to confirm whether the low model estimates when the opposing traffic exceeds the 1,000 vph threshold is considered a valid conclusion or is it a bias in the model. As concluded in phase I, the developed model coefficient of correlation or determination (R^2) was 84%, which is considered a relatively high value for fitting random real-life data. However, from the analysis and prediction estimates, it was found that, in some cases, the model underestimates the predicted number of permissive left-turns, especially when the opposing traffic exceeds the 1,000 vph threshold. This could be attributed to the fact that a majority of the data corresponded to either an off-peak condition or single-lane approach intersections (with volumes less than 1,000 vph). Out of the 229 hours analyzed, about 25% represented a peak condition compared to the rest of the hours. Collecting daily data (10-12 hours) at an intersection results in about 3-4 hours that are considered peak with high volumes when compared to the rest of the day. Moreover, most of the peak hour conditions with volumes around the 1,500 vph resulted in a very low number of permissive left-turns. Therefore, additional peak hours are needed to balance the ratio between peak and off-peak conditions in the model.

Another crucial objective of this research is the automation of the decision process at the Traffic Management Center (TMC). The UCF research team developed a software tool, based on the DSS, which is connected to the controller in the field in order to automate the modification/selection process of the FYA mode on an hour-by-hour basis. The software tool receives volume data as well as signal phasing and timing (SPaT) inputs for a given day and generates recommendations. While there are variety of ways to collect volumes, SPaT information needed a specific programming interface. VISSIM add-on modules such as Econolite ASC/3 and its application programming interface (API) were utilized for this task. The controller was connected with VISSIM Econolite ASC/3 interface along with the already coded Visual Basic version of the DSS model. These components, unified under the Windows operating environment and integrated with VISSIM, provided the ability to simulate one or more intersections with a unifying controller management interface and the ability to model both standard and custom saturated timing strategies. Any changes made to the controller settings were stored in the simulated controller's database. This was considered the first step towards the virtual field testing process before the actual pilot study in the field.

The refined model provides the traffic engineers with the tools to utilize the efficiency of the permissive left-turn at peak and off-peak times and reduce the delay at approaches when there are low volumes on the roadways. The all-new FYA four-section configuration provides the opportunity for a fully adjustable system and provides the TMCs with more tools to operate the intersections as efficiently as possible.

1.2 Objectives

The main project objectives are:

1. Expand the database and increase the number of intersections to 50 intersections
2. Refine the DSS model and validate it using the expanded database
3. Modify the coded version of the DSS model to reflect the results of the new database
4. Virtual testing of the DSS through VISSIM API interface with the controller
5. Field testing through pilot study

1.3 Summary of Project Tasks

Task 1: Data Procurement from FDOT
Task 2: Data Extraction
Task 3: Refine Developed Decision Support System (DSS)
Task 4: Virtual Testing of the DSS using VISSIM API
Task 5: Pilot Study for Field Testing
Task 6: Final Report

2. DATA PROCUREMENT

2.1 Video Data

As mentioned earlier, model expansion is expected to increase the size of the database to 50 intersections. With the assistance of the Florida Department of Transportation (FDOT), the additional video data were obtained from their representatives.

The University of Central Florida (UCF) Research Team has investigated the video collection data that was provided to the team from the Florida Department of Transportation (FDOT) representatives. The data was collected through the use of a Video Collection Unit (VCU). The VCU used for the data collection process was provided by Miovision Technologies. The VCU is affixed to either a mast arm, utility pole or other rigid object nearby the intersection to provide a clear view of the intersection. The camera had the capability of being extended up to 25 feet above the intersection, providing a clear vantage of all of the intersection approaches. Figure 2-1 provides an example of the VCU and a typical arrangement at an intersection where video data is being collected.

Figure 2-1: VCU Attached to a Utility Pole at a Height of 20 Feet

Through the use of a proprietary process, Miovision Technologies provides the Turning Movement Counts (TMCs) for all of the video data that was provided to UCF. The process involves automated video detection to conduct the TMCs and provide a gap analysis for the intersections from the video data. These files come in the form of Microsoft Excel spreadsheets that can easily be imported for data analysis purposes at a future date. This is a key element in ensuring that a complete set of parameters are available to the UCF research team.

2.2 Data Refinement and Filtering

The video collection files that were provided by the FDOT representatives were processed for refinement and filtering to serve as usable data in phase II of the FYA Project. Intersection characteristics and criteria such as size, geometry and land use were not limited; however, the specific operation of the left-turn had to adhere to the standards of the FYA Project. The left-turns were required to run in a protected-permissive mode with the use of either a 5-section signal head or the flashing yellow arrow that employs the use of the 4-section head. All left-turn approaches that were running in a fully protected mode were omitted from the database. Many intersections had dual-left-turns which resulted in a protected mode for the left-turn that could not be used. Intersections that operated as a split phase for the approach were also not included in the database. Some of the videos obtained were placed at intersections with no signals at all and were omitted from the database as well.

The outcome of this investigation resulted in 18 intersections that adhered to the requirements of the project scope and may potentially be used for data extraction. Of those 18 intersections, 33 unique approaches were analyzed as compared to 31 unique approaches in phase I of the study. However, the number of hours per intersection approach is dramatically greater than that of phase I. The total number of hours of the video data provided by the FDOT representatives added up to 1,363 hours of potentially usable video data.

From the usable video data, further filtering was conducted to ensure that the video data had an adequate mix of peak and off-peak conditions to provide an acceptable sample size for the statistical analysis. For this project, peak hours were considered 7:00 AM to 9:00 AM, 12:00 PM to 2:00 PM and 4:00 PM to 6:00 PM, for the morning, midday and evening peak periods respectively. This resulted in a maximum of six hours of peak data per day for each collection. All other hours were considered off peak. The overnight hours which included the late night and early morning hours were eliminated because of the extremely low traffic volumes. This process resulted in selecting hours only between 7:00 AM and 7:00 PM for the data extraction task. The hours that were considered off peak are the hours of 9:00 AM to 12:00 PM, 2:00 PM to 4:00 PM and 6:00 PM to 7:00 PM, a total of six hours to balance out the peak hours.

This filtering brings the new total video data hours provided by the FDOT to 1,078 hours. The final total hour count for the study was 1,369 hours (291 hours in phase I and 1078 hours in phase II). This significantly increased the sample size of the video data collection bank and would increase the confidence in the data set. The summary of the final video data sets that were used for extraction in task 2 are provided in Table 2-1 including the number of hours for each of the framework parameters.

Table 2-1: Summary of Project Data Properties

Properties		Phase I	Phase II	Total
Opposing Lanes (Hours)	1	12	218	**230**
	2	127.16	499	**626.16**
	3	138.91	263	**401.91**
	4	13	98	**111**
Land Use (Hours)	Residential	56.25	96	**152.25**
	Commercial	68.66	444	**512.66**
	Downtown	23	9	**32**
	Industrial	0	360	**360**
	Residential/Commercial (Mixed)	37	169	**206**
	Residential/School	86.16	0	**86.16**
	Tourist	20	0	**20**
Criteria (Hours)	Rural	83.25	0	**83.25**
	Urban	59	846	**905**
	On/Off Ramp	19.66	14	**33.66**
	Single Lane	47	218	**265**
	Pedestrian	82.16	0	**82.16**
Signal Head (Hours)	Permitted	12	0	**12**
	5-Section Head	205.07	1042	**1247.07**
	Flashing Yellow Arrow	74	36	**110**
Total Hours	Peak	152.66	542.5	**695.16**
	Off-Peak	138.41	535.5	**673.91**
Total Approaches	Unique Approaches	31	33	**64**
	Data Collection Days	34	98	**132**

Table 2-2 provides a summary of the intersection data that had previously been collected by UCF during phase I. Table 2-3 is a detailed analysis of the specific intersections and properties of those intersections that were provided to UCF from FDOT representatives for phase II. The tables outline each of the intersections, approaches and significant parameters that were considered in the data collection process.

Table 2-2: Phase I Intersection Summary

Number	Major Road	Minor Road	Approach		County	Peak Hours		Off-Peak Hours		Lanes Crossed	Land Use	Criteria	Signal Head
1A 1B	SR 50	Chuluota Rd	EBL	Major	Orange	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	3.75	6:00, 9:00, 14:00, 18:00	3	Residential	Rural	5-Section
						6		6.5	6:00, 9:00, 14:00, 18:00, 19:00, 20:00, 21:00	3	Residential	Rural	5-Section
			WBL	Major		5	7:00, 8:00, 12:00, 13:00, 16:00	3	6:00, 9:00, 14:00	3	Residential	Rural	5-Section
2	SR 50	Rouse Lake Rd (Wal-Mart Entrance)	WBL	Major	Orange	2	15:30, 16:30	7	13:30, 14:30, 17:30, 18:30, 19:30, 20:30, 21:30	2	Commercial	Urban	5-Section
			EBL	Major		2		4	13:30, 14:30, 17:30, 18:30	3	Commercial	Urban	5-Section
3	SR 50	Mills Ave	EBL	Major	Orange	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	7	6:00, 9:00, 14:00, 18:00, 19:00, 20:00, 21:00	3	Downtown	Urban	5-Section
			SBL	Minor		6		4	9:00, 14:00, 18:00, 19:00	2	Downtown	Urban	5-Section
4	Dean Rd	SR 408 West	NBL	Major	Orange	5	8:30, 12:00, 13:00, 16:00, 17:00	7	9:30, 10:30, 14:00, 18:00, 19:00, 20:00, 21:00	2	Residential	Ramp	Permitted
5	Curry Ford Rd	Chickasaw Tr	SBL	Minor	Orange	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	5	6:00, 9:00, 14:00, 18:00, 19:00	2	Mixed	Single Lane	5-Section
			NBL	Minor		6		3	9:00, 14:00, 18:00	2	Mixed	Single Lane	5-Section
6	Chickasaw Tr	Valencia College Ln	SBL	Major	Orange	2	16:00, 17:00	3	15:00, 18:00, 19:00	2	Residential/ School	Single Lane	5-Section
			EBL	Minor		2		3		1	Residential/ School	Single Lane	5-Section
7B	Avalon Park Blvd	Waterford Chase Pkwy	NBL	Major	Orange	4	11:43, 12:43, 15:43, 16:43	6	8:43, 9:43, 10:43, 13:43, 14:43, 17:43	2	Residential/ School	Peds	5-Section
			EBL	Minor		4		6		2	Residential/ School	Peds	5-Section
8A 8B 8C	Lake Underhill Rd	Woodbury Rd	SBL	Minor	Orange	3	7:45, 11:45, 12:45	5.5	8:45, 9:45, 10:45, 13:45, 14:45, 15:45	2	Residential/ School	Peds	5-Section
						1	17:06	0.66	18:06	2	Residential/ School	Peds	5-Section
						5	7:59, 11:59, 12:59, 15:59, 16:59	6	8:59, 9:59, 10:59, 13:59, 14:59, 17:59	2	Residential/ School	Peds	5-Section
			NBL	Minor		4	11:59, 14:59, 15:59, 16:59	3	13:59, 14:59, 17:59	1	Residential/ School	Single Lane	5-Section

Table 2-2: Phase I Intersection Summary (Continued)

Flashing Yellow Arrow Phase I Data Summary Table													
Number	Major Road	Minor Road	Approach		County	Peak Hours		Off-Peak Hours		Lanes Crossed	Land Use	Criteria	Signal Head
9	Lake Underhill Rd	Chickasaw Tr	EBL	Major	Orange	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	4	6:00, 9:00, 14:00, 18:00	2	Mixed	Single Lane	5-Section
10	International Dr South	Vineland Rd	NBL	Major	Orange	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	7	6:00, 9:00, 14:00, 18:00, 19:00, 20:00, 21:00	2	Tourist	Peds	5-Section
			SBL	Major		5	8:00, 12:00, 13:00, 16:00, 17:00	2	9:00, 14:00	2	Tourist	Peds	5-Section
11	CR 535	Overstreet Rd	SBL	Major	Orange	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	7	6:00, 9:00, 14:00, 18:00, 19:00, 20:00, 21:00	3	Residential/ School	Peds	5-Section
			NBL	Major		5	8:00, 12:00, 13:00, 16:00, 17:00	3	9:00, 14:00, 18:00	3	Residential/ School	Peds	5-Section
12	CR 535	Lakeside Village Ln	NBL	Major	Orange	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	6:00, 9:00, 18:00, 19:00, 20:00, 21:00	3	Commercial	Rural	FYA
13	US 192	Academy Dr	EBL	Major	Osceola	4	7:00, 8:00, 12:00, 13:00	3	6:00, 9:00, 14:00	3	Residential	Rural	FYA
			WBL	Major		4		3		3	Residential	Rural	FYA
14	Sand Lake Rd	Winegard Rd	EBL	Major	Orange	5	6:53, 7:53, 13:00, 16:00, 17:00	1	19:00	4	Commercial	Rural	FYA
15	US 17-92	Church Ave	NBL	Major	Seminole	5	7:00, 8:00, 12:00, 13:00, 17:25	2	18:25, 19:25	4	Commercial	Urban	FYA
16	SR 50	SR 417 North	EBL	Major	Orange	5.66	7:00, 8:00, 12:20, 13:00, 16:00, 17:00	2	18:00, 19:00	3	Commercial	Ramp	5-Section
17	Forest City Rd	Edgewater Dr	EBL	Minor	Orange	4	12:00, 13:00, 16:00, 17:00	3	14:00, 15:00, 18:00	3	Commercial	Urban	FYA
18	Pershing Ave	Wild Horse Rd	EBL	Major	Orange	4	12:00, 13:00, 16:00, 17:00	3	14:00, 15:00, 18:00	3	Residential/ School	Urban	FYA
19	SR 50	Cricket Club Cir	EBL	Major	Orange	4	12:00, 13:00, 16:00, 17:00	3	14:00, 15:00, 18:00	3	Mixed	Rural	FYA
20	Lake Underhill Rd	Dean Rd	WBL	Major	Orange	4	12:00, 13:00, 16:00, 17:00	3	14:00, 15:00, 18:00	3	Commercial	Rural	FYA
			SBL	Minor		4	12:00, 13:00, 16:00, 17:00	3	14:00, 15:00, 18:00	3	Commercial	Rural	FYA

Table 2-3: Phase II Intersection Summary

Number	Major Road	Minor Road	Approach		County	Peak Hours		Off-Peak Hours		Lanes Crossed	Land Use	Criteria	Signal Head
21	US 1	SR 520	NBL	Minor	Brevard	6	8:53, 7:53, 11:53, 12:53, 15:53, 16:53	3	8:53, 13:53, 17:53	4	Downtown	Urban	5-Section
22A	Orange Drive	Florida's Turnpike North	EBL	Major	Broward	3	11:30, 12:30, 16:00	1	15:00	2	Residential	Ramp	5-Section
22B						1	13:00	2	14:00, 15:00	2	Residential	Ramp	5-Section
22C						5	7:00, 8:00, 12:00, 16:00, 17:00	2	11:00, 15:00	2	Residential	Ramp	5-Section
23	SR 816 (Oakland Park Blvd)	Inverrary Blvd	EBL	Major	Broward	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	4	9:00, 10:00, 11:00, 15:00	4	Mixed	Urban	5-Section
			NBL	Minor		6		4		2	Mixed	Urban	5-Section
			SBL	Minor		6		4		2	Mixed	Urban	5-Section
24A	SR 818 (Griffin Rd)	Ravenswood Rd	NBL	Minor	Broward	3	11:30, 12:30, 16:00	1	15:00	3	Mixed	Urban	5-Section
			SBL	Minor		3		1		3	Mixed	Urban	5-Section
24B			NBL	Minor		1	13:00	2	14:00, 15:00	3	Mixed	Urban	5-Section
			SBL	Minor		1		2		3	Mixed	Urban	5-Section
25A	SR 858 (Miramar Pkwy)	Monarch Lakes Blvd	EBL	Major	Broward	2.5	12:00, 13:00, 16:00	1.5	11:30, 15:00	4	Mixed	Urban	5-Section
25B						1	13:00	2	14:00, 15:00	4	Mixed	Urban	5-Section
26A	Gate Parkway	Blue Cross/Florida Blue Campus	WBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Industrial	Urban	FYA
26B						6		6		2	Industrial	Urban	FYA
26C						6		6		2	Industrial	Urban	FYA
27A	Gate Parkway	Blunt Mill Road	EBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	3	Industrial	Urban	5-Section
			WBL	Major		6		6		3	Industrial	Urban	5-Section
27B			EBL	Major		6		6		3	Industrial	Urban	5-Section
			WBL	Major		6		6		3	Industrial	Urban	5-Section
27C			EBL	Major		6		6		3	Industrial	Urban	5-Section
			WBL	Major		6		6		3	Industrial	Urban	5-Section
28A	Gate Parkway	E. Deer Lake Dr	WBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Industrial	Urban	5-Section
			EBL	Major		6		6		2	Industrial	Urban	5-Section
28B			WBL	Major		6		6		2	Industrial	Urban	5-Section
			EBL	Major		6		6		2	Industrial	Urban	5-Section
28C			WBL	Major		6		6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Industrial	Urban	5-Section
			EBL	Major		6		6		2	Industrial	Urban	5-Section
28D			WBL	Major		6		6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Industrial	Urban	5-Section
			EBL	Major		6		6		2	Industrial	Urban	5-Section
28E			WBL	Major		6		6		2	Industrial	Urban	5-Section
			EBL	Major		6		6		2	Industrial	Urban	5-Section
28F			WBL	Major		6		6		2	Industrial	Urban	5-Section
			EBL	Major		6		6		2	Industrial	Urban	5-Section

Table 2-3: Phase II Intersection Summary (Continued)

Flashing Yellow Arrow Phase II Data Summary Table													
Number	Major Road	Minor Road	Approach		County	Peak Hours		Off-Peak Hours		Lanes Crossed	Land Use	Criteria	Signal Head
29A 29B 29C	Gate Parkway	W. Deer Lake Dr	WBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Commercial	Urban	5-Section
			EBL	Major		6		6		2	Commercial	Urban	5-Section
			SBL	Minor		6		6		1	Commercial	Single Lane	5-Section
			WBL	Major		6		6		2	Commercial	Urban	5-Section
			EBL	Major		6		6		2	Commercial	Urban	5-Section
			SBL	Minor		6		6		1	Commercial	Single Lane	5-Section
			WBL	Major		6		6		2	Commercial	Urban	5-Section
			EBL	Major		6		6		2	Commercial	Urban	5-Section
			SBL	Minor		6		6		1	Commercial	Single Lane	5-Section
30A 30B 30C 30D	Gate Parkway	Deerwood Park Blvd	WBL	Minor	Duval	2	16:00, 17:00	1	18:00	2	Commercial	Urban	5-Section
						6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Commercial	Urban	5-Section
						6		6		2	Commercial	Urban	5-Section
						6		6		2	Commercial	Urban	5-Section
31A 31B 31C 31D 31E 31F	Gate Parkway	Skinner Lake Dr	NBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	3	Commercial	Urban	5-Section
			SBL	Major		6		6		4	Commercial	Urban	5-Section
			EBL	Minor		6		6		1	Commercial	Single Lane	5-Section
			NBL	Major		6		6		3	Commercial	Urban	5-Section
			SBL	Major		6		6		4	Commercial	Urban	5-Section
			EBL	Minor		6		6		1	Commercial	Single Lane	5-Section
			NBL	Major		6		6		3	Commercial	Urban	5-Section
			SBL	Major		6		6		4	Commercial	Urban	5-Section
			EBL	Minor		6		6		1	Commercial	Single Lane	5-Section
			NBL	Major		6		6		3	Commercial	Urban	5-Section
			SBL	Major		6		6		4	Commercial	Urban	5-Section
			EBL	Minor		6		6		1	Commercial	Single Lane	5-Section
			NBL	Major		6		6		3	Commercial	Urban	5-Section
			SBL	Major		6		6		4	Commercial	Urban	5-Section
			EBL	Minor		6		6		1	Commercial	Single Lane	5-Section
			NBL	Major		6		6		3	Commercial	Urban	5-Section
			SBL	Major		6		6		4	Commercial	Urban	5-Section
			EBL	Minor		6		6		1	Commercial	Single Lane	5-Section

Table 2-3: Phase II Intersection Summary (Continued)

Flashing Yellow Arrow Phase II Data Summary Table													
Number	**Major Road**	**Minor Road**	**Approach**		**County**	**Peak Hours**		**Off-Peak Hours**		**Lanes Crossed**	**Land Use**	**Criteria**	**Signal Head**
32A 32B 32C	**Gate Parkway**	**Touchton Rd**	WBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Industrial	Urban	**5-Section**
			EBL	Major		6		6		2	Industrial	Urban	**5-Section**
			SBL	Minor		6		6		1	Industrial	Single Lane	**5-Section**
			WBL	Major		6		6		2	Industrial	Urban	**5-Section**
			EBL	Major		6		6		2	Industrial	Urban	**5-Section**
			SBL	Minor		6		6		1	Industrial	Single Lane	**5-Section**
			WBL	Major		6		6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Industrial	Urban	**5-Section**
			EBL	Major		6		6		2	Industrial	Urban	**5-Section**
			SBL	Minor		6		6		1	Industrial	Single Lane	**5-Section**
33A 33B 33C	**Town Center Pkwy**	**Babies 'R' Us Entrance**	WBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	3	Commercial	Urban	**5-Section**
						6		6		3	Commercial	Urban	**5-Section**
						6		6		3	Commercial	Urban	**5-Section**
34A 34B 34C	**Town Center Pkwy**	**Publix Entrance**	SBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	3	Commercial	Urban	**5-Section**
						6		6		3	Commercial	Urban	**5-Section**
						6		6		3	Commercial	Urban	**5-Section**
35	**US 27, 301, 441 (Pine Ave)**	**SR 464 (SW 17th St)**	NBL	Major	Marion	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	5	9:00, 11:00, 14:00, 15:00, 18:00	3	Mixed	Urban	**5-Section**
			SBL	Major		6		5		3	Mixed	Urban	**5-Section**
			EBL	Minor		6		5		2	Mixed	Urban	**5-Section**
			WBL	Minor		6		5		3	Mixed	Urban	**5-Section**
36A 36B 36C 36D 36E 36F	**SR 424 (Edgewater Dr)**	**SR 426 (Fairbanks Ave)**	SBL	Major	Orange	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	10	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Residential	Urban	**5-Section**
						6		10	18:00, 19:00, 20:00, 21:00, 9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Residential	Urban	**5-Section**
						6		6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Residential	Urban	**5-Section**
						6		9	19:00, 20:00, 21:00, 9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Residential	Urban	**5-Section**
						6		6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Residential	Urban	**5-Section**
						6		5	9:00, 10:00, 11:00, 14:00, 15:00	2	Residential	Urban	**5-Section**

Table 2-3: Phase II Intersection Summary (Continued)

Flashing Yellow Arrow Phase II Data Summary Table														
Number	Major Road	Minor Road	Approach		County	Peak Hours		Off-Peak Hours		Lanes Crossed	Land Use	Criteria	Signal Head
37A 37B	SR 7	Bella Terra Way	WBL	Minor	Palm Beach	6	12:00, 13:00, 16:00, 17:00, 7:00, 8:00	7	11:00, 14:00, 15:00, 18:00, 9:00, 10:00, 11:00	1	Mixed	Single Lane	5-Section
			EBL	Minor		6		7		1	Mixed	Single Lane	5-Section
			WBL	Minor		6	12:00, 13:00, 16:00, 17:00, 7:00, 8:00	6	14:00, 15:00, 18:00, 9:00, 10:00, 11:00	1	Mixed	Single Lane	5-Section
			EBL	Minor		6		6		1	Mixed	Single Lane	5-Section
			WBL	Minor		6		6		1	Mixed	Single Lane	5-Section
			EBL	Minor		6		6		1	Mixed	Single Lane	5-Section
38	US 1	Flomich St	NBL	Major	Volusia	2	16:00, 17:00	2.5	14:00, 15:00, 18:00	2	Commercial	Urban	5-Section
			SBL	Major		2		2.5		2	Commercial	Urban	5-Section

2.3 Conclusions

The additional data provided by FDOT representatives was a great asset to the success of this project. It is noted that with the usable data added to the collection, the database has increased to 38 intersections across the State of Florida. The intersections database now includes locations in Central, South and Northeast Florida as shown in Figure 2-2. It is of importance to mention that distribution of the data hours are not even for the 5-Section Head and flashing yellow arrow. The video data only included 110 hours that have a flashing yellow arrow configuration out of a total of 1,369 hours at all the intersections due to the fact that the FYA signals are still considered new in the State of Florida.

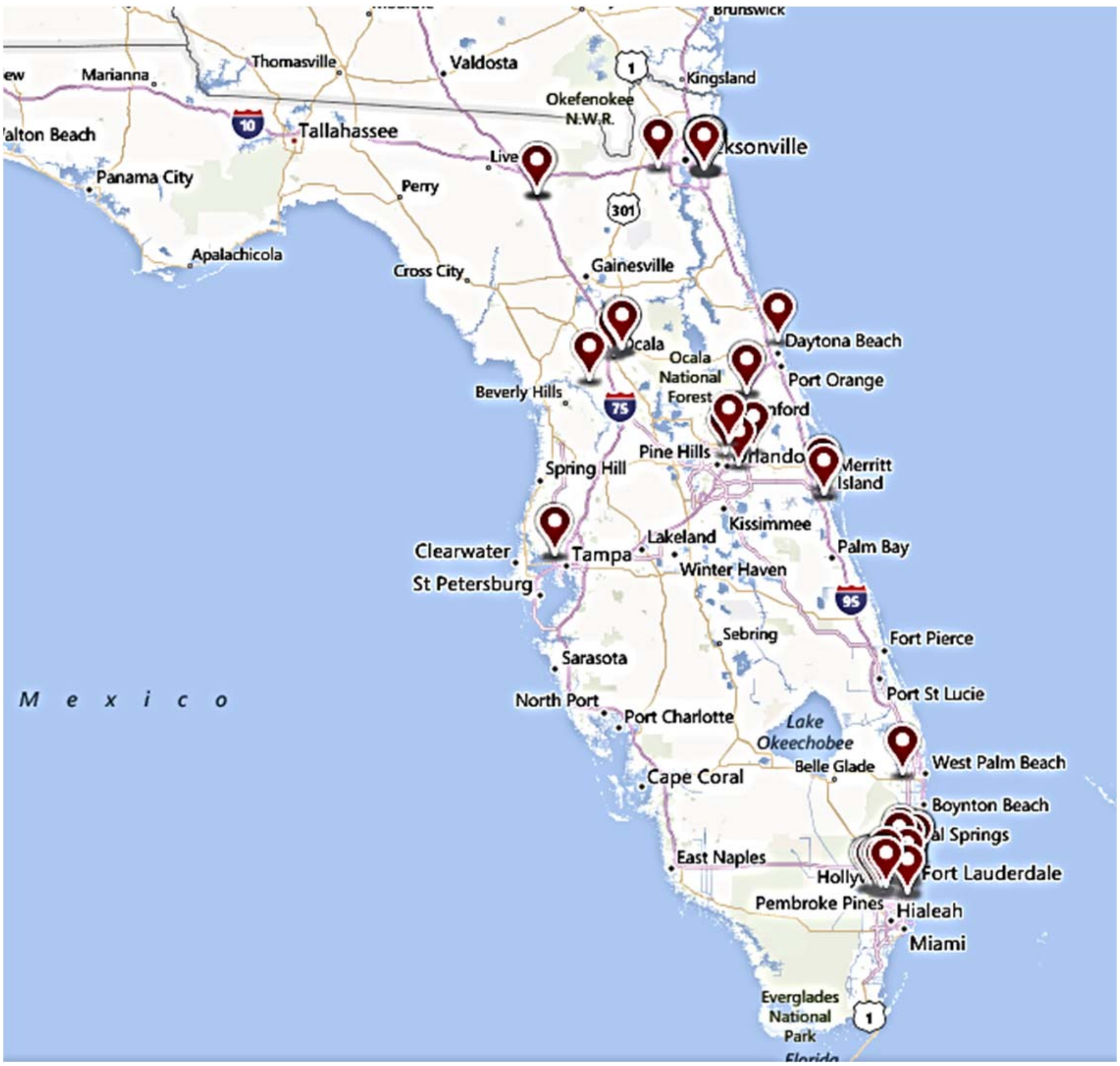


Figure 2-2: Map View of Intersection Locations across the State

3. DATA EXTRACTION

3.1 Data Extraction Overview

The University of Central Florida (UCF) Research Team extracted all of the video data that was provided by the Florida Department of Transportation (FDOT), which totaled 1,080 hours. The data extraction task has included each selected video being processed and watched in detail. The left-turn parameters related to the traffic volume during the permissive green time, and the extents of these periods were extracted by watching the videos second-by-second, as these specific parameters cannot be logically processed by a machine. The processing of the videos required that all of the appropriate parameters be extracted from the 1,080 hours of data that were potentially viable for this study in preparation for the data analysis.

The data extraction process required the identification of specific data that reflect the nature of the project parameters. Parameters that included the geometrics and operational aspects of the intersection are important to classify the intersection. Additionally, specific categorical data parameters were used because they were considered significant enough to affect the characteristics of the traffic flow and behavior of the driver. It should be noted that this task is an expansion of the database created in phase I of the project to increase the domain and improve reliability of the developed model through the addition of about 38 intersections and analyzing an additional 1,000 hours of video.

There were several factors that required only research-based work and did not involve the use of video data. The intersection parameters that were identified in task 1 included:

- Identified Approach
- Major Road Name
- Minor Road Name
- County
- Date Including the Day of the Week
- Time of Day
- Peak Hours
- Geometry
- Surrounding Land Use Data
- Surrounding Area Criteria
- Special Cases and/or Considerations
- Number of Lanes Crossed by the Left-Turn
- Posted Speed Limit
- FYA or 5-Section Signal Configuration

Additional factors required viewing and analyzing the video clips to acquire the needed data. The data extraction process included the determination of:

- Permissive Green Time
- Permissive Left-Turn Volumes
- Opposing Thru Traffic during the Permissive Phase
- Opposing Right Turning Traffic during the Permissive Phase

The time allocation for permissive left-turns is critical to understand how the timing changes hourly throughout the day and how effective the timing is to allow left-turning vehicles to make the turn during the permissive phase. This specific measure is calculated from the moment that no left-turn indication is present on the signal head and adjacent thru traffic has the green phase. The time includes the yellow phase and is stopped at the moment where the thru traffic has been given the red phase.

It is important that the left-turns occurring during the permissive phase are accounted for. The measure provides the ability to examine the times in which the permissive phase is useful for the operation of the intersection. The traffic volumes in the opposing lanes that are oncoming, impede the left-turning vehicles during the permissive left-turn phase and provide a parameter that shows the crossing volumes that the driver is challenged with when making the left-turn. This includes all the opposing thru lanes plus any exclusive right turn lanes affecting the left-turning traffic or other obstacles such as pedestrian traffic.

Each of the intersection approaches had a data sheet generated for each hour of data collection. This data sheet has the parameters that are necessary for the analysis portion of the project. A sample data extraction sheet that was being utilized by the research team is shown in Table 3-1.

Table 3-1: Sample Data Extraction Sheet – Phase II

Flashing Yellow Arrow Left Turn Data Collection							
Approach	**Major Street:** Gate Parkway			**Speed:** 45 MPH			**Type:**
EBL	**Minor Street:** E. Deer Lake Drive			**Geometry:** 4-Leg			Major
Opposing Lanes: 2 Lanes		**Criteria:** Urban		**Land Use:** Industrial			**County**
Left Turn Related Crashes: N/A			**Total Intersection Crashes:** N/A				Duval
Date	**Start**	**End**	**Totals for Values Below for Collection Period**				
Tue 3/4/14	07:00	07:59	**50:51**	**11**	**598**	**38**	**0:00**
Cycle	Start Clock Time	End Clock Time	Permitted Green Time	Left Turn Volume	Opposing TH	Opposing RT	Stop Delay
1	0:00	0:12	0:12	0	4	0	0:00
2	0:35	4:14	3:39	2	10	0	0:00
3	4:39	5:23	0:44	1	11	1	0:00
4	6:13	7:46	1:33	0	14	2	0:00
5	8:10	11:41	3:31	0	27	1	0:00
6	12:08	22:02	9:54	2	81	11	0:00
7	22:27	25:08	2:41	0	23	1	0:00
8	25:29	29:36	4:07	3	55	7	0:00
9	30:08	31:06	0:58	1	19	0	0:00
10	31:33	32:36	1:03	0	18	1	0:00
11	32:59	35:37	2:38	0	33	1	0:00
12	36:01	37:07	1:06	0	25	1	0:00
13	37:29	43:06	5:37	0	65	4	0:00
14	43:30	44:34	1:04	0	21	1	0:00
15	44:58	46:05	1:07	0	19	0	0:00
16	46:30	47:36	1:06	0	23	1	0:00
17	48:00	49:06	1:06	0	14	0	0:00
18	49:28	50:35	1:07	0	12	1	0:00
19	51:00	52:05	1:05	0	23	0	0:00
20	52:30	53:35	1:05	0	27	3	0:00
21	54:08	55:20	1:12	0	24	0	0:00
22	55:43	59:59	4:16	2	50	2	0:00

3.2 Data Extraction Challenges

The research team encountered several challenges during the data extraction process. Low traffic volumes were an issue at several sites during the off peak and weekend hours. Even with the elimination of a large amount of these hours through the initial data filtering, there were a number of hours that had very little or no left-turning vehicles at all. Particularly, this has affected one of the signals that have a flashing yellow arrow as a left-turn signal, eliminating 24 of the 36 data hours that were to be used for this intersection. These low volumes have rendered the data unusable for the data hours affected in addition to making the permissive green time difficult to determine. It should be noted that a full detailed analysis about these data hours were completed prior to beginning the data analysis.

Many of the cameras provided a clear view of the intersection itself but did not have full views of the influence areas of the intersections. When the signal head is not visible, the queue areas are largely responsible for helping the research team determine the signal that should be displayed. A clear view of the traffic signal was also an impediment at many of the intersections. In all, the cameras were not angled to optimize the data extraction process and did not facilitate some of the additional data extraction activities that occurred with the data analysis. These factors made it much more time consuming to determine the permissive green time for each cycle.

In general, most of the phase II intersections had many more cycles than those collected in phase I. This resulted in longer data extraction times for the research team. Although additional parameters were desired, the research team determined that the most important ones were the permissive green times, permissive left-turns and opposing traffic volumes. Being that these parameters are at the crux of the research goals, they were prioritized and completed as the first step of the data extraction. As needed for the data analysis, the additional parameters of left-turn timing, left-turn gap, opposing lane utilization and left-turn stop delay were collected moving forward.

The data analysis, which took place as part of task 3, pinpointed the appropriate selection of data sets by identifying those sets that may have low left-turn volume or other circumstances that may require removal from the data set. Additionally, the team refined these data extraction sheets to data tables containing the pertinent information from each data hour. The team also utilized the Turning Movement Counts (TMCs), provided by Miovision Technologies, throughout the entire process, as necessary.

3.3 Data Extraction Progress

Based on the data extraction, the following table identifies each data collection set and its data extraction progress. As shown in Table 3-2, 100% of the data extraction hours are completed (1,080 hours).

Table 3-2: FYA Project Phase II Data Extraction Progress

Flashing Yellow Arrow Phase II Data Extraction Progress Matrix						
Number	Major Road	Minor Road	Approach	Cycle Times & Traffic Counts		
				Hours Required	Hours Complete	Complete
				1079.5	1079.5	100%
21	US 1	SR 520	NBL	9	9	Yes
22A	Orange Drive	Florida's Turnpike North	EBL	4	4	Yes
22B				3	3	Yes
22C				7	7	Yes
23	SR 816 (Oakland Park Blvd)	Inverrary Blvd	EBL	10	10	Yes
			NBL	10	10	Yes
			SBL	10	10	Yes
24A	SR 818 (Griffin Rd)	Ravenswood Rd	NBL	4	4	Yes
			SBL	4	4	Yes
24B			NBL	3	3	Yes
			SBL	3	3	Yes
25A	SR 858 (Miramar Pkwy)	Monarch Lakes Blvd	EBL	4	4	Yes
25B				3	3	Yes
26A	Gate Parkway	Blue Cross/Florida Blue Campus	WBL	12	12	Yes
26B				12	12	Yes
26C				12	12	Yes
27A	Gate Parkway	Blunt Mill Road	EBL	12	12	Yes
			WBL	12	12	Yes
27B			EBL	12	12	Yes
			WBL	12	12	Yes
27C			EBL	12	12	Yes
			WBL	12	12	Yes
28A	Gate Parkway	E. Deer Lake Dr	WBL	12	12	Yes
			EBL	12	12	Yes
28B			WBL	12	12	Yes
			EBL	12	12	Yes
28C			WBL	12	12	Yes
			EBL	12	12	Yes
28D			WBL	12	12	Yes
			EBL	12	12	Yes
28E			WBL	12	12	Yes
			EBL	12	12	Yes
28F			WBL	12	12	Yes
			EBL	12	12	Yes

Table 3-2: FYA Project Phase II Data Extraction Progress (Continued)

29A	Gate Parkway	W. Deer Lake Dr	WBL	12	12	Yes
			EBL	12	12	Yes
			SBL	12	12	Yes
29B			WBL	12	12	Yes
			EBL	12	12	Yes
			SBL	12	12	Yes
29C			WBL	12	12	Yes
			EBL	12	12	Yes
			SBL	12	12	Yes
30A	Gate Parkway	Deerwood Park Blvd	WBL	3	3	Yes
30B				12	12	Yes
30C				12	12	Yes
30D				12	12	Yes
31A	Gate Parkway	Skinner Lake Dr	NBL	12	12	Yes
			SBL	12	12	Yes
			EBL	12	12	Yes
31B			NBL	12	12	Yes
			SBL	12	12	Yes
			EBL	12	12	Yes
31C			NBL	12	12	Yes
			SBL	12	12	Yes
			EBL	12	12	Yes
31D			NBL	12	12	Yes
			SBL	12	12	Yes
			EBL	12	12	Yes
31E			NBL	12	12	Yes
			SBL	12	12	Yes
			EBL	12	12	Yes
31F			NBL	12	12	Yes
			SBL	12	12	Yes
			EBL	12	12	Yes
32A	Gate Parkway	Touchton Rd	WBL	12	12	Yes
			EBL	12	12	Yes
			SBL	12	12	Yes
32B			WBL	12	12	Yes
			EBL	12	12	Yes
			SBL	12	12	Yes
32C			WBL	12	12	Yes
			EBL	12	12	Yes
			SBL	12	12	Yes
33A	Town Center Pkwy	Babies 'R' Us Entrance	WBL	12	12	Yes
33B				12	12	Yes
33C				12	12	Yes
34A	Town Center Pkwy	Publix Entrance	SBL	12	12	Yes
34B				12	12	Yes
34C				12	12	Yes

Table 3-2: FYA Project Phase II Data Extraction Progress (Continued)

35	US 27, 301, 441 (Pine Ave)	SR 464 (SW 17th St)	NBL	11	11	Yes
			SBL	11	11	Yes
			EBL	11	11	Yes
			WBL	11	11	Yes
36A	SR 424 (Edgewater Dr)	SR 426 (Fairbanks Ave)	SBL	12	12	Yes
36B				11.5	11.5	Yes
36C				12	12	Yes
36D				12	12	Yes
36E				12	12	Yes
36F				12	12	Yes
36G				12	12	Yes
37A	SR 7	Bella Terra Way	WBL	12	12	Yes
			EBL	12	12	Yes
37B			WBL	12	12	Yes
			EBL	12	12	Yes
37C			WBL	13	13	Yes
			EBL	13	13	Yes
38	US 1	Flomich St	NBL	4.5	4.5	Yes
			SBL	4.5	4.5	Yes

3.4 Conclusions

The data extraction process was completed for the basic prioritized parameters that will be used to refine the developed model in phase I. Additional parameters such as the left-turn timing, left-turn gap, opposing lane utilization and left-turn stop delay were extracted as necessary to assist in the data analysis process. In addition, further analysis will be conducted to determine the data hours that will be usable in the statistical model in the tasks ahead. The completion of the data extraction paved the way to begin analyzing and assessing the data provided.

It is of importance to note that some minor changes have been made to the data provided to the UCF team. The updated tables have minor updates in regards to specific items discovered during video extraction that differed slightly from the original review of the files and intersection sites. The following, in Table 3-3, is the updated summary of intersection data that included all of the FYA Project Data. Table 3-4 is an updated version of the detailed analysis of the specific intersections that were provided to UCF from FDOT.

Table 3-3: Updated Project Data Properties Summary Table

FYA Data Properties Table				
Properties		**Phase I**	**Phase II**	**Total**
Opposing Lanes (Hours)	1	12	228	**240**
	2	127.16	490.5	**617.66**
	3	138.91	263	**401.91**
	4	13	98	**111**
Land Use (Hours)	Residential	56.25	97.5	**153.75**
	Commercial	68.66	444	**512.66**
	Downtown	23	9	**32**
	Industrial	0	360	**360**
	Residential/Commercial (Mixed)	37	169	**206**
	Residential/School	86.16	0	**86.16**
	Tourist	20	0	**20**
Criteria (Hours)	Rural	83.25	0	**83.25**
	Urban	59	827.5	**886.5**
	On/Off Ramp	19.66	14	**33.66**
	Single Lane	47	238	**285**
	Pedestrian	82.16	0	**82.16**
Signal Head (Hours)	Permitted	12	0	**12**
	5-Section Head	205.07	1043.5	**1248.57**
	Flashing Yellow Arrow	74	36	**110**
Total Hours	Peak	152.66	548.5	**701.16**
	Off-Peak	138.41	531.0	**669.41**
Total Approaches	Unique Approaches	31	33	**64**
	Data Collection Days	34	98	**132**

Table 3-4: FYA Project Phase II Updated Intersection Summary

Flashing Yellow Arrow Phase II Data Summary Table													
Number	**Major Road**	**Minor Road**	**Approach**		**County**	**Peak Hours**		**Off-Peak Hours**		**Lanes Crossed**	**Land Use**	**Criteria**	**Signal Head**
21	US 1	SR 520	NBL	Major	Brevard	6	6:53, 7:53, 11:53, 12:53, 15:53, 16:53	3	8:53, 13:53, 17:53	4	Downtown	Urban	5-Section
22A 22B 22C	Orange Drive	Florida's Turnpike North	EBL	Major	Broward	3	11:30, 12:30, 16:00	1	15:00	2	Residential	Ramp	5-Section
						1	13:00	2	14:00, 15:00	2	Residential	Ramp	5-Section
						5	7:00, 8:00, 12:00, 16:00, 17:00	2	11:00, 15:00	2	Residential	Ramp	5-Section
23	SR 816 (Oakland Park Blvd)	Inverrary Blvd	EBL	Major	Broward	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	4	9:00, 10:00, 11:00, 15:00	4	Mixed	Urban	5-Section
			NBL	Minor		6		4		1	Mixed	Single Lane	5-Section
			SBL	Minor		6		4		2	Mixed	Single Lane	5-Section
24A 24B	SR 818 (Griffin Rd)	Ravenswood Rd	NBL	Minor	Broward	3	11:30, 12:30, 16:00	1	15:00	3	Mixed	Urban	5-Section
			SBL	Minor		3		1		3	Mixed	Urban	5-Section
			NBL	Minor		1	13:00	2	14:00, 15:00	3	Mixed	Urban	5-Section
			SBL	Minor		1		2		3	Mixed	Urban	5-Section
25A 25B	SR 858 (Miramar Pkwy)	Monarch Lakes Blvd	EBL	Major	Broward	2.5	12:00, 13:00, 16:00	1.5	11:30, 15:00	4	Mixed	Urban	5-Section
						1	13:00	2	14:00, 15:00	4	Mixed	Urban	5-Section
26A 26B 26C	Gate Parkway	Blue Cross/Florida Blue Campus	WBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Industrial	Urban	FYA
						6		6		2	Industrial	Urban	FYA
						6		6		2	Industrial	Urban	FYA
27A 27B 27C	Gate Parkway	Blunt Mill Road	EBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	3	Industrial	Urban	5-Section
			WBL	Major		6		6		3	Industrial	Urban	5-Section
			EBL	Major		6		6		3	Industrial	Urban	5-Section
			WBL	Major		6		6		3	Industrial	Urban	5-Section
			EBL	Major		6		6		3	Industrial	Urban	5-Section
			WBL	Major		6		6		3	Industrial	Urban	5-Section
28A 28B 28C 28D 28E 28F	Gate Parkway	E. Deer Lake Dr	WBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Industrial	Urban	5-Section
			EBL	Major		6		6		2	Industrial	Urban	5-Section
			WBL	Major		6		6		2	Industrial	Urban	5-Section
			EBL	Major		6		6		2	Industrial	Urban	5-Section
			WBL	Major		6		6		2	Industrial	Urban	5-Section
			EBL	Major		6		6		2	Industrial	Urban	5-Section
			WBL	Major		6		6		2	Industrial	Urban	5-Section
			EBL	Major		6		6		2	Industrial	Urban	5-Section
			WBL	Major		6		6		2	Industrial	Urban	5-Section
			EBL	Major		6		6		2	Industrial	Urban	5-Section
			WBL	Major		6		6		2	Industrial	Urban	5-Section
			EBL	Major		6		6		2	Industrial	Urban	5-Section

Table 3-4: FYA Project Phase II Updated Intersection Summary (Continued)

Flashing Yellow Arrow Phase II Data Summary Table

Number	Major Road	Minor Road	Approach		County	Peak Hours		Off-Peak Hours		Lanes Crossed	Land Use	Criteria	Signal Head
29A 29B 29C	Gate Parkway	W. Deer Lake Dr	WBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Commercial	Urban	5-Section
			EBL	Major		6		6		2	Commercial	Urban	5-Section
			SBL	Minor		6		6		1	Commercial	Single Lane	5-Section
			WBL	Major		6		6		2	Commercial	Urban	5-Section
			EBL	Major		6		6		2	Commercial	Urban	5-Section
			SBL	Minor		6		6		1	Commercial	Single Lane	5-Section
			WBL	Major		6		6		2	Commercial	Urban	5-Section
			EBL	Major		6		6		2	Commercial	Urban	5-Section
			SBL	Minor		6		6		1	Commercial	Single Lane	5-Section
30A	Gate Parkway	Deerwood Park Blvd	WBL	Minor	Duval	2	16:00, 17:00	1	18:00	2	Commercial	Urban	5-Section
30B						6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Commercial	Urban	5-Section
30C						6		6		2	Commercial	Urban	5-Section
30D						6		6		2	Commercial	Urban	5-Section
31A 31B 31C 31D 31E 31F	Gate Parkway	Skinner Lake Dr	NBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	3	Commercial	Urban	5-Section
			SBL	Major		6		6		4	Commercial	Urban	5-Section
			EBL	Minor		6		6		1	Commercial	Single Lane	5-Section
			NBL	Major		6		6		3	Commercial	Urban	5-Section
			SBL	Major		6		6		4	Commercial	Urban	5-Section
			EBL	Minor		6		6		1	Commercial	Single Lane	5-Section
			NBL	Major		6		6		3	Commercial	Urban	5-Section
			SBL	Major		6		6		4	Commercial	Urban	5-Section
			EBL	Minor		6		6		1	Commercial	Single Lane	5-Section
			NBL	Major		6		6		3	Commercial	Urban	5-Section
			SBL	Major		6		6		4	Commercial	Urban	5-Section
			EBL	Minor		6		6		1	Commercial	Single Lane	5-Section
			NBL	Major		6		6		3	Commercial	Urban	5-Section
			SBL	Major		6		6		4	Commercial	Urban	5-Section
			EBL	Minor		6		6		1	Commercial	Single Lane	5-Section
			NBL	Major		6		6		3	Commercial	Urban	5-Section
			SBL	Major		6		6		4	Commercial	Urban	5-Section
			EBL	Minor		6		6		1	Commercial	Single Lane	5-Section

Table 3-4: FYA Project Phase II Updated Intersection Summary (Continued)

Flashing Yellow Arrow Phase II Data Summary Table

Number	Major Road	Minor Road	Approach		County	Peak Hours		Off-Peak Hours		Lanes Crossed	Land Use	Criteria	Signal Head
32A 32B 32C	Gate Parkway	Touchton Rd	WBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Industrial	Urban	5-Section
			EBL	Major		6		6		2	Industrial	Urban	5-Section
			SBL	Minor		6		6		1	Industrial	Single Lane	5-Section
			WBL	Major		6		6		2	Industrial	Urban	5-Section
			EBL	Major		6		6		2	Industrial	Urban	5-Section
			SBL	Minor		6		6		1	Industrial	Single Lane	5-Section
			WBL	Major		6		6		2	Industrial	Urban	5-Section
			EBL	Major		6		6		2	Industrial	Urban	5-Section
			SBL	Minor		6		6		1	Industrial	Single Lane	5-Section
33A 33B 33C	Town Center Pkwy	Babies 'R' Us Entrance	WBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	3	Commercial	Urban	5-Section
						6		6		3	Commercial	Urban	5-Section
						6		6		3	Commercial	Urban	5-Section
34A 34B 34C	Town Center Pkwy	Publix Entrance	SBL	Major	Duval	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	3	Commercial	Urban	5-Section
						6		6		3	Commercial	Urban	5-Section
						6		6		3	Commercial	Urban	5-Section
35	US 27, 301, 441 (Pine Ave)	SR 464 (SW 17th St)	NBL	Major	Marion	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	5	9:00, 11:00, 14:00, 15:00, 18:00	3	Mixed	Urban	5-Section
			SBL	Major		6		5		3	Mixed	Urban	5-Section
			EBL	Minor		6		5		2	Mixed	Urban	5-Section
			WBL	Minor		6		5		3	Mixed	Urban	5-Section
36A 36B 36C 36D 36E 36F 36G	SR 424 (Edgewater Dr)	SR 426 (Fairbanks Ave)	SBL	Major	Orange	6	7:00, 8:00, 12:00, 13:00, 16:00, 17:00	6	9:00, 10:00, 11:00, 14:00, 15:00, 18:00	2	Residential	Urban	5-Section
						6		5.5		2	Residential	Urban	5-Section
						6		6		2	Residential	Urban	5-Section
						6		6		2	Residential	Urban	5-Section
						6		6		2	Residential	Urban	5-Section
						6		6		2	Residential	Urban	5-Section
						6		6		2	Residential	Urban	5-Section

Table 3-4: FYA Project Phase II Updated Intersection Summary (Continued)

Flashing Yellow Arrow Phase II Data Summary Table													
Number	**Major Road**	**Minor Road**	**Approach**		**County**	**Peak Hours**		**Off-Peak Hours**		**Lanes Crossed**	**Land Use**	**Criteria**	**Signal Head**
37A 37B 37C	**SR 7**	**Bella Terra Way**	WBL	Minor	Palm Beach	6	12:00, 13:00, 16:00, 17:00, 7:00, 8:00	6	14:00, 15:00, 18:00, 9:00, 10:00, 11:00	1	Mixed	Single Lane	**5-Section**
			EBL	Minor		6		6		1	Mixed	Single Lane	**5-Section**
			WBL	Minor		6		6		1	Mixed	Single Lane	**5-Section**
			EBL	Minor		6		6		1	Mixed	Single Lane	**5-Section**
			WBL	Minor		6	12:00, 13:00, 16:00, 17:00, 7:00, 8:00	7	11:00, 14:00, 15:00, 18:00, 9:00, 10:00, 11:00	1	Mixed	Single Lane	**5-Section**
			EBL	Minor		6		7		1	Mixed	Single Lane	**5-Section**
38	**US 1**	**Flomich St**	NBL	Major	Volusia	2	16:00, 17:00	2.5	14:00, 15:00, 18:00	2	Commercial	Urban	**5-Section**
			SBL	Major		2		2.5		2	Commercial	Urban	**5-Section**

4. REFINE DEVELOPED DECISION SUPPORT SYSTEM

4.1 Overview

The UCF Research Team completed the extraction of the video data that was provided by the Florida Department of Transportation (FDOT), which totaled 1,080 hours. The data included all the left-turn related parameters during the permissive or permissive green time (Perm) and the extents of these periods in preparation for the data analysis. The extracted data provides the ability to examine the times in which the permissive phase is useful for the operation of the intersection. The oncoming traffic volumes in the opposing lanes impede the left-turning vehicles during the permissive left-turn phase and show the crossing volumes that the driver is challenged with when making the left-turn. The following categorical data parameters were significant enough to affect the characteristics of the traffic flow and behavior of the driver.

Final parameters that were included in the analysis were as follows:

- Date Including the Day of the Week (Day)
- Time of Day (TOD)
- Peak Hours (Pk/Non)
- Geometry (Gmtry)
- Surrounding Land Use Data (LU)
- Surrounding Area Criteria (Cri)
- Number of Lanes Crossed by the Left-Turn (Xing Lanes)
- Posted Speed Limit (Speed)
- Permissive Green Times (Perm Grn Tme)
- Permissive Left-Turn Volumes (Perm LT)
- Opposing Thru Traffic during the Permissive Phase (Perm Opp Thru)
- Opposing Right-Turning Traffic during the Permissive Phase (Perm Opp RT)
- Total Opposing Traffic during the Permissive Phase (Tot Perm Opp)

It should be noted that task 2 served as an expansion of the database created in phase I of the project, which included 240 hours of video, increasing the domain and improving reliability of the developed model through the addition of the 18 intersections with 33 approaches and analyzing an additional 1,080 hours of video. Total entries for phases I and II amounted to 1,322 hours of video. Phase II data also included more than 31,000 cycles which will be utilized in the refined decision support system as explained later in this report.

4.2 Data Mining

This stage usually starts with data mining which may involve data cleaning, data transformations, or selecting specific variables ("fields"). Data Mining is relatively less concerned with identifying the specific relations between the involved variables. However, it is a knowledge discovery process.

There were several challenges during the data preparation process. Extremely low traffic volumes were an issue at several sites especially during the off peak and weekend hours. Even with the elimination of a large amount of these hours through the initial data filtering, there were a number of hours that had very little or no left-turning vehicles despite the large amount of permissive green time provided, particularly along the minor side streets. These low volumes have rendered unusable data hours in addition to making the permissive green time difficult to determine. The team refined the data extraction sheets and included the pertinent information from each hour and their corresponding comments as shown in the final compiled data in Table 4-1.

The analysis in task 3 pinpointed the data sets that had low left-turning volume as well as other circumstances that required removal from the data set which might affect the modeling process and are summarized as follows:

1. Intersections with very high permissive green times (up to 55 min) and no permissive left-turns while having moderate opposing volumes (up to 500 vph)
2. Intersections with very high permissive green times (up to 55 min) with extremely low permissive left-turns (max of 2 vph) due to very low minor road volumes
3. Intersections with very low permissive green times (as low as 1 min) with very low or no permissive left-turns and very low or no opposing volumes (max of 5 vph)

The cleaning process resulted in the removal of 264 hours. The final total remaining hours used in the statistical analysis were 1,058 hours.

Table 4-1: Excerpts from Hourly Data Table – Phase II

Day	Hour	Peak	Criteria	Land Use	Xing Ln	Perm Green Time	Perm Left-Turns	Total Perm Opp	Comments
Tue	16:00	Peak	Urban	Ind	2	34:09	19	705	Light Volume on Minor Road, Channelized Right Turn
Tue	17:00	Peak	Urban	Ind	2	31:11	21	855	Light Volume on Minor Road, Channelized Right Turn
Tue	18:00	Non	Urban	Ind	2	39:59	14	746	Light Volume on Minor Road, Channelized Right Turn
Sat	7:00	Peak	Urban	Ind	2	58:47	0	153	Light Volume on Minor Road, No Permissive Left-Turns with high Perm green times- Consider Removal
Sat	8:00	Peak	Urban	Ind	2	58:17	0	260	Light Volume on Minor Road, No Permissive Left-Turns with high Perm green times- Consider Removal
Sat	9:00	Non	Urban	Ind	2	57:24	0	349	Light Volume on Minor Road, No Permissive Left-Turns with high Perm green times- Consider Removal
Sat	10:00	Non	Urban	Ind	2	56:53	1	472	Light Volume on Minor Road, Low Permissive Left-Turns
Sat	11:00	Non	Urban	Ind	2	56:22	1	568	Light Volume on Minor Road, Low Permissive Left-Turns
Sat	12:00	Peak	Urban	Ind	2	55:16	0	615	Light Volume on Minor Road, No Permissive Left-Turns with high Perm green times- Consider Removal
Sat	13:00	Peak	Urban	Ind	2	57:42	0	672	Light Volume on Minor Road, No Permissive Left-Turns with high Perm green times- Consider Removal
Sat	14:00	Non	Urban	Ind	2	52:47	0	683	Light Volume on Minor Road, No Permissive Left-Turns with high Perm green times- Consider Removal
Sat	15:00	Non	Urban	Ind	2	49:27	0	715	Light Volume on Minor Road, No Permissive Left-Turns with high Perm green times- Consider Removal

Table 4-1: Excerpts from Hourly Data Table – Phase II (Continued)

Day	Hour	Peak	Criteria	Land Use	Xing Ln	Perm Green Time	Perm Left-Turns	Total Perm Opp	Comments
Thu	16:00	Peak	On Ramp	Res	2	15:15	22	419	This is the major approach; there is a large volume of cross traffic.
Thu	17:00	Peak	On Ramp	Res	2	15:48	9	514	This is the major approach; there is a large volume of cross traffic.
Wed	7:00	Peak	Urban	Mxd	4	25:39	0	1295	No Permissive Left-Turns but due to high opposing volumes
Wed	8:00	Peak	Urban	Mxd	4	24:15	0	1440	No Permissive Left-Turns but due to high opposing volumes
Wed	9:00	Non	Urban	Mxd	4	26:54	0	1272	No Permissive Left-Turns but due to high opposing volumes
Wed	10:00	Non	Urban	Mxd	4	24:52	0	1337	No Permissive Left-Turns but due to high opposing volumes
Wed	11:00	Non	Urban	Mxd	4	25:34	0	1278	No Permissive Left-Turns but due to high opposing volumes
Wed	13:00	Peak	Urban	Mxd	4	26:42	0	1305	No Permissive Left-Turns but due to high opposing volumes
Wed	15:00	Non	Urban	Mxd	4	28:01	0	1332	No Permissive Left-Turns but due to high opposing volumes
Wed	16:00	Peak	Urban	Mxd	4	26:43	0	1194	No Permissive Left-Turns but due to high opposing volumes
Wed	7:00	Peak	Single Lane	Res	1	15:09	47	260	No comments
Wed	8:00	Peak	Single Lane	Res	1	17:22	77	254	No comments
Wed	9:00	Non	Single Lane	Res	1	14:54	46	173	No comments
Wed	10:00	Non	Single Lane	Res	1	14:12	54	299	No comments
Wed	11:00	Non	Single Lane	Res	1	13:23	75	270	No comments
Wed	12:00	Peak	Single Lane	Res	1	14:22	45	336	No comments

4.3 Model Refinement

The process of refining the interactive model previously developed in phase I, including all the previously mentioned parameters for the determination of left-turning traffic during the permissive phase, required several steps. Preliminary data exploration was first conducted to examine the data set and the relationship between the variables. Then, the statistical analysis was performed to refine the final model along with the criteria needed for the decision support system. Details of each of the above-mentioned steps are discussed in the following sections.

4.3.1 Data Exploration

Preliminary investigation of the data sets is crucial since it is an analytic process designed to explore data in the search for consistent patterns and/or systematic relationships between variables, and then to validate the findings by applying the detected patterns to new subsets of data. Figure 4-1 shows the permissive left-turn volume by time of day. Although the line of fit is consistent with the general trend, that is, increasing during off-peak hours while decreasing during peak hours, there is a considerable variability in the data. Variability refers to how spread out a group of data is. Variability is also referred to as dispersion. Data sets with similar values are said to have little variability, while data sets that have values that are spread out have high variability.

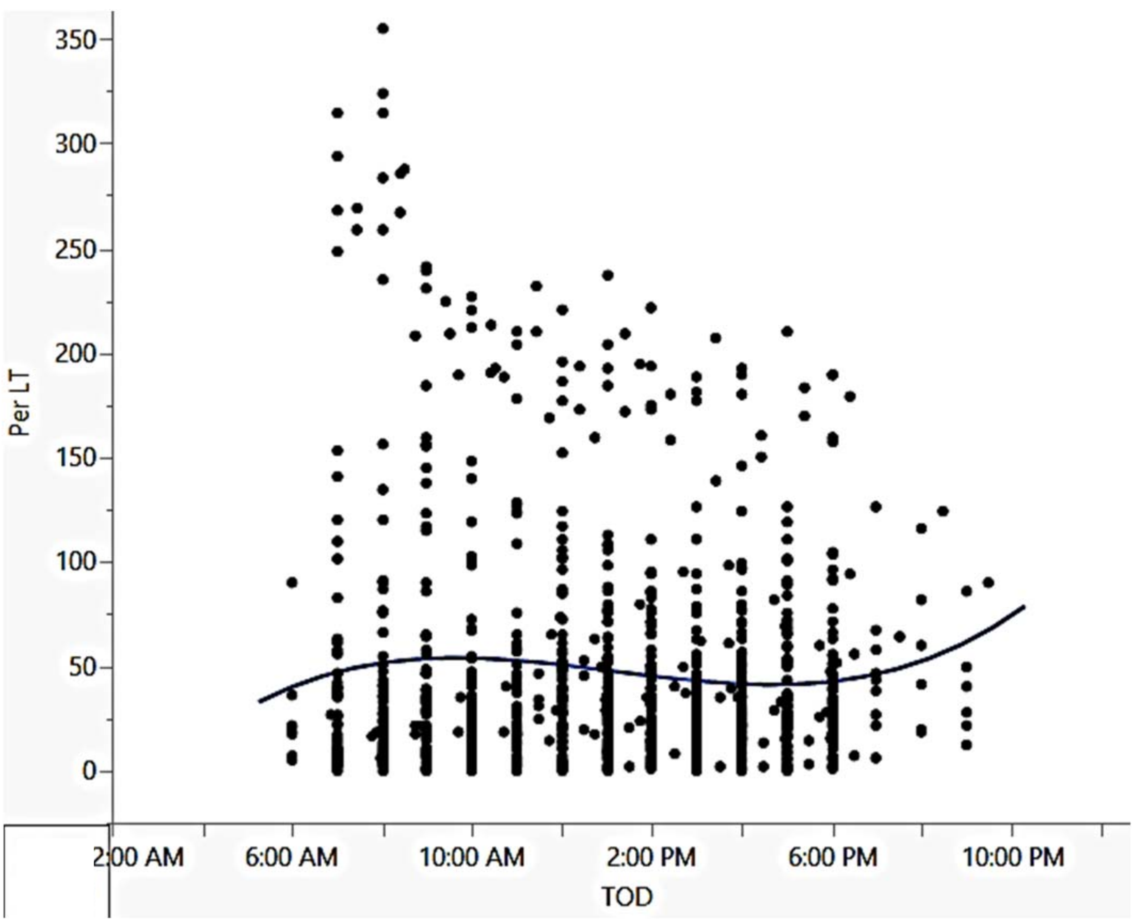


Figure 4-1: Permissive Left-Turns vs. Time of Day

Similarly, Figure 4-2 plots the permissive left-turn (Perm LT) volume against the opposing thru volume during the permissive phase (Tot Perm Opp) and shows the same variability although consistent with the general trend. The concentration of the data points in the lower region pulls down the line of fit towards the smaller values which affects the confidence of prediction resulting in underestimation of the response values. In order to reduce the variability, data sub-setting is known to contribute to variability or at least accommodate this variability through the inclusion of other data parameters. The permissive left-turn plotted against time of day and the permissive opposing volume were apportioned by land use and permissive green times as shown in Figures 4-3 and 4-4, respectively which reduced the high variability in the data.

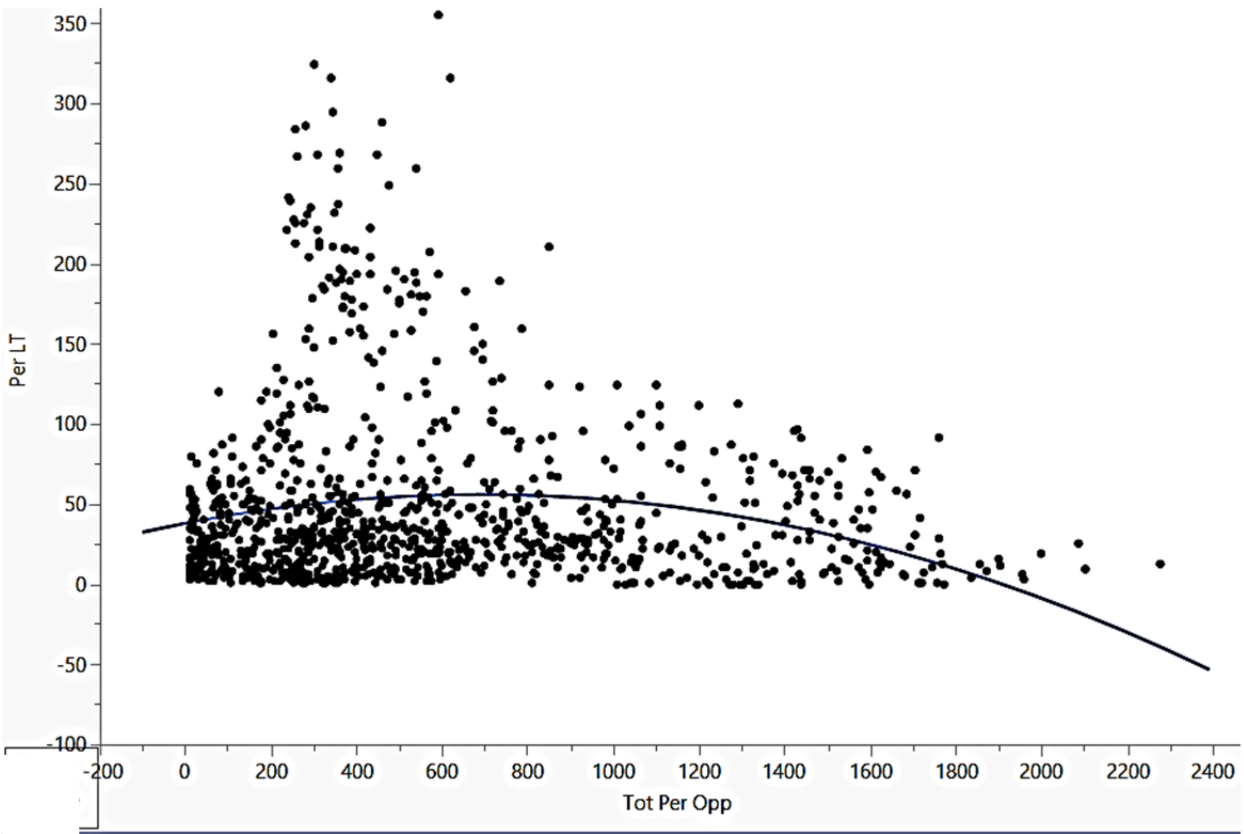


Figure 4-2: Permissive Left-Turns vs. Total Permissive Opposing Volume

Figures 4-3 and 4-4 show the significance of the categorical parameters such as land use, criteria, and the crossing lanes which emphasize on the fact that the intersection environment plays a major role in the driver's expectancy and decision.

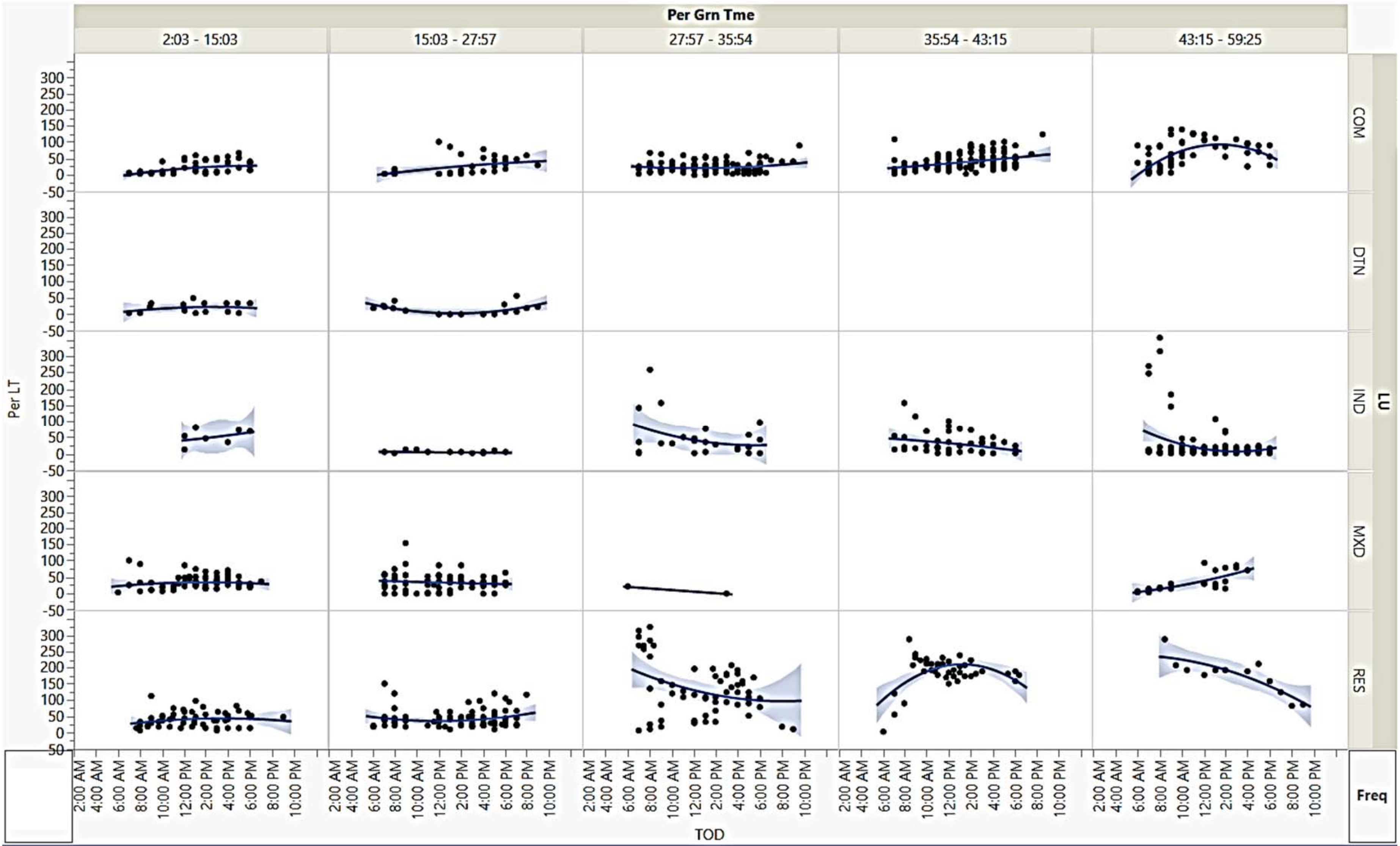


Figure 4-3: Permissive Left-Turn vs. Time of Day by Land Use and Permissive Green Time

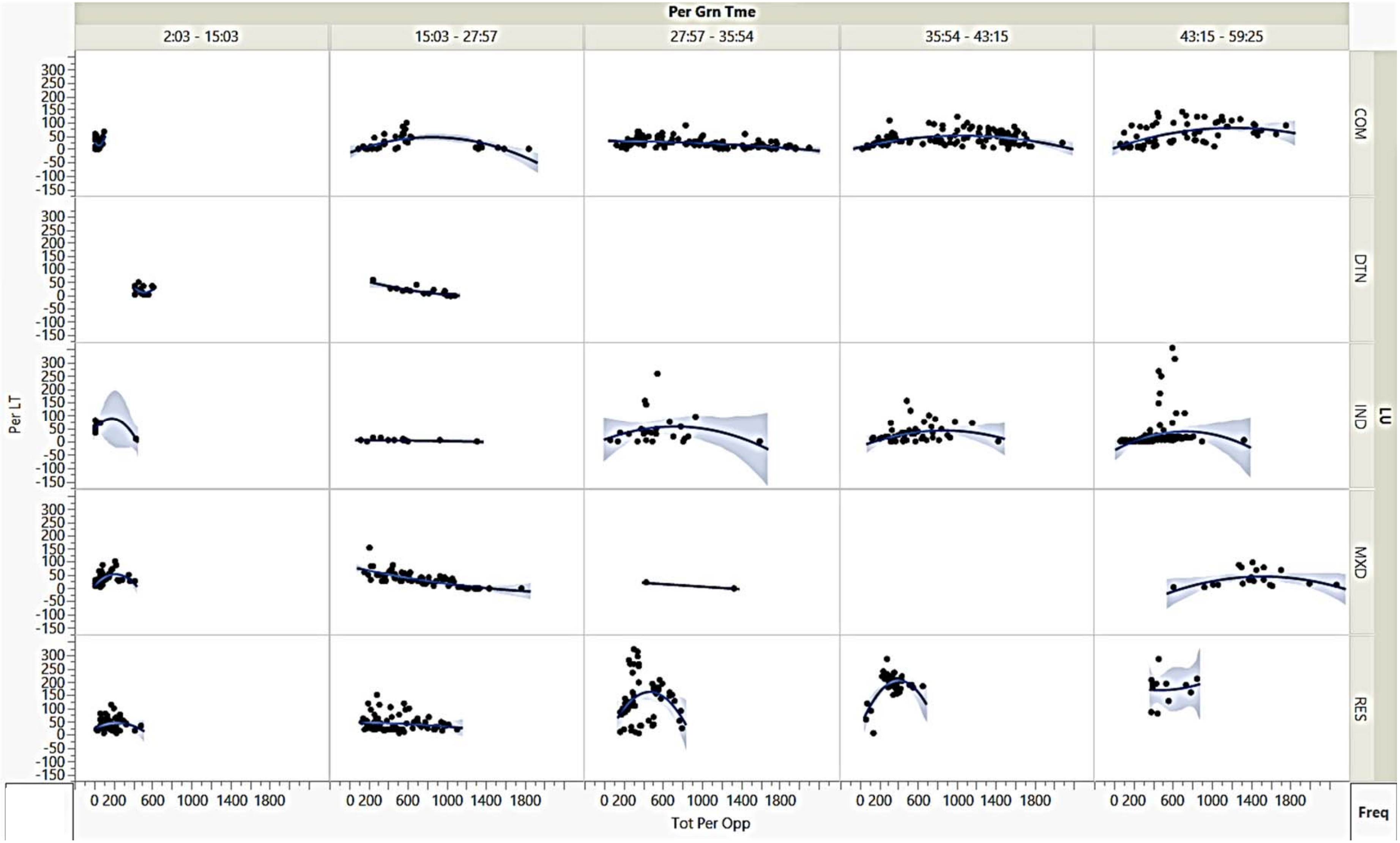


Figure 4-4: Permissive Left-Turn vs. Total Permissive Opposing Volume by Land Use and Permissive Green Time

4.3.2 Regression Analysis

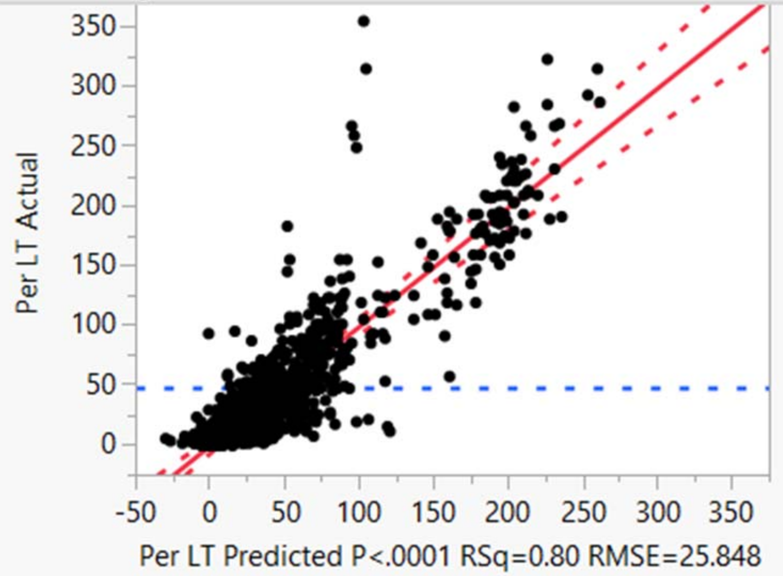
Statistical analysis was conducted for the 1,058 hours of processed data using JMP's forward stepwise regression approach with all main effects and interactions as candidate effects according to the effect hierarchy principle. Stepwise regression is a very basic way of handling variable inclusion issues when there are a large numbers of variables. This step-by-step iterative construction of the regression model that involves automatic selection of independent variables can be achieved either by trying out one independent variable at a time and including it in the regression model if it is statistically significant, or by including all potential independent variables in the model and eliminating those that are not statistically significant, or by a combination of both methods.

After several trials, the analysis resulted in a model that included six of the main effects parameters to the second and third degree along with 37 two-way and three-way factor interaction terms. However, the highest coefficient of correlation (R^2) achieved was 79% as shown in Figure 4-5. The main effects included; time of day (TOD), geometry (Gmtry), speed (Speed), permissive green time (Perm Grn Tme), and total permissive opposing volume (Tot Perm Opp) as well as the remaining two-way and three-way interaction terms as shown in Table 4-2. All the interaction terms between the categorical factors were normalized according to JMP's settings (-1, 0, and 1).

It should be noted that the Lack of Fit was also reported. It gives details for a test that assesses whether the model fits the data well. The Lack of Fit report is generated automatically when the data permits. The test relies on the ability to estimate the variance of the response using an estimate that is independent of the model. Constructing this estimate requires that response values are available at replicated values of the model effects. The test involves computing an estimate of pure error, based on a sum of squares, using these replicated observations. The difference between the error sum of squares from the model and the pure error sum of squares is called the lack of fit sum of squares. The lack of fit variation can be significantly greater than pure error variation if the model is not adequate, which is not the case here because the lack of fit was not significant. If the lack of fit was significant, then it means that the model have the wrong functional form for the predictor, or might not have enough or the correct interaction effects. The developed interactive model from the regression analysis is shown on Figure 4-6.

Since the coefficient of correlation was less than the 80% threshold, other modeling techniques were investigated which included time series analysis and neural networks. However, due to the inconsistency in the dates and times, time series analysis was not applicable. Neural network analysis is explained in the next section.

Actual by Predicted Plot



Summary of Fit

RSquare	0.795353
RSquare Adj	0.786675
Root Mean Square Error	25.84824
Mean of Response	47.88563
Observations (or Sum Wgts)	1058

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	43	2633021.8	61233.1	91.6482
Error	1014	677485.3	668.1	**Prob > F**
C. Total	1057	3310507.2		<.0001*

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	1003	677485.34	675.459	.
Pure Error	11	0.00	0.000	**Prob > F**
Total Error	1014	677485.34		.
				Max RSq
				1.0000

Figure 4-5: Regression Analysis Summary Statistics

Table 4-2: Parameter Estimates of the Regression Model

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	113.49553	2.724443	41.66	<.0001*
Gmtry[3L]	22.477935	1.994078	11.27	<.0001*
(TOD-46311.5)*Cri{Turst-U}	0.0018273	0.000199	9.18	<.0001*
(TOD-46311.5)*LU{DTN&IND&COM&MXD-RES}	0.0011468	0.000232	4.95	<.0001*
(TOD-46311.5)*Xing Ln{1&2-3&4}	0.0006831	0.000224	3.05	0.0023*
(TOD-46311.5)*(Tot Per Opp-561.698)	-1.135e-6	3.29e-7	-3.45	0.0006*
Gmtry[3L]*LU{DTN&IND-COM&MXD}	16.001214	3.007892	5.32	<.0001*
Cri{R-Turst&U&SC}*(Per Grn Tme-1831.75)	-0.052671	0.004788	-11.00	<.0001*
LU{DTN&IND&COM&MXD-RES}*Speed{35-40}	-16.88534	3.223973	-5.24	<.0001*
Speed{35-40}*Xing Ln{1&2-3&4}	-47.80462	4.721571	-10.12	<.0001*
Speed{45-55}*(Per Grn Tme-1831.75)	0.0230746	0.003561	6.48	<.0001*
Speed{25&30&35&40-45&55}*(Tot Per Opp-561.698)	-0.06196	0.006089	-10.18	<.0001*
Speed{45-55}*(Tot Per Opp-561.698)	0.0790188	0.025415	3.11	0.0019*
Xing Ln{1-2}*(Tot Per Opp-561.698)	-0.051393	0.011471	-4.48	<.0001*
(TOD-46311.5)*PK[Non]*LU{DTN&IND-COM&MXD}	0.0002412	7.556e-5	3.19	0.0015*
(TOD-46311.5)*PK[Non]*Speed{45-55}	0.0002453	7.882e-5	3.11	0.0019*
(TOD-46311.5)*Cri{R&Turst&U&SC-RMP}*LU{DTN&IND&COM&MXD-RES}	-0.001834	0.000231	-7.94	<.0001*
(TOD-46311.5)*Cri{Turst-U}*LU{DTN&IND&COM&MXD-RES}	-0.002271	0.000233	-9.76	<.0001*
(TOD-46311.5)*Cri{R&Turst&U&SC-RMP}*Xing Ln{1&2-3&4}	-0.000994	0.00022	-4.52	<.0001*
(TOD-46311.5)*Cri{Turst&U-SC}*(Tot Per Opp-561.698)	-2.909e-6	5.843e-7	-4.98	<.0001*
(TOD-46311.5)*LU{DTN&IND-COM&MXD}*Speed{25&30&35&40-45&55}	0.0006576	9.266e-5	7.10	<.0001*
(TOD-46311.5)*LU{DTN&IND&COM&MXD-RES}*(Tot Per Opp-561.698)	2.2656e-6	4.721e-7	4.80	<.0001*
(TOD-46311.5)*Speed{45-55}*Xing Ln{1-2}	0.0009879	0.00021	4.71	<.0001*
(TOD-46311.5)*Xing Ln{1&2-3&4}*(Tot Per Opp-561.698)	-1.2e-6	2.226e-7	-5.39	<.0001*
PK[Non]*LU{DTN&IND-COM&MXD}*(Per Grn Tme-1831.75)	-0.003104	0.001039	-2.99	0.0029*
Gmtry[3L]*Cri{Turst-U}*LU{DTN&IND-COM&MXD}	15.526513	2.891571	5.37	<.0001*
Gmtry[3L]*Xing Ln{1-2}*(Tot Per Opp-561.698)	-0.080753	0.010311	-7.83	<.0001*
Cri{R-Turst&U&SC}*LU{DTN&IND&COM&MXD-RES}*Speed{45-55}	56.779804	2.543421	22.32	<.0001*
Cri{Turst&U-SC}*LU{DTN&IND&COM&MXD-RES}*Speed{25-30}	22.097692	3.955869	5.59	<.0001*
Cri{R&Turst&U&SC-RMP}*Speed{35-40}*Xing Ln{1&2-3&4}	46.908962	5.693831	8.24	<.0001*
Cri{R&Turst&U&SC-RMP}*Speed{35-40}*Xing Ln{1-2}	10.543562	2.494031	4.23	<.0001*
Cri{R&Turst&U&SC-RMP}*Speed{45-55}*(Tot Per Opp-561.698)	-0.104521	0.025175	-4.15	<.0001*
LU{DTN&IND&COM&MXD-RES}*Speed{25&30&35&40-45&55}*Xing Ln{1&2-3&4}	-8.940412	1.36172	-6.57	<.0001*
LU{DTN&IND&COM&MXD-RES}*Speed{45-55}*(Per Grn Tme-1831.75)	-0.053776	0.003444	-15.61	<.0001*
LU{DTN&IND&COM&MXD-RES}*Xing Ln{1&2-3&4}*(Per Grn Tme-1831.75)	-0.008048	0.001694	-4.75	<.0001*
LU{DTN-IND}*Xing Ln{3-4}*(Per Grn Tme-1831.75)	0.0292893	0.004627	6.33	<.0001*

Table 4-2: Parameter Estimates of the Regression Model (Continued)

LU{DTN-IND}*Xing Ln{1-2}*(Tot Per Opp-561.698)	0.0515441	0.010434	4.94	<.0001*
Speed{35-40}*Xing Ln{3-4}*(Per Grn Tme-1831.75)	-0.035614	0.00799	-4.46	<.0001*
Speed{25&30&35&40-45&55}*Xing Ln{1&2-3&4}*(Tot Per Opp-561.698)	-0.015759	0.004622	-3.41	0.0007*
(TOD-46311.5)*(TOD-46311.5)	2.0532e-8	5.741e-9	3.58	0.0004*
Speed{25&30-35&40}*Speed{25&30-35&40}	-26.07397	4.7082	-5.54	<.0001*
(Per Grn Tme-1831.75)*(Per Grn Tme-1831.75)*(Per Grn Tme-1831.75)	-1.002e-8	1.298e-9	-7.72	<.0001*
(Tot Per Opp-561.698)*(Tot Per Opp-561.698)	-8.66e-5	1.034e-5	-8.37	<.0001*
(Tot Per Opp-561.698)*(Tot Per Opp-561.698)*(Tot Per Opp-561.698)	4.5161e-8	7.261e-9	6.22	<.0001*

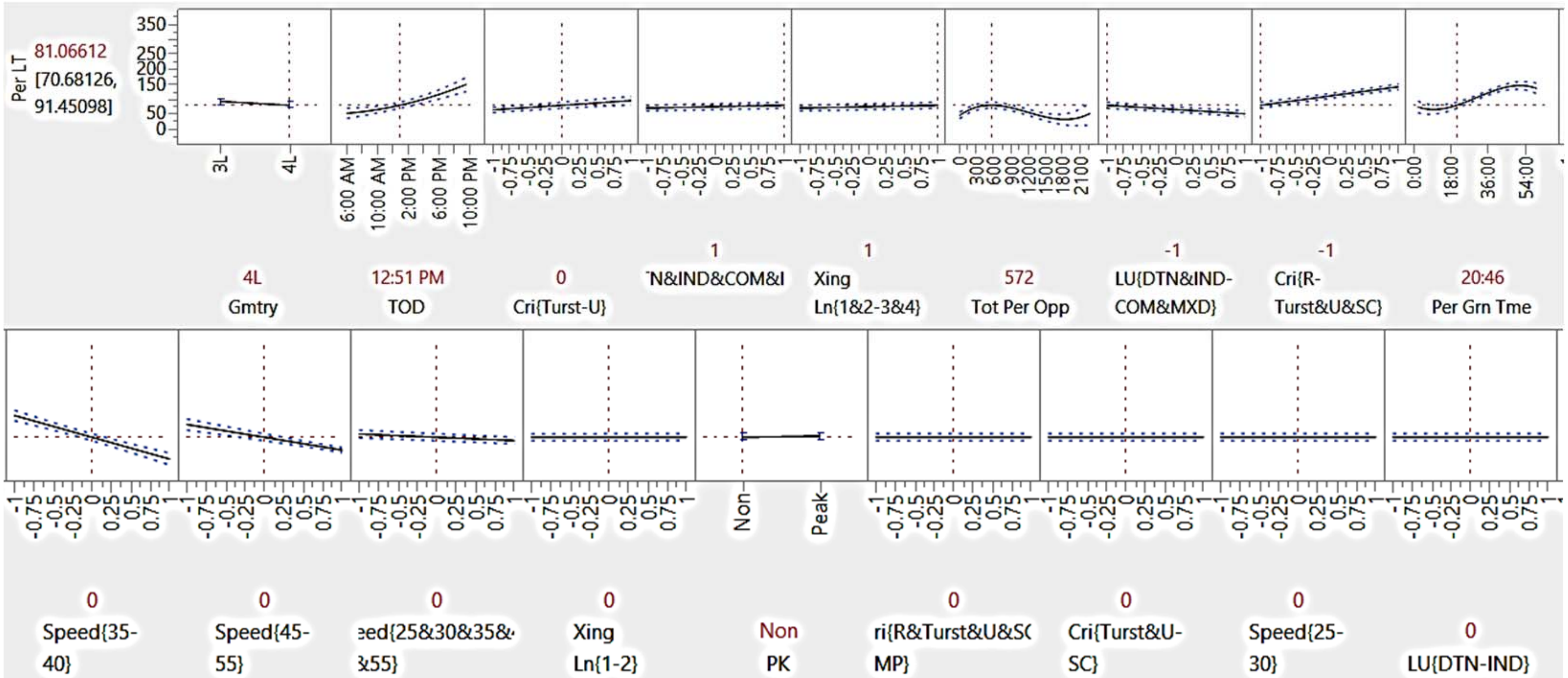


Figure 4-6: Interactive Model from Regression Analysis

4.3.3 Neural Networks (NN) Modeling

Neural networks are applicable in virtually every situation in which a relationship between the predictor variables (independents, inputs) and predicted variables (dependents, outputs) exists, even when that relationship is very complex and not easy to articulate in the usual terms of correlations or differences between groups. They fit non-linear models using nodes and layers.

The Neural platform implements a fully connected multi-layer network with one or two layers. Unlimited number of nodes can be added to either layer. They are generally presented as systems of interconnected "neurons" which send messages to each other as shown on Figure 4-7. The connections have numeric weights that can be tuned based on experience, making neural nets adaptive to inputs and capable of learning. Neural networks are used to predict one or more response variables using a flexible function of the input variables. They are considered very good predictors when the non-parametric variables have high variability as they induce hypotheses that generalize better than those of competing algorithms. Several empirical studies have pointed out that neural networks provide superior predictive accuracy to commonly used symbolic learning algorithms. The main technique is learning the target concept than other commonly used data mining methods.

NN is typically defined by three types of parameters:

1. The interconnection pattern between the different layers of neurons
2. The learning process for updating the weights of the interconnections
3. The activation function that converts a neuron's weighted input to its output activation.

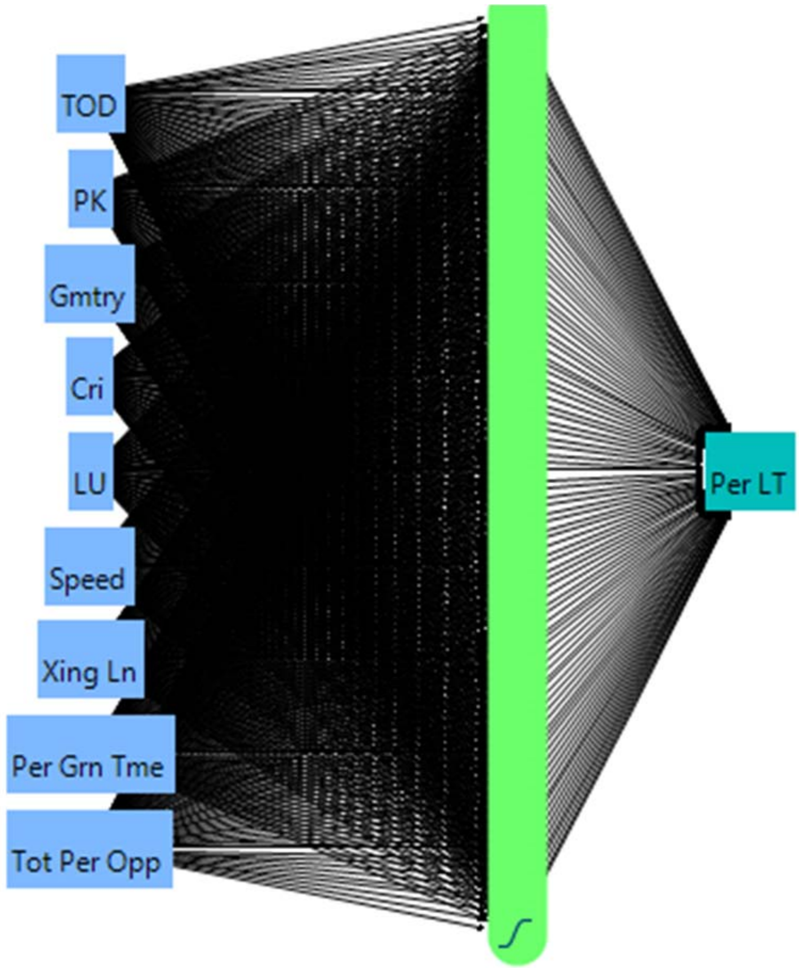


Figure 4-7: Neural Network Modeling Diagram

Neural networks use an independent data set to assess the predictive power of the model. This is achieved by splitting the data into two data sets. One is used for "Training" and the other is used for "Validation". The training set is the part that estimates model parameters, while the validation set is the part that estimates the optimal value of the response, and assesses or validates the predictive ability of the model. As can be seen from Table 4-2, the data set is split into the training model with 82% of the entries (867 hours) while the validation model included the remaining 18% (191 hours). There were two types of validation, K-Fold and Holdback. The K-Fold method divides the original data into K subsets. In turn, each of the K sets is used to validate the model fit on the rest of the data, fitting a total of K models. The model giving the best validation statistic is chosen as the final model. The Holdback method randomly divides the original data into the training and validation sets. The user holdback or specifies certain proportion of the original data to use as the validation set which was the method used in the study. The analysis resulted in a coefficient of correlation of 90% for the main model and 88% for the validation model as shown on Table 4-3. Figure 4-8 displays the actual versus predicted values for each of the two data sets which shows high correlation. The final interactive model is displayed on Figure 4-9.

Table 4-3: Neural Network Summary Statistics

Training		Validation	
Per LT		Per LT	
Measures	**Value**	**Measures**	**Value**
RSquare	0.9017192	RSquare	0.881777
RMSE	17.589305	RMSE	18.955818
Mean Abs Dev	8.6606475	Mean Abs Dev	14.067646
-LogLikelihoo	3716.161	-LogLikelihoo	832.96045
SSE	268235.62	SSE	68630.702
Sum Freq	867	Sum Freq	191

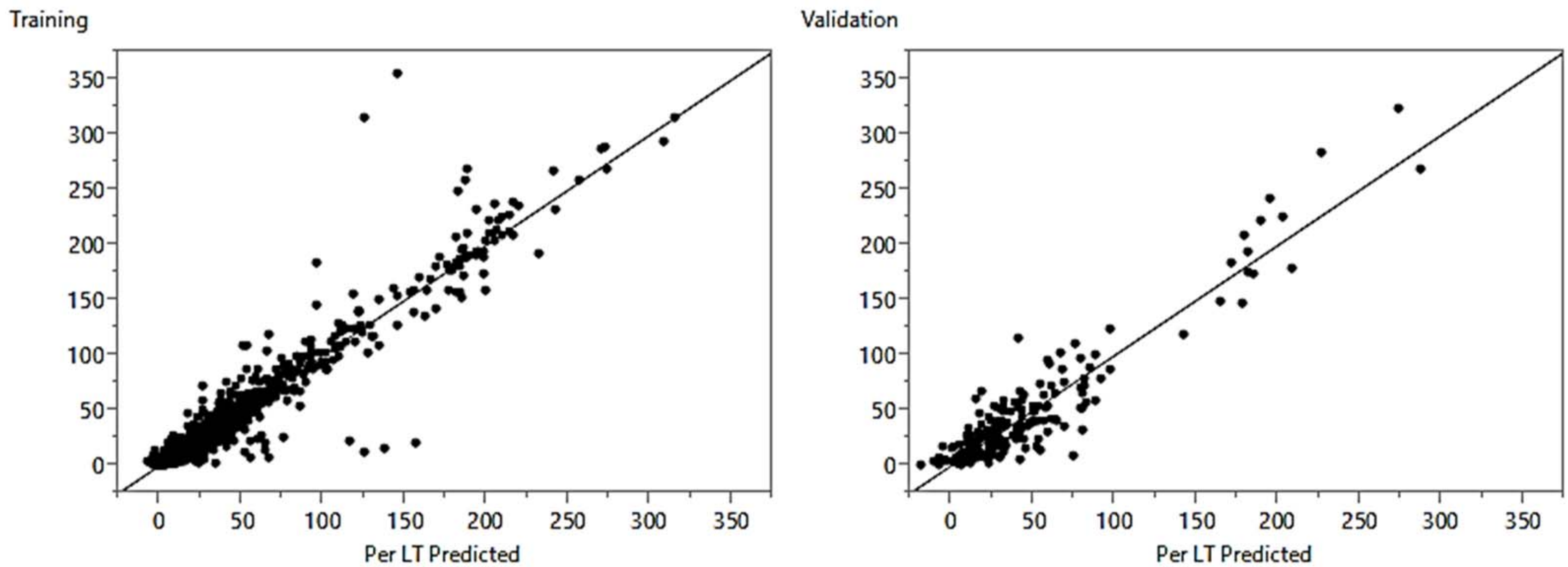


Figure 4-8: Actual by Predicted for Training and Validation Data Sets

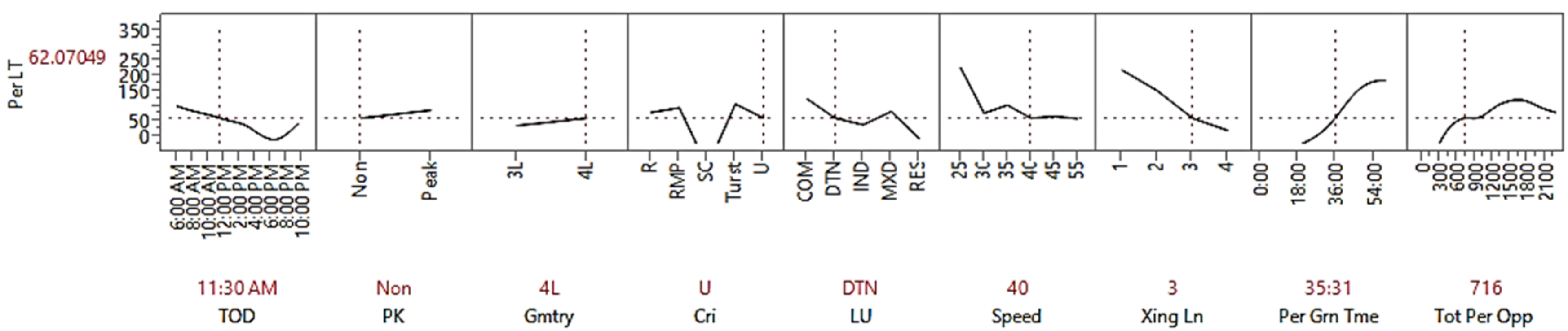


Figure 4-9: Interactive Model from Neural Network Analysis

4.4 Decision Support System Refinement

As discussed in phase I, after the model predicts the number of left-turns during the permissive phase, the analyst or the controller (after field implementation) has to decide whether to accept or reject the permissive phase. The same four criteria mentioned in phase I are still valid, which included two criteria related to operations and the other two related to safety:

1. Permissive Left-Turn Index (Perm LT Index)
   Perm LT Index = (Perm LT Vol * Tot Perm Opp Vol) / (Perm Grn Time in seconds) -- 1
2. Permissive Left-Turn Ratio (Perm LT Ratio)
   Perm LT Ratio = Perm LT Vol / Tot LT Vol ------------------------ 2
3. Left-Turn Crashes per year in the past 3 years < 2 (LT Crashes)
   LT Crashes/Yr < 2 or > 2 crashes in the past 3 years --------------------------- 3
4. Heavy Pedestrian or School Activity (Peds/SC)
   Peds/SC = Yes or No -------------------------- 4

However, in order to dynamically predict the permissive lefts in the field, two out of the nine independent parameters in the model need to be known or given, which are the opposing thru traffic and the amount of permissive green times. The remaining seven categorical parameters are easy to determine for each intersection and should be preset in the intersection database of the Traffic Management Center (TMC). The seven parameters are time of day, land use, criteria, geometry, crossing lanes, speed limit, and whether it is peak or off-peak. Thus, in the case of field detection by the controller, additional methodology or procedure is required to get this information in advance of each hour of the day before giving a recommendation.

The permissive green times and the opposing thru traffic were determined on a cycle-by-cycle basis from the field. This was achieved through the use of loop detectors or video detection to count the number of opposing vehicles, while the cycle length and splits were used to determine the amount of permissive green time in each cycle. The logic to give recommendation was based on calculating the average headway for three to five cycles before recommending a decision for the rest of the hour. From the 31,000-cycle data collected in this project, it was determined that on average, a minimum of 4 seconds is needed to consider accepting a permissive phase. Excerpts from the cycle data collected are shown on Table 4-4.

Virtual testing using VISSIM application programming interface (API) in task 4 will confirm the applicability and validity of the above mentioned procedure and logic before moving on to the final objective of running a field test through the use of a pilot study.

Table 4-4: Excerpts from Cycle Data Table – Phase II

Day	TOD	Peak	Gmtry	Cri	LU	Speed	Xing Lanes	Perm Grn Tme	Perm LT	Tot Perm Opp
Mon	7:00	PK	4L	U	DTN	45	4	**0:33**	1	**6**
Mon	7:00	PK	4L	U	DTN	45	4	**0:45**	3	**4**
Mon	7:00	PK	4L	U	DTN	45	4	**0:35**	0	**13**
Mon	7:00	PK	4L	U	DTN	45	4	**0:49**	3	**16**
Mon	7:00	PK	4L	U	DTN	45	4	**0:42**	2	**15**
Mon	7:00	PK	4L	U	DTN	45	4	**0:28**	2	**2**
Mon	7:00	PK	4L	U	DTN	45	4	**0:31**	1	**10**
Mon	7:00	PK	4L	U	DTN	45	4	**0:28**	0	**6**
Mon	7:00	PK	4L	U	DTN	45	4	**0:33**	1	**6**
Mon	7:00	PK	4L	U	DTN	45	4	**0:39**	0	**12**
Mon	7:00	PK	4L	U	DTN	45	4	**0:49**	3	**25**
Mon	7:00	PK	4L	U	DTN	45	4	**0:49**	1	**23**
Mon	7:00	PK	4L	U	DTN	45	4	**0:33**	0	**27**
Mon	7:00	PK	4L	U	DTN	45	4	**0:48**	0	**37**
Mon	7:00	PK	4L	U	DTN	45	4	**0:28**	1	**23**
Mon	7:00	PK	4L	U	DTN	45	4	**0:39**	1	**27**
Mon	7:00	PK	4L	U	DTN	45	4	**0:45**	2	**25**
Mon	7:00	PK	4L	U	DTN	45	4	**0:43**	3	**18**
Mon	7:00	PK	4L	U	DTN	45	4	**0:40**	0	**37**
Mon	7:00	PK	4L	U	DTN	45	4	**0:48**	1	**43**
Mon	7:00	PK	4L	U	DTN	45	4	**0:48**	1	**40**
Mon	7:00	PK	4L	U	DTN	45	4	**0:44**	0	**41**
Mon	7:00	PK	4L	U	DTN	45	4	**0:44**	1	**35**
Mon	8:00	PK	4L	U	DTN	45	4	**0:47**	0	**51**
Mon	8:00	PK	4L	U	DTN	45	4	**0:48**	1	**54**
Mon	8:00	PK	4L	U	DTN	45	4	**0:49**	3	**38**
Mon	8:00	PK	4L	U	DTN	45	4	**0:28**	0	**15**
Mon	8:00	PK	4L	U	DTN	45	4	**0:49**	1	**36**
Mon	8:00	PK	4L	U	DTN	45	4	**0:46**	1	**31**
Mon	8:00	PK	4L	U	DTN	45	4	**0:47**	0	**31**
Mon	8:00	PK	4L	U	DTN	45	4	**0:49**	0	**29**
Mon	8:00	PK	4L	U	DTN	45	4	**0:31**	1	**18**

Table 4-4: Excerpts from Cycle Data Table – Phase II (Continued)

Day	TOD	Peak	Gmtry	Cri	LU	Speed	Xing Lanes	Perm Grn Tme	Perm LT	Tot Perm Opp
Mon	8:00	PK	4L	U	DTN	45	4	**0:30**	0	**13**
Mon	8:00	PK	4L	U	DTN	45	4	**0:33**	0	**9**
Mon	8:00	PK	4L	U	DTN	45	4	**0:42**	0	**17**
Mon	8:00	PK	4L	U	DTN	45	4	**0:44**	1	**18**
Mon	8:00	PK	4L	U	DTN	45	4	**0:36**	1	**33**
Mon	8:00	PK	4L	U	DTN	45	4	**0:34**	0	**18**
Mon	8:00	PK	4L	U	DTN	45	4	**0:50**	0	**24**
Mon	8:00	PK	4L	U	DTN	45	4	**0:48**	2	**35**
Mon	8:00	PK	4L	U	DTN	45	4	**0:22**	2	**7**
Mon	8:00	PK	4L	U	DTN	45	4	**0:39**	1	**22**
Mon	13:00	PK	4L	U	DTN	45	4	**0:48**	0	**45**
Mon	13:00	PK	4L	U	DTN	45	4	**0:36**	4	**30**
Mon	14:00	Non	4L	U	DTN	45	4	**0:48**	0	**32**
Mon	14:00	Non	4L	U	DTN	45	4	**0:42**	4	**31**
Mon	14:00	Non	4L	U	DTN	45	4	**0:48**	3	**24**
Mon	14:00	Non	4L	U	DTN	45	4	**0:49**	2	**31**
Mon	14:00	Non	4L	U	DTN	45	4	**0:48**	1	**29**
Mon	14:00	Non	4L	U	DTN	45	4	**0:48**	1	**27**
Mon	14:00	Non	4L	U	DTN	45	4	**0:37**	2	**18**
Mon	14:00	Non	4L	U	DTN	45	4	**0:36**	1	**15**
Mon	14:00	Non	4L	U	DTN	45	4	**0:47**	0	**41**
Mon	14:00	Non	4L	U	DTN	45	4	**0:48**	0	**25**
Mon	14:00	Non	4L	U	DTN	45	4	**0:40**	2	**26**
Mon	14:00	Non	4L	U	DTN	45	4	**0:48**	1	**32**
Mon	14:00	Non	4L	U	DTN	45	4	**0:37**	1	**23**
Mon	14:00	Non	4L	U	DTN	45	4	**0:46**	5	**10**
Mon	14:00	Non	4L	U	DTN	45	4	**0:48**	4	**31**
Mon	14:00	Non	4L	U	DTN	45	4	**0:49**	2	**42**
Mon	14:00	Non	4L	U	DTN	45	4	**0:48**	1	**30**
Mon	14:00	Non	4L	U	DTN	45	4	**0:49**	3	**17**
Mon	14:00	Non	4L	U	DTN	45	4	**0:38**	2	**29**
Mon	16:00	PK	4L	U	DTN	45	4	**0:14**	0	**6**

4.5 Conclusions

Model refinement required the expansion of the database conducted in phase I of the project which included 240 hours, to increase the domain and improve reliability of the developed model through the addition of 18 intersections with 33 approaches and analyzing additional 1,080 hours. Total entries for Phases I and II amounted to 1,322 hours. Preliminary analysis pinpointed the data sets that had low left-turning volume as well as other circumstances that required removal from the data set not to affect the modeling process. The cleaning process resulted in the removal of 264 hours. The final total remaining hours used in the statistical analysis were 1,058 hours. Further analysis revealed high variability in the data set which was enhanced through data sub-setting using other parameters in the data set.

Several modeling techniques were investigated which included stepwise regression, time series analysis and neural networks. Based on the analysis, neural networks model provided the highest correlation between the independent variables and the response reaching 90%. The maximum coefficient of correlation achieved by the regression analysis was 79% which means that 79% of the data set is explained by the model. Neural network analysis is a very powerful tool for non-parametric variables with high variability as they provide superior predictive accuracy to commonly used algorithms. Additional procedure was needed for the refined DSS to be able to dynamically update the controller with the correct information. The logic to give recommendation will be based on calculating the average headway for three to five cycles before recommending a decision for the rest of the hour.

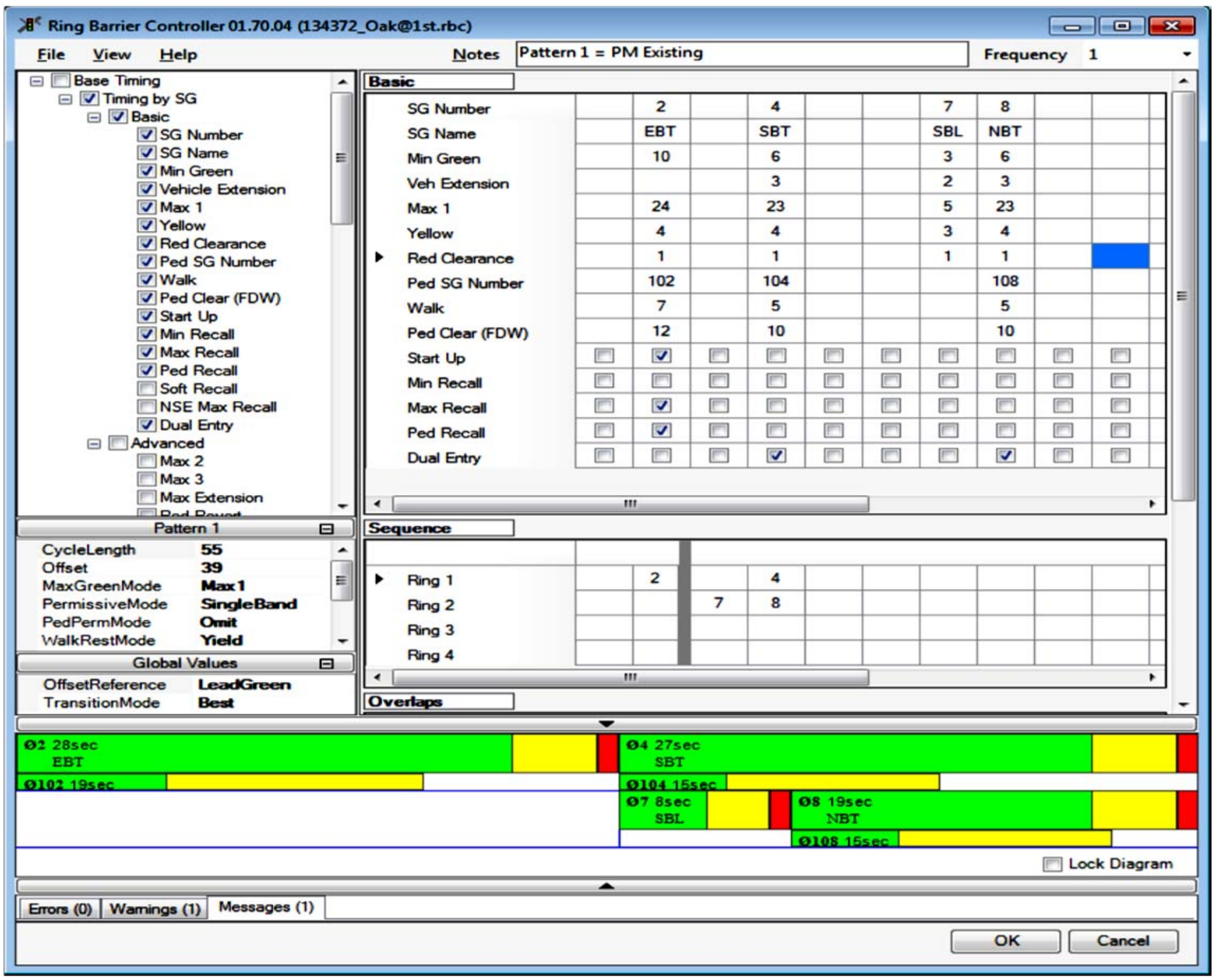
5. VIRTUAL TESTING OF THE DECISION SUPPORT SYSTEM USING VISSIM API

5.1 Overview

The main objective of this task was to test the final refined neural network model along with the decision support system criteria in a simulated environment before moving on to the field testing environment. Virtual testing is called Software-in-the-Loop-Simulation (SILS). The term 'software-in-the-loop testing', or SIL testing, is used to describe a test methodology where executable code such as algorithms (or even an entire controller strategy), usually written for a particular system, is tested within a modelling environment that can help prove or test the software. This is an advanced step compared to the HILS (Hardware-in-the-Loop-Simulation) testing where an actual traffic controller is needed along with a controller interface device (CID). Virtual testing was conducted using the latest version of the microscopic traffic simulation model VISSIM 7.13 along with its application programming interface modules which included the use of COM (Component Object Module) server as well as the VISVAP (VISSIM Vehicle Actuated Programming) module. These components, unified under the Windows operating environment and integrated with VISSIM, provide the ability to simulate one or more intersections with a unifying controller management interface and the ability to model both standard and custom saturated timing strategies.

5.2 VISSIM Ring Barrier Controller (RBC)

VISSIM PTV Group has developed a ring barrier traffic controller to replicate typical NEMA, 170, and 2070 ring and barrier operation. This controller is based on the latest NTCIP 1202 standards (The National Transportation Communications for Intelligent Transportation Systems Protocol) and is based on firmware implemented by public agencies; providing field tested logic and standardization required for any meaningful replication of traffic signal controller operations. The RBC provided most of the standard traffic controller features in North America, while providing a robust graphical user interface for programming. The RBC also includes Preemption and Transit Signal Priority. However, in order to simulate special cases such as programmable traffic actuated signal controls, either phase or stage based junction controls over public transport pre-emption, network or corridor controls, or VMS applications such as variable speed control or temporary use of should lanes, PTV API packages and add-on modules were needed. These modules enabled the integration of external applications such as user-defined signal controllers in order to take influence on the simulation model. Functionality was provided to read relevant information such as detector information, current signal states and write signal states. Figure 5-1 shows a standard ring barrier controller graphical user interface.



SG Number		2		4			7	8		
SG Name		EBT		SBT			SBL	NBT		
Min Green		10		6			3	6		
Veh Extension				3			2	3		
Max 1		24		23			5	23		
Yellow		4		4			3	4		
Red Clearance		1		1			1	1		
Ped SG Number		102		104				108		
Walk		7		5				5		
Ped Clear (FDW)		12		10				10		
Start Up	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐
Min Recall	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Max Recall	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐
Ped Recall	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐
Dual Entry	☐	☐	☐	☑	☐	☐	☐	☑	☐	☐

Sequence					
Ring 1		2		4	
Ring 2			7	8	
Ring 3					
Ring 4					

Figure 5-1: VISSIM Ring Barrier Controller GUI

5.3 VISSIM COM Server

The Component Object Model (COM) is used to describe how binary components of different programs collaborate. COM gives access to data and functions contained in other programs. Data contained in Vissim were accessed via the COM interface using Vissim as an automation server. The Vissim COM scripts were called directly from the Vissim main menu. It should be noted that COM does not depend on a certain programming language. COM Objects can be used in a wide range of programming and scripting languages, including VBA, VBS, Python, C, C++, C#, Delphi and MATLAB. Figure 5-2 depicts part of the VISSIM-COM concept. Figure 5-3 displays excerpts from the COM coding. The VISSIM-COM was based on a strict object hierarchy with two main object types:

- Collections (array, list): store individual objects (Links).
- Containers: store a single object (Link).

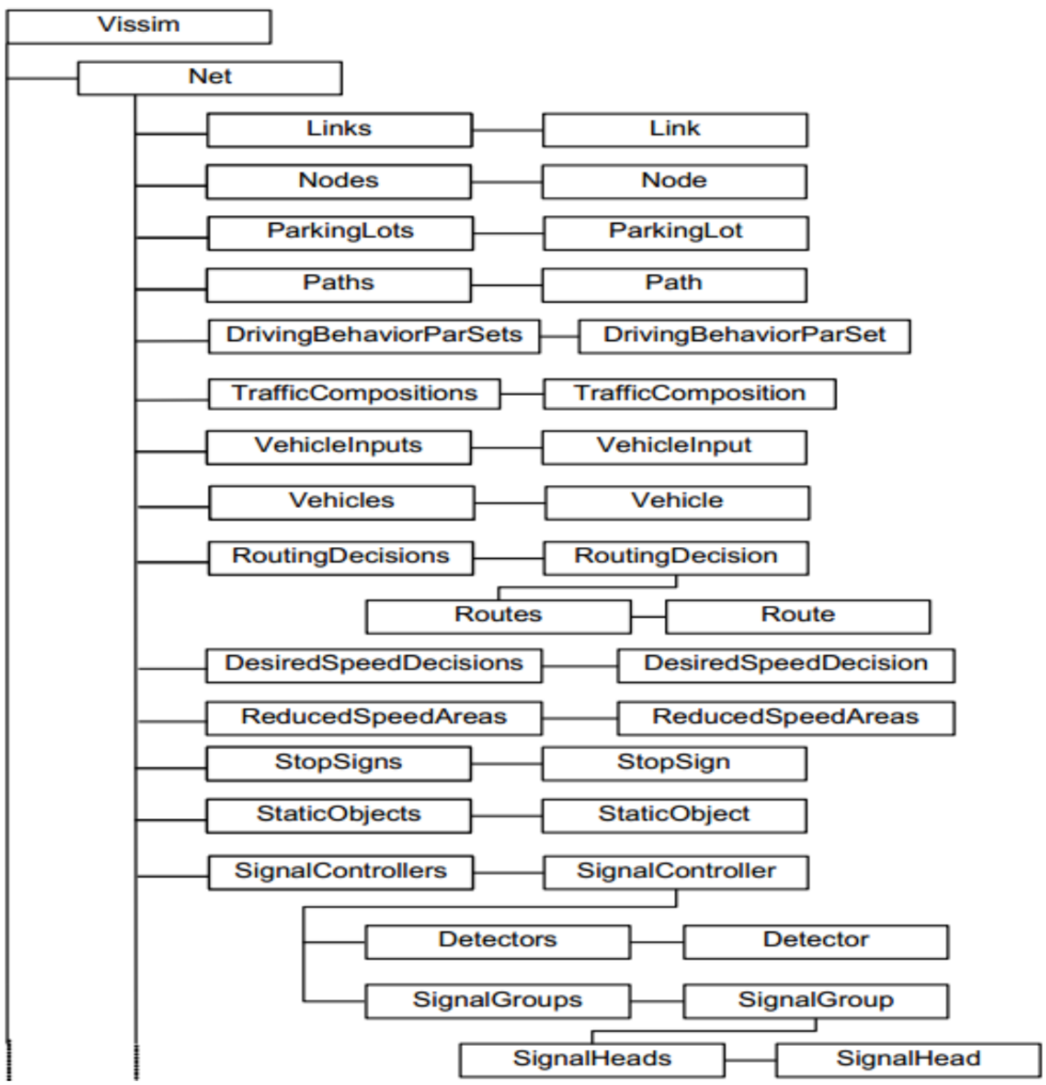


Figure 5-2: The VISSIM-COM Object Model

test_en.m

```
%% Vissim-COM programming - example code %%
clear all;
close all;
%% Create Vissim-COM server
vis=actxserver('VISSIM.vissim');
%% Loading the traffic network
access_path=pwd;
vis.LoadNet([access_path '\test.inp']);
vis.LoadLayout([access_path '\vissim.ini']);
%% Simulation settings
sim=vis.Simulation;
period_time=3600;
sim.set('Period', period_time);
step_time=3;
sim.set('Resolution', step_time);
%% Define the network object
vnet=vis.Net;
%% Setting the traffic demands of the network
vehins=vnet.VehicleInputs;
vehin_1=vehins.GetVehicleInputByNumber(1);
vehin_1.set('AttValue', 'Volume', 1500); % main road
vehin_2=vehins.GetVehicleInputByNumber(2);
vehin_2.set('AttValue', 'Volume', 100); % side street
%% The objects of the traffic signal control
scs=vnet.SignalControllers;
sc=scs.GetSignalControllerByNumber(1);
sgs=sc.SignalGroups;
sg_1=sgs.GetSignalGroupByNumber(1);
sg_2=sgs.GetSignalGroupByNumber(2);
dets=sc.Detectors;
det_1=dets.GetDetectorByNumber(1);
%% Access to Evaluation object
eval=vis.Evaluation;
%% Access to DataCollectionPoint object
datapoints=vnet.DataCollections;
datapoint_1=datapoints.GetDataCollectionByNumber(1);
%% Access to Link object
links=vnet.Links;
link_1=links.GetLinkByNumber(1);
%% Running the simulation
for i=0:(period_time*step_time)
    sim.RunSingleStep;
    if rem(i/step_time,20)==0       % verifying at every 20 seconds
        igeny=det_1.get('AttValue','Presence'); %get detector occupancy:0/1.
        if igeny==1                    % demand -> demand-actuated stage
            sg_1.set('AttValue','State',1); % main road red (1)
            sg_2.set('AttValue','State',3); % side street green (3)
          else                  % no demand on loop -> main road is green
            sg_1.set('AttValue','State',3);
            sg_2.set('AttValue','State',1);
      end
    end
    datapoint_1.GetResult('Speed','Mean',0) %get avg speed from DataPoint 1.
    link_1.GetSegmentResult('Volume',0,0.0,1,0) %get traffic flow on Link 1.
end
%% Delete Vissim-COM server (also closes the Vissim GUI)
delete(vis);
```

Figure 5-3: Excerpts of VISSIM COM Coding

5.4 VISSIM Vehicle Actuated Programming (VISVAP)

VAP (Vehicle Actuated Programming) is a programming language for defining custom signal operations and logic based routing and speed element changes. VisVAP is a graphical editor used to define traffic control logic. Writing complex VAP coding is a difficult task and requires significant coding experience. VisVAP reduces the effort required to develop complex signal control logic. In addition, VisVAP was used as a tool for testing intersection operations in debugging mode. VisVAP enhanced the use of freely-definable signal control logics using the VAP language in offering a comfortable tool for creating and editing program logics as flow charts. The appearance and design of flow charts in VisVAP facilitate loops and other features. VisVAP was used for both stage and signal group oriented scenarios. VisVAP debug functionality allows to go through the control logic step by step during a running simulation. It also showed the current values of all parameters used in the logic. At the same time, actual detector variables were retrieved from the simulation and processed in the logic through the use of two main types of parameters; VAP parameters (system defined) and User-defined parameters and constants. It should be noted that the signal control logic was defined as a flow chart in the chart section for each ring separately as shown in Figure 5-4 for Ring 1.

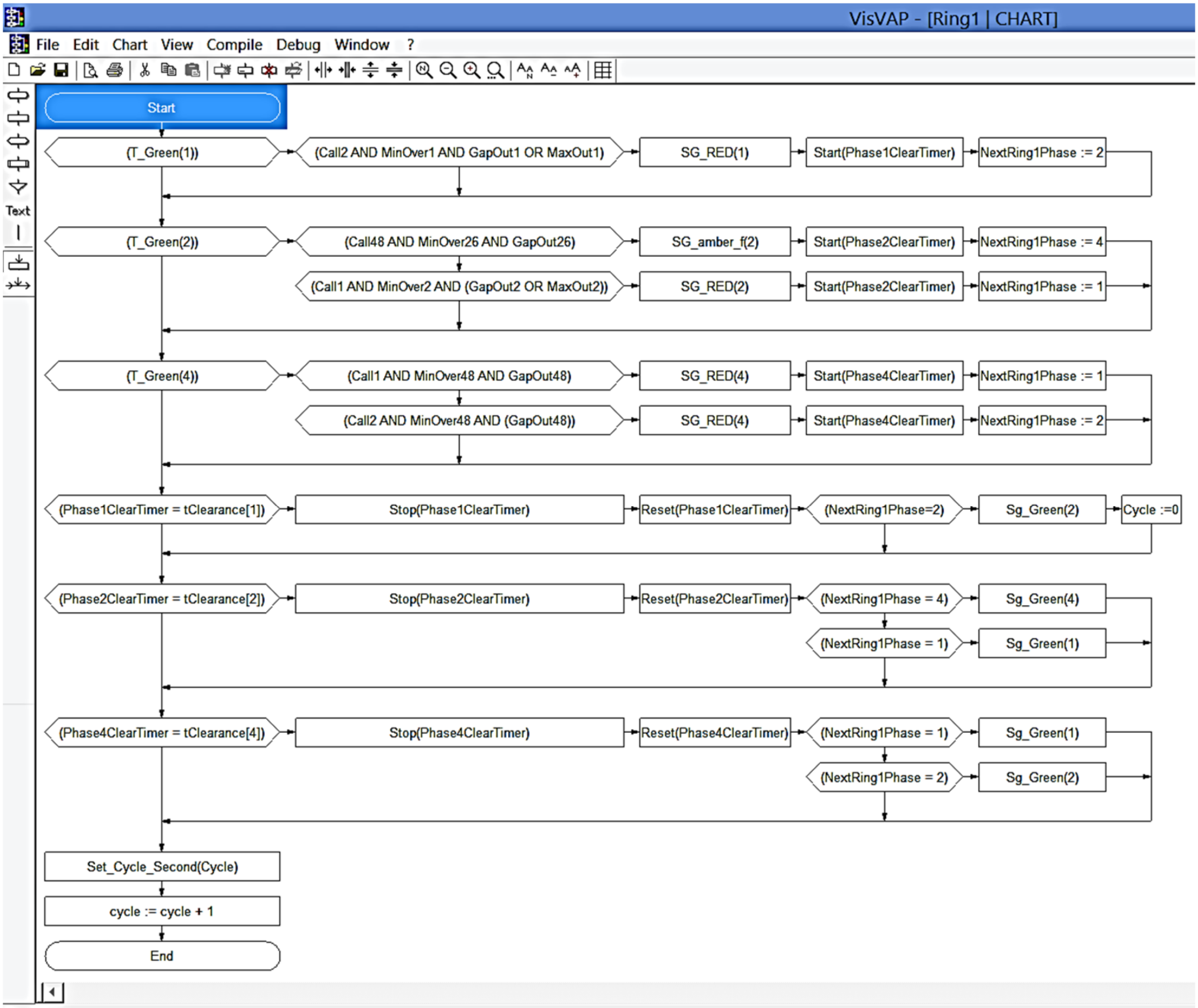


Figure 5-4: Signal Control Logic Flow Chart

5.5 Controller Logic Issues

In a typical protected-permissive (PPLT) situation, it is possible for the circular green indication and green arrow indication to illuminate simultaneously. However, by converting to the flashing yellow arrow, the flashing yellow arrow and green arrow indications cannot illuminate simultaneously. In unusual situations, additional or different phases could serve as parent phases to drive the flashing yellow arrow overlap. The same overlap logic can also be used to drive right turn arrows where appropriate.

If existing controller software cannot be modified to provide this functionality, the same effect can be achieved using external logic, although with less flexibility. It is assumed that new controller software and any significant upgrade of existing controller software will include this functionality; so that over time, external logic will no longer be needed. The special logic described above can be implemented using a "logic box" external to the signal controller or with software enhancements in the signal controller. Using the NTCIP objects defined for actuated signal controllers, the flashing yellow arrow logic would be embodied in a new overlap type. Assuming the controller supports configurable cabinet input/output assignments, the four arrow head can be driven by a combination of outputs from a phase and an overlap. For example, the overlap could drive all but the green arrow, with the left-turn and opposing thru phases designated as parent phases, and the left-turn phase designated as a modifier phase. A normal signal conflict monitor can be used by outputting the left-turn-phase yellow to a load switch with a dummy load, in order to satisfy the yellow-follows-green check, and turning off dark check for the overlap. If the flashing yellow arrow is formally adopted, conflict/malfunction monitors could add explicit support for it.

5.6 DSS Testing Procedure and Results

Virtual testing of the developed DSS required several steps as well as the integration of different components. The first step was to ensure that the intersections under study were calibrated to field conditions. Simulation models require a detailed and complete description of the layout of the site in order to produce a realistic output. Calibration of a micro simulation model for mixed traffic requires special procedures to address the unique characteristics of such traffic. The procedure included the examination of field data from the videos database along with the microscopic simulation in VISSIM. The bulk of the calibration effort was dedicated to matching the left-turns and the opposing traffic during the permissive phases in terms of the start time, end time, and extent of the modeled hour.

As mentioned earlier, the two main challenging components needed to complete the testing procedure were the opposing thru traffic and the amount of permissive green times. Loop detectors played a major role in the calibration process along with the signal timings. Through the VAP interface, loop detector measurements were accessed on a cycle-by-cycle basis, and were used to generate commands for the traffic signals. A trace file was exported from the VAP process to record loop detector and signal-related variables.

Through this information, all of the independent parameters in the model were determined along with the remaining categorical parameters that should be preset in the intersection database of the traffic management center (TMC).

The permissive green times and the opposing thru traffic were determined on a cycle-by-cycle basis from the field. The logic was based on calculating the average headway and gap time for the opposing traffic from the loop detectors data for the first three to five cycles, before recommending a decision for the left-turn signal head, either flashing or not for the next 15-minute period. This iterative process is repeated until the rest of the hour. Figure 5-5 shows the eastbound left (EBL) for the intersection of SR 50 at Mills Avenue during an off-peak hour along with the signal timing tables and signal changes on-screen. At this specific location, the permissive phase was always rejected during the peak hours. Figure 5-6 shows the southbound left (SBL) permissive phase for the same intersection during a different off-peak hour of the day. Figure 5-7 shows the end of the protected phase (yellow signal) for the intersection during the peak hour with rejected permissive phase due to the heavy opposing flow.

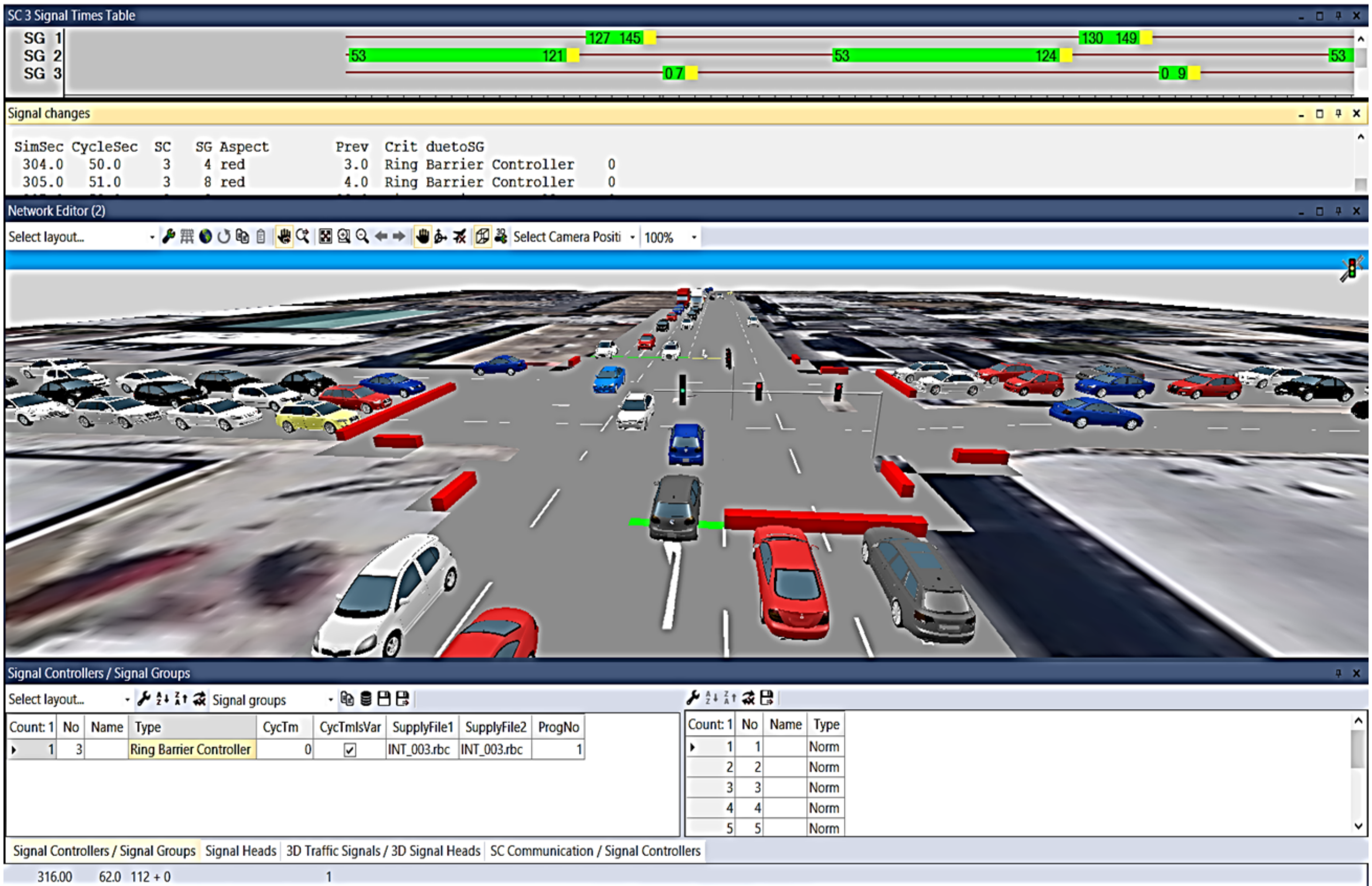


Figure 5-5: SR 50 and Mills Avenue during Off-Peak Hour (EBL) with On-Screen Data

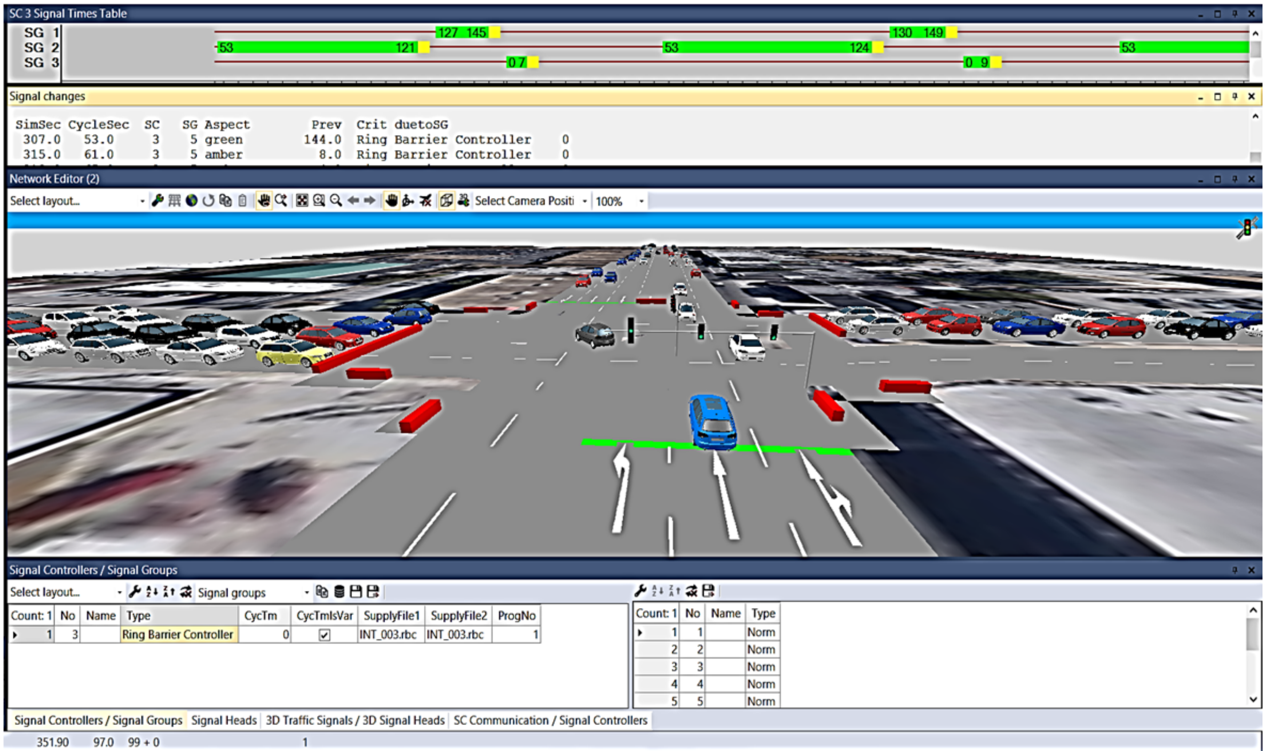


Figure 5-6: SR 50 and Mills Avenue during Off-Peak Hour (SBL) with On-Screen Data

Figure 5-7: SR 50 and Mills Avenue End of Protected Phase during Peak Hour (SBL)

The main criteria tested in this environment were the two operational criteria and one of the safety criteria which included the activation of the pedestrian phase. The remaining criterion required the information related to the historical time of day crashes which should be in a preset database at the traffic management center (TMC).

From the 31,000 cycle data collected in this project, it was determined that on average, a minimum of 4 seconds is needed to consider accepting a permissive phase especially for crossing four lanes. Lower values were acceptable especially for crossing less than three lanes. Excerpts from the DSS testing for collected and simulated data are shown on Table 5-1.

Table 5-1: DSS Testing – Simulated vs. Observed Permissive Left-Turns

TOD	PK	Speed	Xing Ln	Perm Grn Tme	Perm Opp Thru	Perm Opp Rt	Tot Perm Opp	Avg Hdwy	Perm LT Index	Obs Per LT	Simulated Perm LT
11:30	Peak	35	2	20:18	250	28	278	4.38	8	34	35
12:30	Peak	35	2	19:17	240	24	264	4.38	5	20	24
15:00	Non	35	2	21:41	211	27	238	5.47	5	28	27
16:00	Peak	35	2	20:47	179	25	204	6.11	7	41	42
13:00	Peak	35	2	21:40	157	19	176	7.39	5	40	35
14:00	Non	35	2	21:19	149	27	176	7.27	4	26	30
15:00	Non	35	2	21:39	129	27	156	8.33	2	19	34
7:00	Peak	35	2	16:32	196	45	241	4.12	10	42	44
8:00	Peak	35	2	15:42	258	44	302	3.12	11	35	47
17:00	Peak	35	2	15:48	417	97	514	1.84	5	9	0
7:00	Peak	45	4	1:39	1178	117	1295	1.19	0	0	0
8:00	Peak	45	4	0:15	1263	177	1440	1.01	0	0	0
9:00	Non	45	4	2:54	1117	155	1272	1.27	0	0	0
10:00	Non	45	4	0:52	1210	127	1337	1.12	0	0	0
11:00	Non	45	4	1:34	1141	137	1278	1.20	0	0	0
12:00	Peak	45	4	1:36	1069	153	1222	1.26	0	0	0
13:00	Peak	45	4	2:42	1163	142	1305	1.23	0	0	0
15:00	Non	45	4	4:01	1176	156	1332	1.26	0	0	0
16:00	Peak	45	4	2:43	1059	135	1194	1.34	0	0	0
17:00	Peak	45	4	21:39	1629	143	1772	0.73	0	0	0
7:00	Peak	30	1	15:09	164	96	260	3.50	13	47	55
8:00	Peak	30	1	17:22	141	113	254	4.10	19	77	65
9:00	Non	30	1	14:54	116	57	173	5.17	9	46	53
10:00	Non	30	1	14:12	184	115	299	2.85	19	54	55
11:00	Non	30	1	13:23	169	101	270	2.97	25	75	67
12:00	Peak	30	1	14:22	210	126	336	2.57	18	45	54
13:00	Peak	30	1	13:32	115	83	198	4.10	24	98	89
15:00	Non	30	1	15:19	110	66	176	5.22	10	52	55
16:00	Peak	30	1	14:13	184	60	244	3.50	15	51	61
17:00	Peak	30	1	15:06	180	83	263	3.44	19	65	55
7:00	Peak	30	2	15:09	134	147	281	3.23	47	153	146
8:00	Peak	30	2	17:22	111	80	191	5.46	22	120	124
9:00	Non	30	2	14:54	106	73	179	4.99	23	115	42
10:00	Non	30	2	14:12	166	99	265	3.22	15	48	51
11:00	Non	30	2	13:23	139	110	249	3.22	18	58	44
12:00	Peak	30	2	14:22	180	83	263	3.28	20	65	61
13:00	Peak	30	2	13:32	200	111	311	2.61	18	48	51
15:00	Non	30	2	15:19	186	108	294	3.13	20	63	60
16:00	Peak	30	2	14:13	230	94	324	2.63	15	40	43

Table 5-1: DSS Testing – Simulated vs. Observed Permissive Left Turns (Continued)

17:00	Peak	30	2	15:06	239	149	388	2.34	23	54	50
11:30	Peak	35	3	10:45	73	16	89	7.25	4	31	36
12:30	Peak	35	3	11:41	78	24	102	6.87	7	45	40
15:00	Non	35	3	11:32	72	10	82	8.44	4	37	41
16:00	Peak	35	3	12:57	61	22	83	9.36	4	42	62
11:30	Peak	35	3	10:45	73	81	154	4.19	11	47	49
12:30	Peak	35	3	11:41	70	91	161	4.35	12	53	50
15:00	Non	35	3	11:32	56	95	151	4.58	12	54	56
13:00	Peak	35	3	9:34	46	7	53	10.83	3	29	27
14:00	Non	35	3	9:53	52	11	63	9.41	2	18	20
15:00	Non	35	3	8:39	55	10	65	7.98	4	30	23
13:00	Peak	35	3	9:34	50	70	120	4.78	8	37	38
14:00	Non	35	3	9:53	58	100	158	3.75	12	46	45
15:00	Non	35	3	8:39	65	75	140	3.71	11	40	43
7:00	Peak	45	2	11:48	384	45	429	5.01	28	141	170
9:00	Non	45	2	13:39	477	42	519	4.35	27	117	130
10:00	Non	45	2	17:21	452	4	456	5.44	5	25	76
11:00	Non	45	2	15:30	918	8	926	2.56	7	18	17
13:00	Peak	45	2	15:12	953	28	981	2.40	32	77	69
14:00	Non	45	2	16:14	737	9	746	3.24	10	33	11
15:00	Non	45	2	12:28	811	5	816	2.68	2	6	26
16:00	Peak	45	2	1:28	1310	1	1311	1.17	2	2	0
17:00	Peak	45	2	5:28	1597	0	1597	1.11	0	0	0
18:00	Non	45	2	14:45	1420	0	1420	1.64	1	2	0
7:00	Peak	45	3	16:01	687	54	741	3.24	17	56	59
8:00	Peak	45	3	14:26	797	42	839	2.75	19	51	39
9:00	Non	45	3	19:54	428	14	442	5.96	4	22	16
10:00	Non	45	3	19:26	284	5	289	9.02	2	14	11
11:00	Non	45	3	18:08	353	8	361	7.00	3	20	15
12:00	Peak	45	3	12:40	425	11	436	5.05	7	36	21
13:00	Peak	45	3	16:59	380	13	393	6.26	4	25	11
14:00	Non	45	3	19:36	315	5	320	8.18	3	26	0
15:00	Non	45	3	20:56	265	3	268	10.06	1	12	9
16:00	Peak	45	3	2:30	307	3	310	9.77	1	8	0
17:00	Peak	45	3	19:41	476	3	479	5.47	1	8	13
18:00	Non	45	3	12:07	441	2	443	4.89	0	1	0
7:00	Peak	45	3	16:01	86	54	140	17.15	1	15	0
8:00	Peak	45	3	14:26	137	128	265	8.70	2	21	28
9:00	Non	45	3	19:54	171	82	253	10.41	1	9	5
10:00	Non	45	3	19:26	176	45	221	11.79	0	2	0
11:00	Non	45	3	18:08	275	99	374	6.76	0	3	0
12:00	Peak	45	3	12:40	336	117	453	4.86	1	5	0

5.7 Conclusions

Virtual testing of the decision support system using VISSIM application programming interface (API) confirmed the applicability and validity of the above mentioned procedure and logic which was an essential component before moving on to the final objective of running a field test.

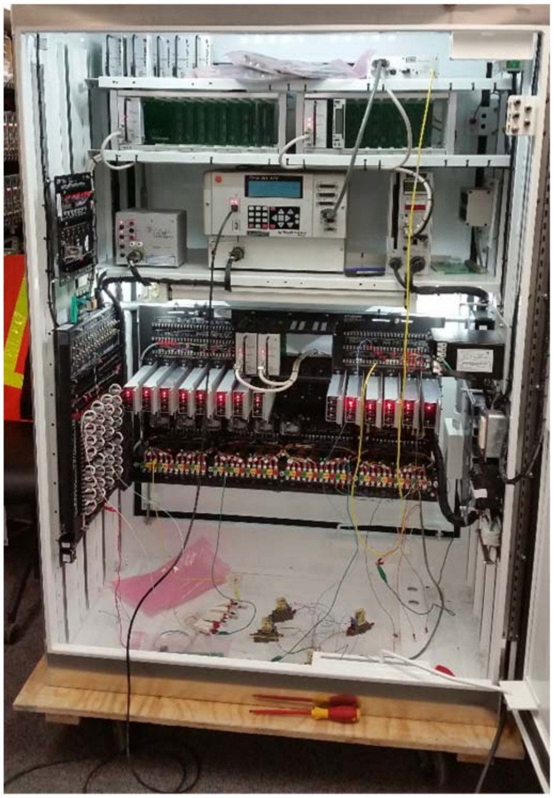
6. PILOT STUDY THROUGH FIELD TESTING

6.1 Overview

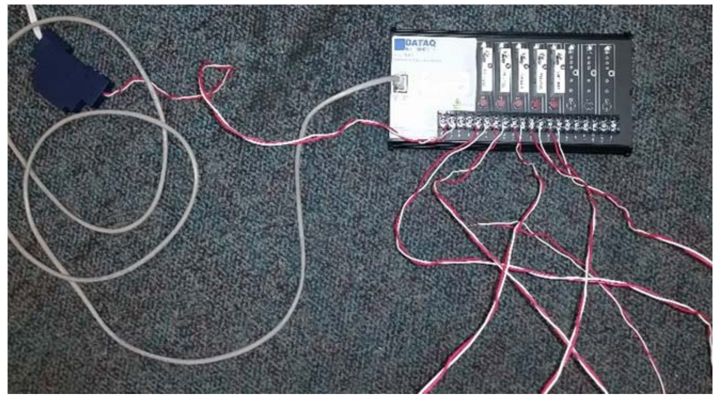
The main objective of this task is to test the final refined decision support system (DSS) and the algorithm criteria based on the cycle by cycle data in a field testing environment as a "proof of concept" before actual implementation in the field. The testing was conducted at Seminole County Traffic Engineering Lab where actual intersection field data was obtained through loop detector mapping to the controller in the lab in real-time mode. This process is called HILS (Hardware-in-the-Loop-Simulation) testing where an actual traffic controller is needed along with a controller interface device (CID) such as the data logger DI-161. The term HIL is used to describe a test methodology where executable code such as algorithms or even an entire controller strategy, usually written for a particular system, is tested within a field environment that can help prove a concept or test a software package. The testing environment required the following different components as shown in Figure 6-1:

1- Traffic signal cabinet with controller and loop detectors
2- CCTV camera feeds connected to a computer to monitor intersection traffic flow
3- Data logger device
4- Communication software

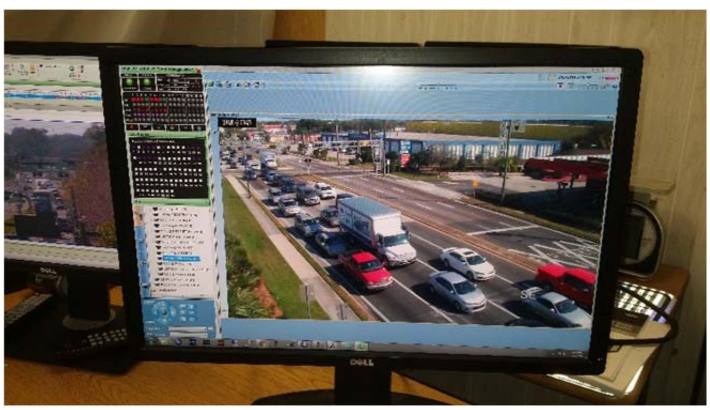
Seminole County Traffic Engineering Staff were very helpful in setting up the testing environment and mapping the intersection loop detectors from the field to the cabinet in the lab. The CCTV cameras were also setup to monitor both the study approach as well as the traffic signal indication. The intersection vehicle detection system through the loop occupancy and the CCTV cameras were connected to the data logger and the communication software to receive data signaling the traffic flow on a second by second basis. The permissive green times and the opposing thru traffic were determined on a cycle-by-cycle basis from the field by the data logger software. The logic was based on modeling the inter-arrival time of vehicles and calculating the minimum headway and gap time per lane for the opposing traffic from the loop detectors data for the first two to three cycles before recommending a decision for the left-turn signal head, either flashing or not for the next cycle. This iterative process is repeated throughout the day on a cycle by cycle basis as will be explained in greater detail in the following sections.



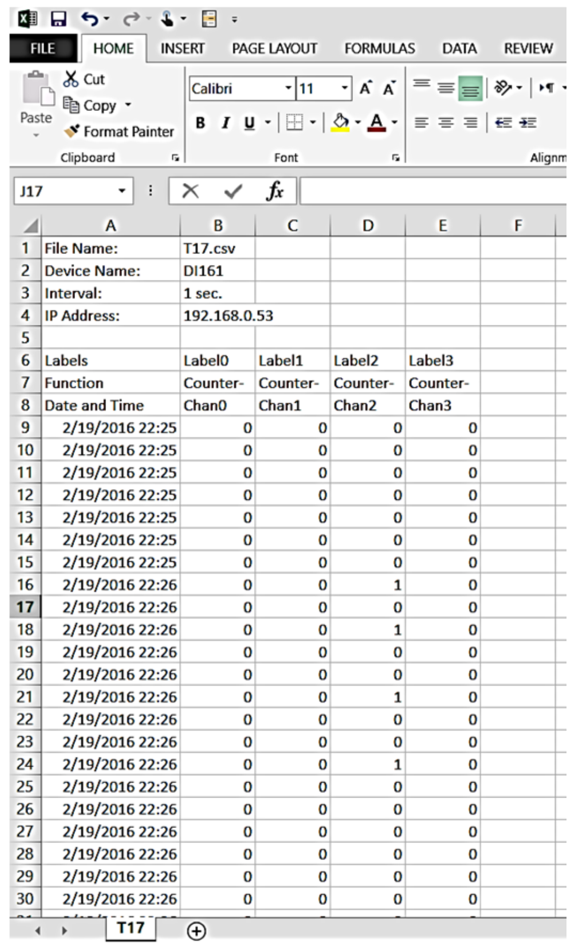
Cabinet with Controller & Loop Detectors



Data Logger Device



CCTV Camera Feeds



	A	B	C	D	E	F
1	File Name:	T17.csv				
2	Device Name:	DI161				
3	Interval:	1 sec.				
4	IP Address:	192.168.0.53				
5						
6	Labels	Label0	Label1	Label2	Label3	
7	Function	Counter-	Counter-	Counter-	Counter-	
8	Date and Time	Chan0	Chan1	Chan2	Chan3	
9	2/19/2016 22:25	0	0	0	0	
10	2/19/2016 22:25	0	0	0	0	
11	2/19/2016 22:25	0	0	0	0	
12	2/19/2016 22:25	0	0	0	0	
13	2/19/2016 22:25	0	0	0	0	
14	2/19/2016 22:25	0	0	0	0	
15	2/19/2016 22:25	0	0	0	0	
16	2/19/2016 22:26	0	0	1	0	
17	2/19/2016 22:26	0	0	0	0	
18	2/19/2016 22:26	0	0	1	0	
19	2/19/2016 22:26	0	0	0	0	
20	2/19/2016 22:26	0	0	0	0	
21	2/19/2016 22:26	0	0	1	0	
22	2/19/2016 22:26	0	0	0	0	
23	2/19/2016 22:26	0	0	0	0	
24	2/19/2016 22:26	0	0	1	0	
25	2/19/2016 22:26	0	0	0	0	
26	2/19/2016 22:26	0	0	0	0	
27	2/19/2016 22:26	0	0	0	0	
28	2/19/2016 22:26	0	0	0	0	
29	2/19/2016 22:26	0	0	0	0	
30	2/19/2016 22:26	0	0	0	0	

Communication Software

Figure 6-1: Testing Environment Components

6.2 Hardware / Software Description

6.2.1- Hardware

- **Board**

The board used in this project is a DATAQ Instruments™ event logger model DI-161 as shown in Figure 6-2. The board is local area network (LAN) based and connects to a computer using an Ethernet cable. It has eight input channels, each of which can operate in one of three modes: **Count**, **Event** or **State**. The Count mode sums the total number of events during each reporting interval. The Event mode reports a single occurrence during each interval even if multiple events may occur. The State mode reports how long an event lasts.

Figure 6-2: DATAQ Model DI-161

- **Wiring and Connection**

The pilot study is designed to monitor up to four lanes in each direction as well as the start / stop state of the thru green phase. The four lanes are monitored in the field either via loop or video detectors; each is connected to an input channel, channels F0 – F3. These channels are configured to operate in **Count** mode. The start / stop state of the thru green phase is monitored by Channel F4 which is configured to operate in **State** mode. Figure 6-3 shows the wires, channel connections and the light bulb on channel F4 indicating that the opposing thru green phase is ON.

Figure 6-3: The DI-161 Board with Wires and Connections

6.2.2 Software

- **Software Development**

The basic communications software that accompanied the DI-161 board was limited compared to what was required in this project. It essentially establishes connection with the board and generates a text file with the data received through the input channels. However, in order to access the text file, data logging has to stop. What was needed, however, was real-time access to the channel data as it is received by the board so that the algorithm can analyze traffic information in real-time and make accurate decisions. Based on discussions with the DATAQ Instruments team, the company that provided the board, the source code for the basic communications software for the DI-161 board was made available to the UCF research team as a courtesy of DATAQ Instruments™. A custom communications software was needed on top of the basic software which has three main functions; control the hardware, display real-time status and execute the proposed FYA algorithm. The UCF research team developed a specific code to retrieve instantaneous channel input data, synchronize opposing thru green phase, analyze traffic information, provide the algorithm decision, and generate a real-time log recording the events. The software was developed using the C# language under Microsoft's™ Visual Studio 2013 development environment. The main screen of the developed software and its different components are shown in Figure 6-4.

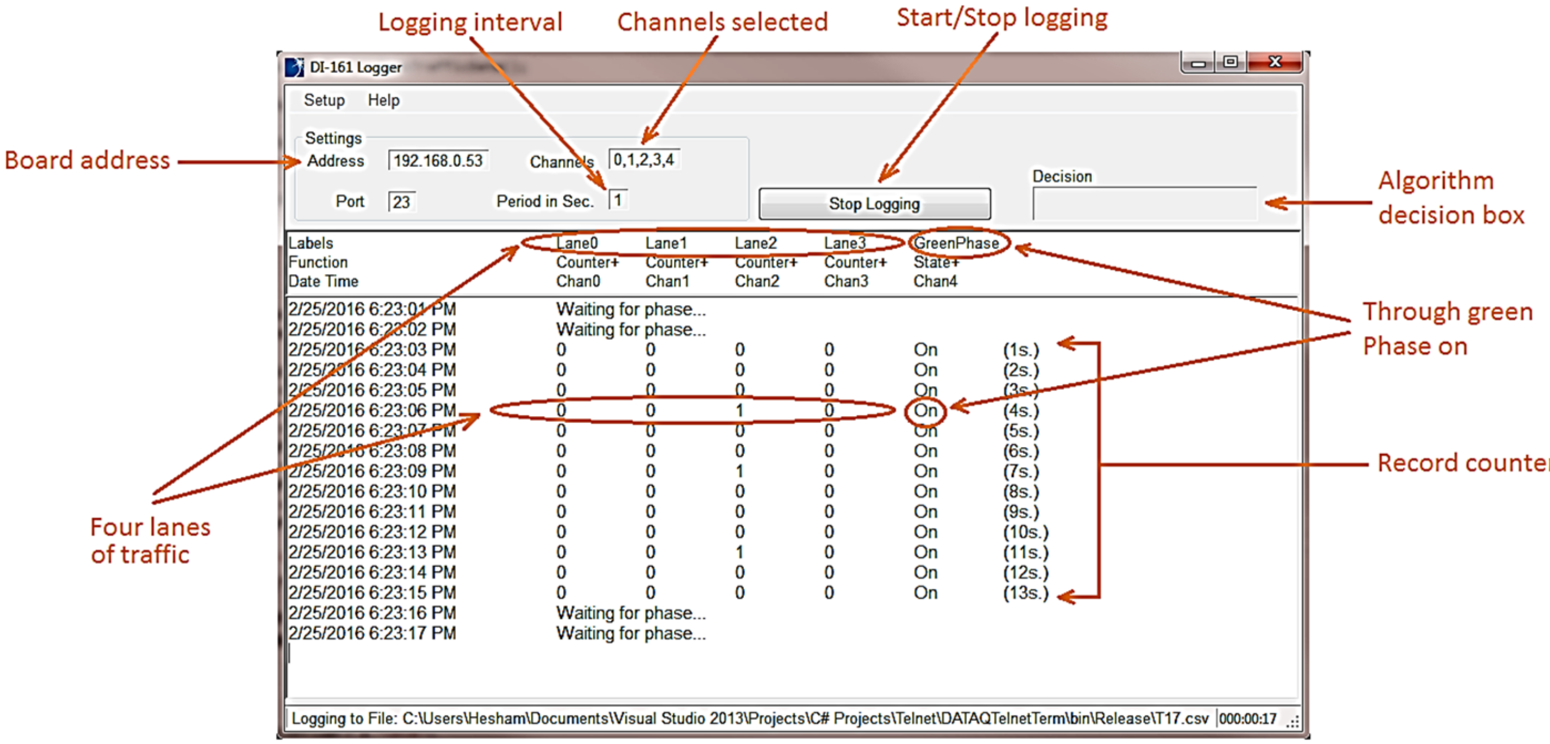
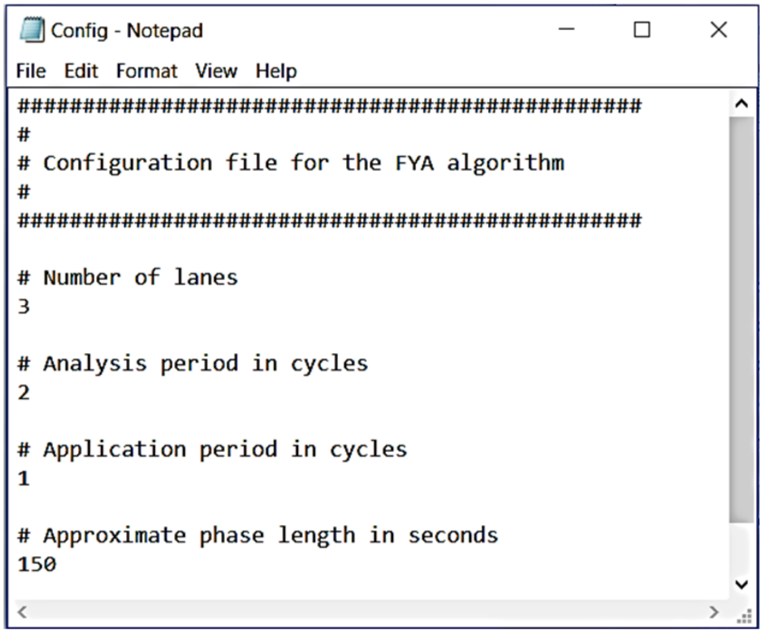


Figure 6-4: UCF Custom Data Logger Software

- **Input Data**

The custom software monitors up to five channels simultaneously; up to four channels for the traffic lanes in **Count Mode** and one channel for the thru green phase in **State Mode**. The algorithm analyzes the traffic flow data received during the thru green phase which is synchronized by the input on the phase channel. There is also a configuration file for specifying different parameters needed for each intersection as shown in Figure 6-5. The configuration file specifies the opposing number of lanes, analysis period to determine the number of cycles to be analyzed before providing a decision, application period which specifies the frequency to provide a decision after the analysis period whether after each cycle or more and lastly, the actuated cycle length in seconds.



Config - Notepad

File Edit Format View Help

```
##################################################
#
# Configuration file for the FYA algorithm
#
##################################################

# Number of lanes
3

# Analysis period in cycles
2

# Application period in cycles
1

# Approximate phase length in seconds
150
```

Figure 6-5: FYA Algorithm Configuration File

6.2.3 Flashing Yellow Arrow Algorithm

- **Headway Modeling**

Modeling the arrival of vehicles was an essential step in the algorithm logic. The vehicle arrival is obviously a random process. Hence, vehicle arrival needs to be characterized statistically. Vehicle arrivals can be modeled in two inter-related ways; modeling the time interval between the successive arrivals of vehicles or modeling how many vehicles arrive in a given interval of time. In the former approach, the random variables represent the time denoting interval between successive arrivals of vehicles and hence some suitable continuous distribution can be used to model the vehicle arrival. In the later approach, the random variables represent the number of vehicles arrived in a given interval of time and hence takes some integer values. In this case, a discrete distribution can be used to model the process.

The developed algorithm utilizes the former approach and uses continuous distributions to model the vehicle arrival process. However, the inter-arrival time or the time headway is not constant due to the stochastic nature of vehicle arrival and also the behavior of vehicle arrival is different at different flow conditions. Therefore, it may be possible that different distributions may work better at different flow conditions.

The negative exponential distribution is used when the traffic is low and is the simplest of the distributions in terms of computation effort. The normal distribution on the other hand is used for highly congested traffic and its evaluation requires standard normal distribution tables. The Pearson Type III distribution is the most general case of negative exponential distribution and can be used for intermediate or normal traffic conditions. Unlike many other distributions, one of the key advantages of the negative exponential distribution is the existence of a closed form solution to the probability density function. The negative exponential distribution is closely related to the Poisson distribution which is a discrete distribution. The probability density function of Poisson distribution is given as:

$$p(x) = \frac{\lambda^x \, e^{-\lambda}}{x!} \qquad \text{(Eq. 1)}$$

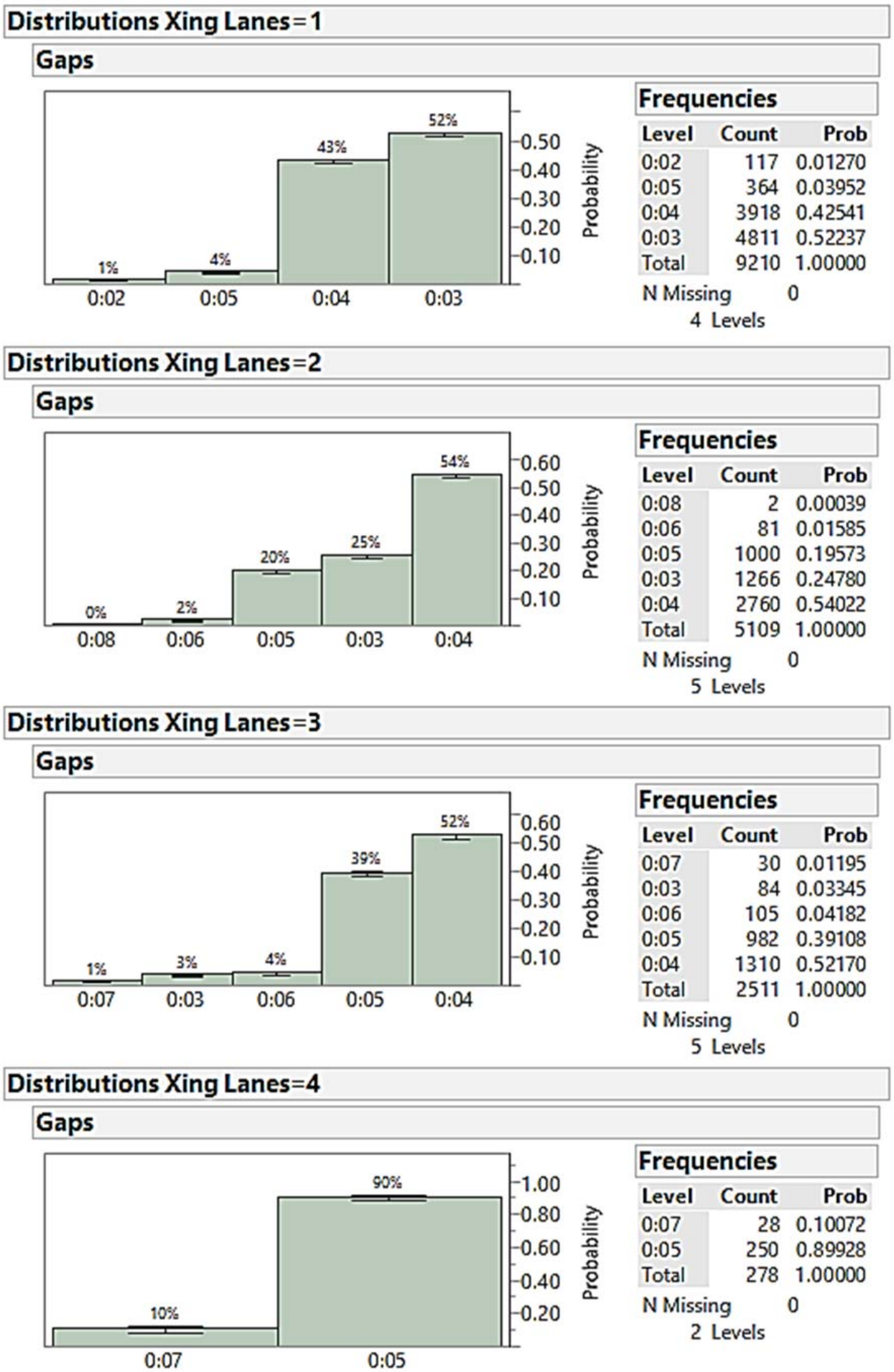
Where, p(x) is the probability of x events (vehicle arrivals) in some time interval (t), and λ is the expected (mean) arrival rate in that interval. If the mean flow rate is q vehicles per hour, then $\lambda = \frac{q}{3600}$ vehicles per second. Here, λ is defined as the average number of vehicles arriving in time t. If the flow rate is q vehicles per hour, then,

$$\lambda = \frac{q \times t}{3600} = \frac{t}{\mu} \qquad \text{(Eq. 2)}$$

Since mean flow rate is the inverse of mean headway, an alternate way of representing the probability density function of negative exponential distribution is given as

$$f(t) = \frac{1}{\mu} \, e^{\frac{-t}{\mu}} \qquad \text{(Eq. 3)}$$

Where $\mu = \frac{1}{\lambda}$ or $\lambda = \frac{1}{\mu}$. Here, μ is the mean headway in seconds which is again the inverse of flow rate. Using the above equations, the observed headway frequency distribution between any interval and flow rate can be computed. Statistical analysis was carried out for the field data to determine the minimum acceptable gap time based on the observed headways. Figure 6-6 shows the distribution of the observed headways for each case of crossing lanes one to four. The analysis shows that the observed headways follow a negative exponential distribution.



Frequencies (Xing Lanes=1)

Level	Count	Prob
0:02	117	0.01270
0:05	364	0.03952
0:04	3918	0.42541
0:03	4811	0.52237
Total	9210	1.00000

N Missing 0
4 Levels

Frequencies (Xing Lanes=2)

Level	Count	Prob
0:08	2	0.00039
0:06	81	0.01585
0:05	1000	0.19573
0:03	1266	0.24780
0:04	2760	0.54022
Total	5109	1.00000

N Missing 0
5 Levels

Frequencies (Xing Lanes=3)

Level	Count	Prob
0:07	30	0.01195
0:03	84	0.03345
0:06	105	0.04182
0:05	982	0.39108
0:04	1310	0.52170
Total	2511	1.00000

N Missing 0
5 Levels

Frequencies (Xing Lanes=4)

Level	Count	Prob
0:07	28	0.10072
0:05	250	0.89928
Total	278	1.00000

N Missing 0
2 Levels

Figure 6-6: Distribution of Gaps by Number of Crossed Lanes

- **Algorithm Logic**

The proposed algorithm is implemented with the goal of safely optimizing traffic operations. In the case of a red arrow signaled for a left-turn, the opposing thru traffic during the green phase is constantly analyzed in real-time to determine whether it would be optimal to switch the red arrow to a flashing yellow arrow. The decision is made based on a number of parameters which include the minimum headway of vehicles in the opposing traffic, the number of lanes to cross, and the number of cycles to be analyzed prior to making the decision.

The algorithm determines the time interval between the successive arrivals of vehicles for each lane independently and computes the corresponding headway for each lane by cycle on a second-by-second basis. It then determines the minimum gap duration by dividing the headway by the flow per lane.

Gap per Lane = Headway / Flow (Eq. 4)

The algorithm then picks the minimum headway and compares it to the minimum acceptable gap in seconds needed for a vehicle to safely cross the given number of lanes. The thresholds used for different crossing number of lanes were obtained from the database of 30,000 cycles collected from the field. If the minimum headway for the corresponding number of lanes is achieved and repeated for a certain number of times, for example, at least five times during the analysis period (whether one or two cycles) which is also an input to the algorithm, the decision is made to switch to a flashing yellow mode. Otherwise, a red arrow is decided upon. The following durations in seconds, shown in Table 6-1, are the minimum acceptable thresholds used to determine the minimum headways for different number of lanes crossed which are used in the decision making process. These thresholds were developed based on the statistical analysis of the cycle by cycle data collected from the field. Tables 6-2 and 6-3 are excerpts from the field data for crossing three and four lanes, respectively.

Table 6-1: FYA Algorithm Criteria

No. of Opposing Lanes Crossed	Min acceptable Gap Time	Comments
1 Lane	3.0 s.	1 Thru lane
2 Lanes	3.5 s.	2 Thru lanes or 1 Thru + 1 RT
3 Lanes	4.0 s.	3 Thru lanes or 2 Thru + 1 RT
4 Lanes	4.5 s.	4 Thru lanes or 3 Thru + 1 RT

Table 6-2: Minimum Acceptable Gap Time for Crossing Three Lanes by Cycle

Collection Period			Speed	Crossing Lanes	Start Clock Time	End Clock Time	Permitted Green Time	Permitted Left Turns	Opposing Volumes			Left Turns	
Day	Hour	Peak							Through	Right	Total	Gap	Follow-Up
Wed	7:00	Peak	45	3	0:00	2:17	2:17	1	13	0	13	0:04	0:02
Wed	7:00	Peak	45	3	2:31	3:07	0:36	0	8	0	8	0:04	0:02
Wed	7:00	Peak	45	3	3:21	4:35	1:14	0	13	0	13	0:04	0:02
Wed	7:00	Peak	45	3	4:51	5:18	0:27	0	3	0	3	0:04	0:02
Wed	7:00	Peak	45	3	5:31	6:52	1:21	2	15	0	15	0:04	0:02
Wed	7:00	Peak	45	3	7:04	7:29	0:25	0	5	0	5	0:04	0:02
Wed	7:00	Peak	45	3	7:42	8:24	0:42	0	9	0	9	0:04	0:02
Wed	7:00	Peak	45	3	8:34	9:21	0:47	0	8	0	8	0:04	0:02
Wed	7:00	Peak	45	3	9:39	9:57	0:18	0	2	0	2	0:04	0:02
Wed	7:00	Peak	45	3	10:14	11:38	1:24	0	19	0	19	0:04	0:02
Wed	7:00	Peak	45	3	11:53	12:30	0:37	1	4	0	4	0:04	0:02
Wed	7:00	Peak	45	3	12:43	13:21	0:38	0	12	2	14	0:04	0:02
Wed	7:00	Peak	45	3	13:35	16:07	2:32	0	19	1	20	0:04	0:02
Wed	7:00	Peak	45	3	16:21	17:48	1:27	2	13	3	16	0:04	0:02
Wed	7:00	Peak	45	3	18:02	19:25	1:23	1	19	0	19	0:04	0:02
Wed	7:00	Peak	45	3	19:40	21:04	1:24	0	18	0	18	0:04	0:02
Wed	7:00	Peak	45	3	21:20	22:45	1:25	3	22	1	23	0:04	0:02
Wed	7:00	Peak	45	3	23:13	26:04	2:51	3	30	1	31	0:04	0:02
Wed	7:00	Peak	45	3	26:53	27:45	0:52	0	16	0	16	0:04	0:02
Wed	7:00	Peak	45	3	28:00	29:24	1:24	0	25	1	26	0:04	0:02
Wed	7:00	Peak	45	3	29:54	31:06	1:12	2	15	1	16	0:04	0:02
Wed	7:00	Peak	45	3	31:20	32:43	1:23	3	25	0	25	0:04	0:02
Wed	7:00	Peak	45	3	33:14	34:25	1:11	1	21	1	22	0:04	0:02
Wed	7:00	Peak	45	3	34:42	36:05	1:23	1	23	0	23	0:04	0:02
Wed	7:00	Peak	45	3	36:34	37:45	1:11	1	31	0	31	0:04	0:02
Wed	7:00	Peak	45	3	38:15	39:27	1:12	2	21	0	21	0:04	0:02
Wed	7:00	Peak	45	3	39:57	41:05	1:08	0	21	0	21	0:04	0:02
Wed	7:00	Peak	45	3	41:21	42:45	1:24	1	30	2	32	0:04	0:02
Wed	7:00	Peak	45	3	43:00	44:24	1:24	0	25	1	26	0:04	0:02
Wed	7:00	Peak	45	3	44:38	46:08	1:30	3	40	0	40	0:04	0:02
Wed	7:00	Peak	45	3	46:33	47:45	1:12	1	20	1	21	0:04	0:02
Wed	7:00	Peak	45	3	48:00	49:24	1:24	2	33	2	35	0:04	0:02
Wed	7:00	Peak	45	3	49:55	51:05	1:10	2	41	0	41	0:04	0:02
Wed	7:00	Peak	45	3	51:20	52:45	1:25	2	26	1	27	0:04	0:02
Wed	7:00	Peak	45	3	53:13	54:24	1:11	0	44	0	44	0:04	0:02
Wed	7:00	Peak	45	3	54:40	56:07	1:27	2	34	0	34	0:04	0:02
Wed	7:00	Peak	45	3	56:20	57:44	1:24	1	37	4	41	0:04	0:02
Wed	7:00	Peak	45	3	58:00	59:25	1:25	0	34	0	34	0:04	0:02
Wed	7:00	Peak	45	3	59:41	59:59	0:18	0	6	0	6	0:04	0:02
Wed	9:00	Non	45	3	0:32	0:58	0:26	1	1	0	1	0:04	0:03
Wed	9:00	Non	45	3	1:10	1:44	0:34	1	12	1	13	0:04	0:03
Wed	9:00	Non	45	3	2:01	2:36	0:35	0	9	1	10	0:04	0:03
Wed	9:00	Non	45	3	3:01	3:25	0:24	1	8	1	9	0:04	0:03
Wed	9:00	Non	45	3	3:46	4:17	0:31	0	2	0	2	0:04	0:03
Wed	9:00	Non	45	3	4:48	5:14	0:26	0	5	0	5	0:04	0:03
Wed	9:00	Non	45	3	5:48	6:17	0:29	1	13	2	15	0:04	0:03
Wed	9:00	Non	45	3	6:37	7:11	0:34	1	3	0	3	0:04	0:03
Wed	9:00	Non	45	3	8:13	8:39	0:26	1	6	0	6	0:04	0:03

Table 6-3: Minimum Acceptable Gap Time for Crossing Four Lanes by Cycle

Collection Period			Speed	Crossing Lanes	Start Clock Time	End Clock Time	Permitted Green Time	Permitted Left Turns	Opposing Volumes			Left Turns	
Day	Hour	Peak							Through	Right	Total	Gap	Follow-Up
Mon	6:53	Peak	45	4	0:25	0:58	**0:33**	1	6	0	**6**	0:05	0:02
Mon	6:53	Peak	45	4	2:46	3:31	**0:45**	3	2	2	**4**	0:05	0:02
Mon	6:53	Peak	45	4	4:37	5:12	**0:35**	0	13	0	**13**	0:05	0:02
Mon	6:53	Peak	45	4	6:34	7:23	**0:49**	3	15	1	**16**	0:05	0:02
Mon	6:53	Peak	45	4	8:57	9:39	**0:42**	2	15	0	**15**	0:05	0:02
Mon	6:53	Peak	45	4	11:21	11:49	**0:28**	2	2	0	**2**	0:05	0:02
Mon	6:53	Peak	45	4	12:50	13:21	**0:31**	1	10	0	**10**	0:05	0:02
Mon	6:53	Peak	45	4	14:41	15:09	**0:28**	0	4	2	**6**	0:05	0:02
Mon	6:53	Peak	45	4	16:34	17:07	**0:33**	1	5	1	**6**	0:05	0:02
Mon	6:53	Peak	45	4	18:41	19:20	**0:39**	0	11	1	**12**	0:05	0:02
Mon	6:53	Peak	45	4	21:17	22:06	**0:49**	3	25	0	**25**	0:05	0:02
Mon	6:53	Peak	45	4	23:44	24:33	**0:49**	1	23	0	**23**	0:05	0:02
Mon	6:53	Peak	45	4	26:42	27:15	**0:33**	0	26	1	**27**	0:05	0:02
Mon	6:53	Peak	45	4	29:34	30:22	**0:48**	0	36	1	**37**	0:05	0:02
Mon	6:53	Peak	45	4	32:52	33:20	**0:28**	1	20	3	**23**	0:05	0:02
Mon	6:53	Peak	45	4	35:35	36:14	**0:39**	1	26	1	**27**	0:05	0:02
Mon	6:53	Peak	45	4	38:21	39:06	**0:45**	2	25	0	**25**	0:05	0:02
Mon	6:53	Peak	45	4	41:34	42:17	**0:43**	3	18	0	**18**	0:05	0:02
Mon	6:53	Peak	45	4	44:40	45:20	**0:40**	0	35	2	**37**	0:05	0:02
Mon	6:53	Peak	45	4	47:44	48:32	**0:48**	1	43	0	**43**	0:05	0:02
Mon	6:53	Peak	45	4	50:53	51:41	**0:48**	1	39	1	**40**	0:05	0:02
Mon	6:53	Peak	45	4	53:56	54:40	**0:44**	0	36	5	**41**	0:05	0:02
Mon	6:53	Peak	45	4	57:07	57:51	**0:44**	1	34	1	**35**	0:05	0:02
Mon	7:53	Peak	45	4	0:00	0:47	**0:47**	0	50	1	**51**	0:05	0:02
Mon	7:53	Peak	45	4	2:57	3:45	**0:48**	1	51	3	**54**	0:05	0:02
Mon	7:53	Peak	45	4	6:15	7:04	**0:49**	3	38	0	**38**	0:05	0:02
Mon	7:53	Peak	45	4	9:15	9:43	**0:28**	0	14	1	**15**	0:05	0:02
Mon	7:53	Peak	45	4	12:08	12:57	**0:49**	1	36	0	**36**	0:05	0:02
Mon	7:53	Peak	45	4	15:12	15:58	**0:46**	1	30	1	**31**	0:05	0:02
Mon	7:53	Peak	45	4	18:16	19:03	**0:47**	0	30	1	**31**	0:05	0:02
Mon	7:53	Peak	45	4	21:15	22:04	**0:49**	0	27	2	**29**	0:05	0:02
Mon	7:53	Peak	45	4	24:21	24:52	**0:31**	1	17	1	**18**	0:05	0:02
Mon	7:53	Peak	45	4	27:20	27:50	**0:30**	0	13	0	**13**	0:05	0:02
Mon	7:53	Peak	45	4	29:44	30:17	**0:33**	0	9	0	**9**	0:05	0:02
Mon	7:53	Peak	45	4	32:16	32:58	**0:42**	0	16	1	**17**	0:05	0:02
Mon	7:53	Peak	45	4	34:57	35:41	**0:44**	1	16	2	**18**	0:05	0:02
Mon	7:53	Peak	45	4	38:07	38:43	**0:36**	1	31	2	**33**	0:05	0:02
Mon	7:53	Peak	45	4	40:41	41:15	**0:34**	0	18	0	**18**	0:05	0:02
Mon	7:53	Peak	45	4	43:11	44:01	**0:50**	0	23	1	**24**	0:05	0:02
Mon	7:53	Peak	45	4	46:23	47:11	**0:48**	2	34	1	**35**	0:05	0:02
Mon	7:53	Peak	45	4	49:15	49:37	**0:22**	2	6	1	**7**	0:05	0:02
Mon	7:53	Peak	45	4	50:59	51:38	**0:39**	1	21	1	**22**	0:05	0:02
Mon	7:53	Peak	45	4	52:55	53:42	**0:47**	3	4	0	**4**	0:05	0:02
Mon	7:53	Peak	45	4	55:57	56:45	**0:48**	1	25	0	**25**	0:05	0:02
Mon	7:53	Peak	45	4	59:03	59:51	**0:48**	1	22	3	**25**	0:05	0:02

- **Decision**

The decision of the algorithm is displayed in a text box on the screen. If the decision is to switch to a flashing yellow arrow mode, the message "Flashing Yellow Arrow" is displayed in Yellow. If the decision is to switch to a red arrow mode, the message "Red Arrow" is displayed in Red. The decision box is shown in Figure 6-7.

Figure 6-7: Decision Display by the Algorithm

- **Quality Assurance and Verification**

The software outputs and stores all the input data and decisions performed by the algorithm to a log file in real-time during the algorithm operation. This log file is intended for algorithm verification and future improvement as well as to help better understand the decision process during various traffic situations. The following section provides the results of two case studies for the DSS lab testing.

6.2.4 DSS Lab Testing Procedure and Results

As mentioned earlier, the testing was conducted at Seminole County Traffic Engineering Lab through the Staff help. They ran a peer-to-peer logic to map the controller data from the field to the lab controller as well as the loop detectors. Vehicle detection was in real-time mode and monitored by CCTV cameras through the Bosch Video Management Software (BVMS). The DSS was tested on two intersections within Seminole County; US 17-92 at Church Avenue and SR 436 (Semoran Blvd) at CR 427 (Ronald Reagan Blvd).

- **US 17-92 at Church Avenue**

At the vicinity of the intersection, US 17-92 is a six-lane divided arterial which runs in the north-south direction with a posted speed limit of 45 mph. Church Avenue is a two-lane undivided local road on one side and a parking lot on the other side as shown in Figure 6-8. Commercial land uses exist on both sides of the road such as McDonald's, Burger King and Long John Silver's. The area gets busy during the lunch hour. The intersection has exclusive northbound and southbound left-turn lanes. The NB and SB left-turn lanes have a four-section head display which operates in a protected permissive mode. The intersection is monitored by CCTV cameras as shown in Figure 6-9, which feed into the County's Traffic Management Center (TMC). In order to test the DSS algorithm, the DI-161 data logger channels were connected to the loop detectors in the cabinet to receive real-time traffic data. Figure 6-10 shows the DI-161 light bulbs for channels F0 and F2 which indicates that lanes 1 and 3 detected two vehicles at the same time. The intersection's cycle length varies according to the demand but was approximately 200 seconds.

Figure 6-8: US 17-92 and Church Avenue Geometry

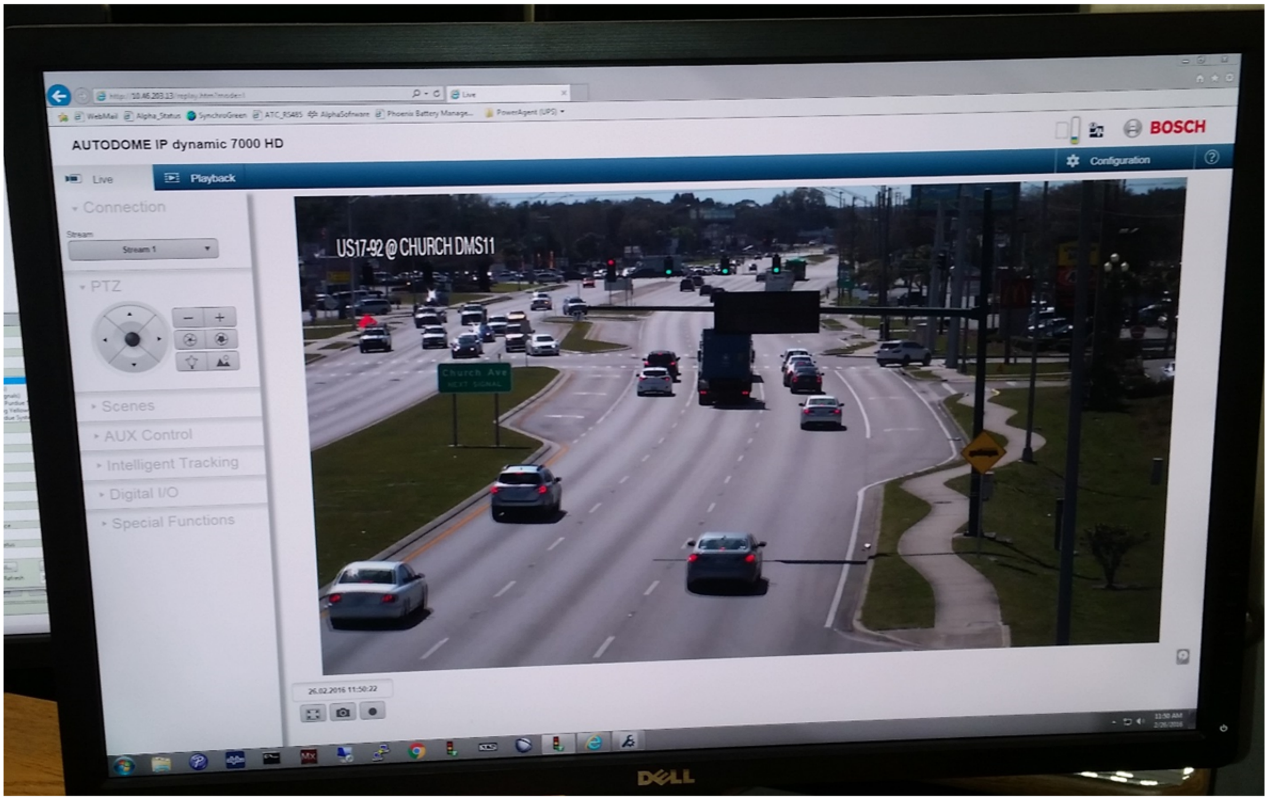


Figure 6-9: US 17-92 at Church Avenue CCTV Camera Feeds

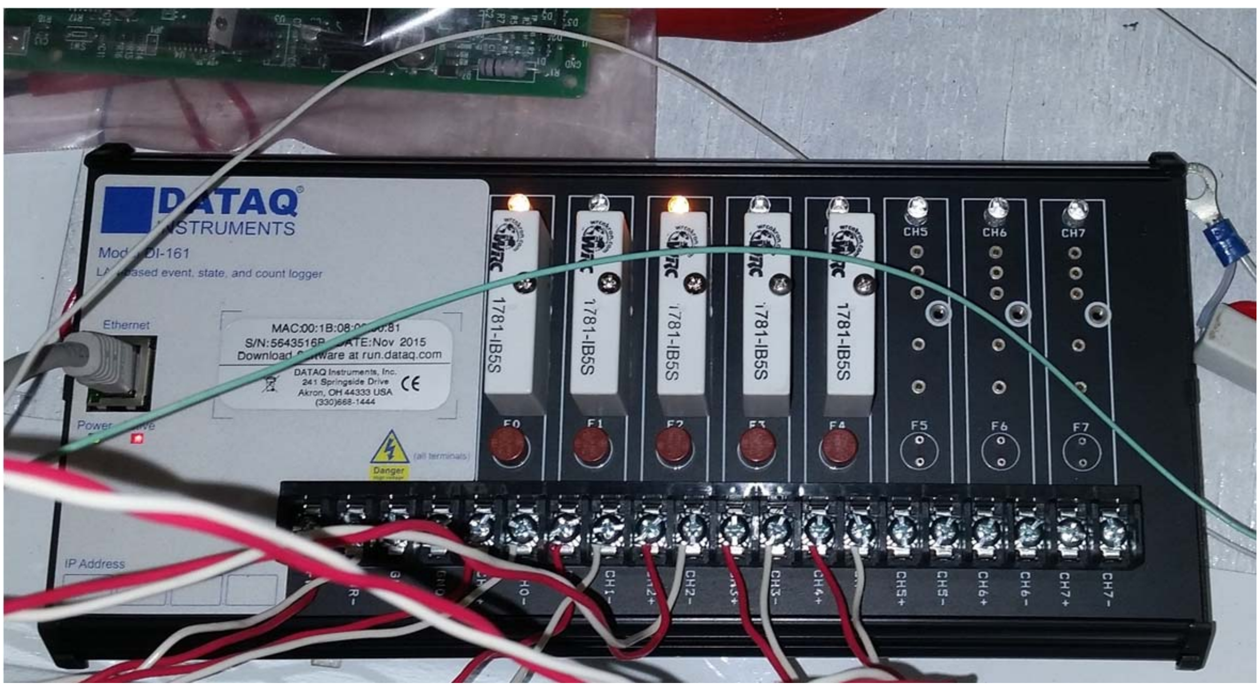


Figure 6-10: DI-161 Data Logger Detection with Channels F0 and F2 Bulbs Lit

- **DSS Results**

The intersection was monitored for approximately one hour during lunch time between 12:00 and 1:00 pm. Table 6-4 displays the DSS log file and outputs for the intersection of US 17-92 and Church Avenue on a second by second basis for one cycle along with the algorithm decision.

Table 6-4: DSS Output Log File for US 17-92 and Church Avenue (One Cycle)

Date Time	Ch0	Ch1	Ch2	Ch3	Interval
2/26/2016 12:19:24 PM	0	0	0	On	103 s
2/26/2016 12:19:25 PM	Waiting for phase...				
2/26/2016 12:19:26 PM	Waiting for phase...				
2/26/2016 12:19:27 PM	Waiting for phase...				
2/26/2016 12:19:28 PM	Waiting for phase...				
2/26/2016 12:19:29 PM	Waiting for phase...				
2/26/2016 12:19:30 PM	Waiting for phase...				
2/26/2016 12:19:31 PM	Waiting for phase...				
2/26/2016 12:19:32 PM	Waiting for phase...				
2/26/2016 12:19:33 PM	Waiting for phase...				
2/26/2016 12:19:34 PM	Waiting for phase...				
2/26/2016 12:19:35 PM	Waiting for phase...				
2/26/2016 12:19:36 PM	Waiting for phase...				
2/26/2016 12:19:37 PM	Waiting for phase...				
2/26/2016 12:19:38 PM	Waiting for phase...				
2/26/2016 12:19:39 PM	Waiting for phase...				
2/26/2016 12:19:40 PM	Waiting for phase...				
2/26/2016 12:19:41 PM	Waiting for phase...				
2/26/2016 12:19:42 PM	Waiting for phase...				
2/26/2016 12:19:43 PM	Waiting for phase...				
2/26/2016 12:19:44 PM	Waiting for phase...				
2/26/2016 12:19:45 PM	Waiting for phase...				
2/26/2016 12:19:46 PM	Waiting for phase...				
2/26/2016 12:19:47 PM	Waiting for phase...				
2/26/2016 12:19:48 PM	Waiting for phase...				
2/26/2016 12:19:49 PM	Waiting for phase...				
2/26/2016 12:19:50 PM	Waiting for phase...				
2/26/2016 12:19:51 PM	Waiting for phase...				
2/26/2016 12:19:52 PM	0	0	0	On	104 s
2/26/2016 12:19:53 PM	0	0	0	On	105 s
2/26/2016 12:19:54 PM	0	0	0	On	106 s
2/26/2016 12:19:55 PM	0	1	0	On	107 s
2/26/2016 12:19:56 PM	0	1	0	On	108 s
2/26/2016 12:19:57 PM	1	0	0	On	109 s
2/26/2016 12:19:58 PM	0	0	1	On	110 s
2/26/2016 12:19:59 PM	0	0	1	On	111 s

Table 6-4: DSS Output Log File for US 17-92 and Church Avenue (One Cycle) (Continued)

Date Time	Ch0	Ch1	Ch2	Ch3	Interval
2/26/2016 12:20:00 PM	0	0	0	On	112 s
2/26/2016 12:20:01 PM	0	1	0	On	113 s
2/26/2016 12:20:02 PM	1	1	0	On	114 s
2/26/2016 12:20:03 PM	0	0	1	On	115 s
2/26/2016 12:20:04 PM	1	1	0	On	116 s
2/26/2016 12:20:05 PM	1	0	0	On	117 s
2/26/2016 12:20:06 PM	0	0	0	On	118 s
2/26/2016 12:20:07 PM	1	0	0	On	119 s
2/26/2016 12:20:08 PM	0	0	0	On	120 s
2/26/2016 12:20:09 PM	0	0	1	On	121 s
2/26/2016 12:20:10 PM	1	1	1	On	122 s
2/26/2016 12:20:11 PM	1	0	0	On	123 s
2/26/2016 12:20:12 PM	0	0	0	On	124 s
2/26/2016 12:20:13 PM	0	1	0	On	125 s
2/26/2016 12:20:14 PM	0	0	0	On	126 s
2/26/2016 12:20:15 PM	0	0	0	On	127 s
2/26/2016 12:20:16 PM	0	0	0	On	128 s
2/26/2016 12:20:17 PM	0	0	0	On	129 s
2/26/2016 12:20:18 PM	0	0	0	On	130 s
2/26/2016 12:20:19 PM	0	0	0	On	131 s
2/26/2016 12:20:20 PM	0	0	0	On	132 s
2/26/2016 12:20:21 PM	1	1	0	On	133 s
2/26/2016 12:20:22 PM	0	0	0	On	134 s
2/26/2016 12:20:23 PM	1	1	0	On	135 s
2/26/2016 12:20:24 PM	0	1	0	On	136 s
2/26/2016 12:20:25 PM	0	0	0	On	137 s
2/26/2016 12:20:26 PM	0	0	1	On	138 s
2/26/2016 12:20:27 PM	0	0	0	On	139 s
2/26/2016 12:20:28 PM	0	0	0	On	140 s
2/26/2016 12:20:29 PM	0	1	0	On	141 s
2/26/2016 12:20:30 PM	1	0	1	On	142 s
2/26/2016 12:20:31 PM	0	1	1	On	143 s
2/26/2016 12:20:32 PM	0	1	0	On	144 s
2/26/2016 12:20:33 PM	0	0	0	On	145 s
2/26/2016 12:20:34 PM	0	0	0	On	146 s
2/26/2016 12:20:35 PM	0	0	0	On	147 s
2/26/2016 12:20:36 PM	0	0	0	On	148 s
2/26/2016 12:20:37 PM	0	0	0	On	149 s
2/26/2016 12:20:38 PM	0	0	1	On	150 s
2/26/2016 12:20:39 PM	0	1	0	On	151 s
2/26/2016 12:20:40 PM	0	0	0	On	152 s
2/26/2016 12:20:41 PM	0	0	0	On	153 s
2/26/2016 12:20:42 PM	0	1	1	On	154 s
2/26/2016 12:20:43 PM	0	0	0	On	155 s

Table 6-4: DSS Output Log File for US 17-92 and Church Avenue (One Cycle) (Continued)

Date Time	Ch0	Ch1	Ch2	Ch3	Interval
2/26/2016 12:20:44 PM	0	0	0	On	156 s
2/26/2016 12:20:45 PM	0	0	0	On	157 s
2/26/2016 12:20:46 PM	0	0	0	On	158 s
2/26/2016 12:20:47 PM	0	0	0	On	159 s
2/26/2016 12:20:48 PM	0	0	0	On	160 s
2/26/2016 12:20:49 PM	0	0	0	On	161 s
2/26/2016 12:20:50 PM	0	0	0	On	162 s
2/26/2016 12:20:51 PM	0	0	0	On	163 s
2/26/2016 12:20:52 PM	0	0	0	On	164 s
2/26/2016 12:20:53 PM	0	0	0	On	165 s
2/26/2016 12:20:54 PM	0	0	0	On	166 s
2/26/2016 12:20:55 PM	0	0	0	On	167 s
2/26/2016 12:20:56 PM	0	0	0	On	168 s
2/26/2016 12:20:57 PM	0	0	0	On	169 s
2/26/2016 12:20:58 PM	0	0	0	On	170 s
2/26/2016 12:20:59 PM	0	0	0	On	171 s
2/26/2016 12:21:00 PM	0	0	0	On	172 s
2/26/2016 12:21:01 PM	1	0	0	On	173 s
2/26/2016 12:21:02 PM	0	0	0	On	174 s
2/26/2016 12:21:03 PM	0	1	0	On	175 s
2/26/2016 12:21:04 PM	1	0	0	On	176 s
2/26/2016 12:21:05 PM	1	0	0	On	177 s
2/26/2016 12:21:06 PM	0	0	0	On	178 s
2/26/2016 12:21:07 PM	1	0	0	On	179 s
2/26/2016 12:21:08 PM	0	1	0	On	180 s
2/26/2016 12:21:09 PM	0	0	0	On	181 s
2/26/2016 12:21:10 PM	0	0	0	On	182 s
2/26/2016 12:21:11 PM	1	0	0	On	183 s
2/26/2016 12:21:12 PM	0	0	0	On	184 s
2/26/2016 12:21:13 PM	0	0	0	On	185 s
2/26/2016 12:21:14 PM	0	0	0	On	186 s
2/26/2016 12:21:15 PM	0	0	0	On	187 s
2/26/2016 12:21:16 PM	0	0	0	On	188 s
2/26/2016 12:21:17 PM	1	0	0	On	189 s
2/26/2016 12:21:18 PM	0	1	0	On	190 s
2/26/2016 12:21:19 PM	0	0	0	On	191 s
2/26/2016 12:21:20 PM	0	0	0	On	192 s
2/26/2016 12:21:21 PM	1	0	0	On	193 s
2/26/2016 12:21:22 PM	0	0	0	On	194 s
2/26/2016 12:21:23 PM	0	0	0	On	195 s
2/26/2016 12:21:24 PM	0	0	0	On	196 s
2/26/2016 12:21:25 PM	0	1	0	On	197 s
2/26/2016 12:21:26 PM	1	0	0	On	198 s
2/26/2016 12:21:27 PM	0	0	0	On	199 s

Table 6-4: DSS Output Log File for US 17-92 and Church Avenue (One Cycle) (Continued)

Date Time	Ch0	Ch1	Ch2	Ch3	Interval
2/26/2016 12:21:28 PM	1	0	1	On	200 s
2/26/2016 12:21:29 PM	1	1	0	On	201 s
2/26/2016 12:21:30 PM	0	0	0	On	202 s
2/26/2016 12:21:31 PM	0	0	0	On	203 s
2/26/2016 12:21:32 PM	0	0	0	On	204 s
2/26/2016 12:21:33 PM	0	0	0	On	205 s
2/26/2016 12:21:34 PM	0	0	0	On	206 s
2/26/2016 12:21:35 PM	0	0	0	On	207 s
2/26/2016 12:21:36 PM	1	1	0	On	208 s
2/26/2016 12:21:37 PM	1	0	0	On	209 s
2/26/2016 12:21:38 PM	0	1	0	On	210 s
2/26/2016 12:21:39 PM	0	0	0	On	211 s
2/26/2016 12:21:40 PM	0	1	1	On	212 s
2/26/2016 12:21:41 PM	0	0	0	On	213 s
2/26/2016 12:21:42 PM	0	0	1	On	214 s
2/26/2016 12:21:43 PM	0	0	0	On	215 s
2/26/2016 12:21:44 PM	0	0	0	On	216 s
2/26/2016 12:21:45 PM	0	0	0	On	217 s
2/26/2016 12:21:46 PM	0	0	1	On	218 s
2/26/2016 12:21:47 PM	0	1	0	On	219 s
2/26/2016 12:21:48 PM	1	0	0	On	220 s
2/26/2016 12:21:49 PM	0	0	0	On	221 s
2/26/2016 12:21:50 PM	0	0	0	On	222 s
2/26/2016 12:21:51 PM	1	0	0	On	223 s
2/26/2016 12:21:52 PM	0	0	0	On	224 s
2/26/2016 12:21:53 PM	0	0	0	On	225 s
2/26/2016 12:21:54 PM	0	0	0	On	226 s
2/26/2016 12:21:55 PM	0	0	0	On	227 s
2/26/2016 12:21:56 PM	0	0	1	On	228 s
2/26/2016 12:21:57 PM	0	0	0	On	229 s
2/26/2016 12:21:58 PM	0	1	0	On	230 s
2/26/2016 12:21:59 PM	0	1	0	On	231 s
2/26/2016 12:22:00 PM	0	0	0	On	232 s
2/26/2016 12:22:01 PM	0	0	0	On	233 s
2/26/2016 12:22:02 PM	0	0	0	On	234 s
2/26/2016 12:22:03 PM	1	0	0	On	235 s
2/26/2016 12:22:04 PM	0	0	0	On	236 s
2/26/2016 12:22:05 PM	**Applying decision**	**Flashing Yellow Arrow**			
2/26/2016 12:22:05 PM	Waiting for phase...				
2/26/2016 12:22:06 PM	Waiting for phase...				
2/26/2016 12:22:07 PM	Waiting for phase...				
2/26/2016 12:22:08 PM	Waiting for phase...				

As can be seen on Table 6-4, the customized data logger software displays the date and time step in real time mode on a second-by-second basis. The channels 0-2 represent the opposing three thru lanes and detects the arrivals of the vehicles in each lane while Channel 3 detects the start and end times of the opposing thru phase during which the flashing yellow arrow phase should be working. The developed software also includes the FYA algorithm, which specifies the minimum acceptable gap time for the corresponding number of lanes crossed and also the frequency of this minimum gap time in each cycle. For example, the study intersection has four opposing lanes to be crossed which correspond with a minimum acceptable gap time of 4.5 seconds as defined in Table 6-1. However, this minimum gap needs to be repeated at least five times, as specified in the algorithm, before deciding on a flashing yellow arrow mode. The algorithm kept receiving data for the first two cycles to calculate the minimum acceptable gap. Then the decision is provided in the third cycle and each cycle afterwards. The red boxes shown on Table 6-4 display the gap pattern and its frequency showing the five times specified in the algorithm to be able to decide on FYA mode. It should be noted that a minimum of five gaps repeated in each cycle is found to be reasonable especially for cycle lengths of 120 second or more. This criterion is updated in the algorithm based on the cycle length of the intersection.

- **DSS Validation**

It should be noted that the intersection was video recorded during the DSS testing for validation purposes. The validation procedure involved matching the same time step from the video file with the DSS log file. The intersection was recorded for 15 minutes which corresponded to five cycles. During the 15 minute period, 12 left-turn vehicles arrived during the permissive phase and were waiting for an acceptable gap. It was worth mentioning that the 12 vehicles were able to find an acceptable gap during the recorded 15 minutes and cleared the intersection. For the reported cycle data in Table 6-4, five vehicles arrived and cleared the intersection. Two consecutive vehicles made the left-turn during the first gap from 12:20:14 to 12:20:20; a total of 7 seconds which included the min gap time of 4.5 seconds and a follow up time of 2.5 seconds. Another truck arrived at 12:20:44 and cleared the intersection during the big gap of 18 seconds. Another two vehicles utilized the remaining two gaps at 12:21:12 and 12:21:30.

- **SR 436 and CR 427**

The second intersection used in testing the algorithm was the intersection of SR 436 and CR 427. The mainline SR 436 is a six-lane divided arterial and CR 427 is a two-lane road as shown in Figure 6-11. There is a gas station on one of the corners and a small office space on the other corner. There is a rail road crossing on the east side of the intersection. The traffic gets heavier in the afternoon as shown in Figure 6-12. Due to the trees location which blocked part of the intersection view, a dual view was needed as shown in Figure 6-12. The intersection was monitored in the afternoon between 3:00 and 4:00 pm on a Friday. As can be seen, the intersection is considered busy although right before the peak period. The study approach was the westbound left-turn lane and the opposing eastbound thru lanes.

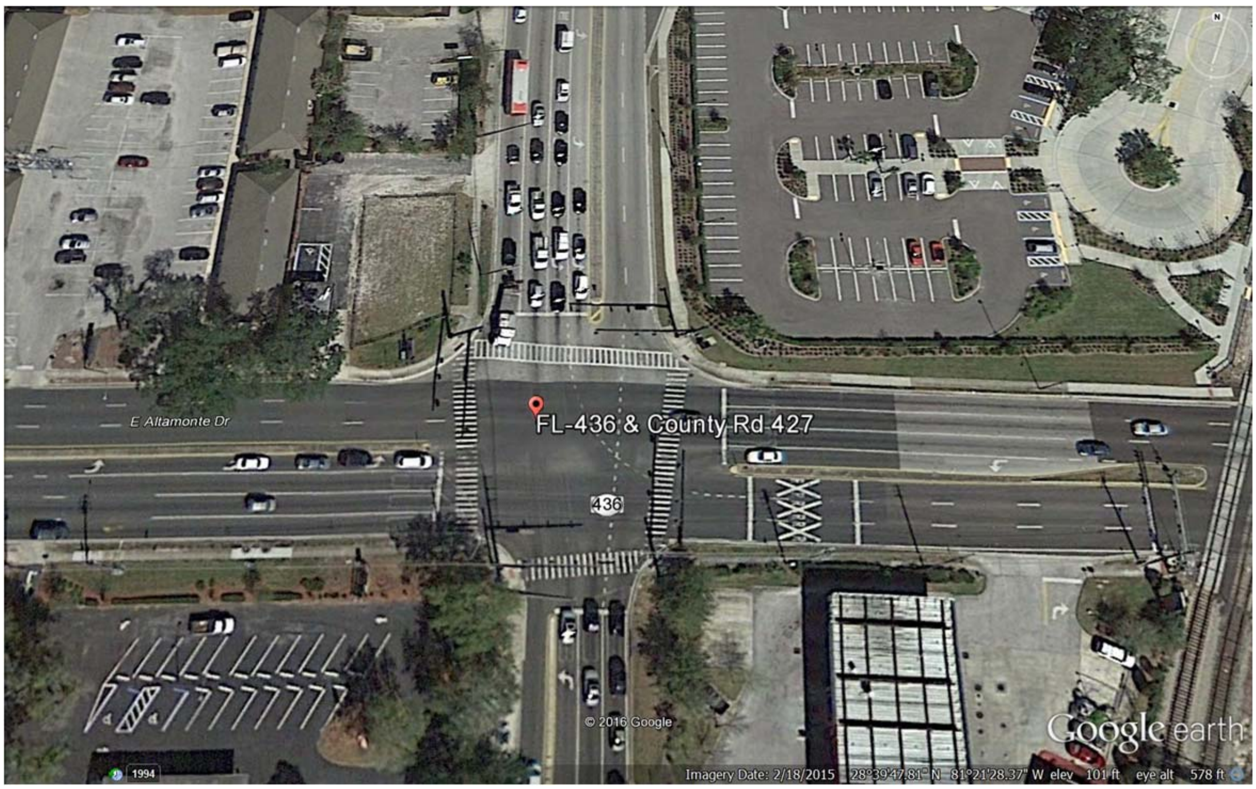


Figure 6-11: SR 436 and CR 427 Geometry

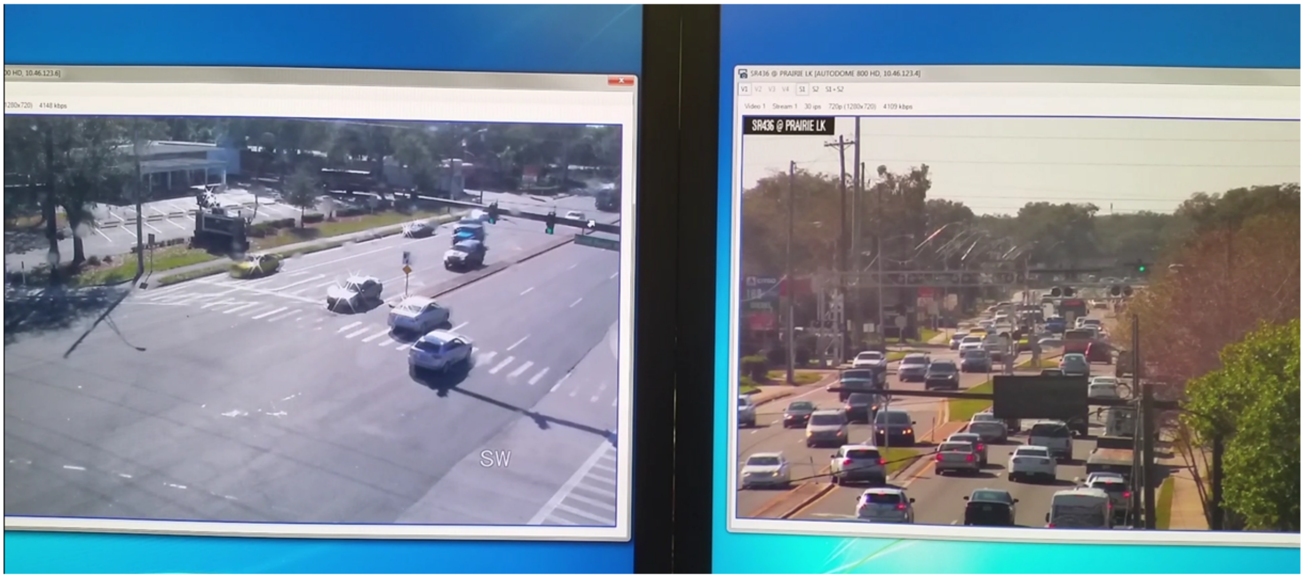


Figure 6-12: SR 436 at CR 427 CCTV Camera Feeds

- **DSS Results**

Table 6-5 displays the DSS log file and outputs for the intersection of SR 436 and CR 427 on a second-by-second basis for just one cycle. The study intersection has three opposing lanes to be crossed which correspond to a minimum acceptable gap time of 4.0 seconds as defined in Table 6-1. However, this minimum gap needs to be repeated at least five times, as specified in the algorithm, before deciding on a flashing yellow arrow mode. As mentioned previously, the algorithm receives data for the first two cycles to calculate the minimum acceptable gap. Then the decision is provided in the third cycle and each cycle afterwards. The red box shown on Table 6-5 displays the gap pattern and its frequency showing only one time out of the five specified in the algorithm to be able to decide on a FYA mode. The cycle length was also around 120 seconds. The DSS decision was to keep it protected until the minimum criteria is satisfied.

Table 6-5: DSS Output Log File for SR 436 and CR 427 (One Cycle)

Date Time	Ch0	Ch1	Ch2	Ch3	Interval
2/26/2016 3:18:27 PM	Waiting for phase...				
2/26/2016 3:18:28 PM	Waiting for phase...				
2/26/2016 3:18:29 PM	Waiting for phase...				
2/26/2016 3:18:30 PM	Waiting for phase...				
2/26/2016 3:18:31 PM	Waiting for phase...				
2/26/2016 3:18:32 PM	Waiting for phase...				
2/26/2016 3:18:33 PM	Waiting for phase...				
2/26/2016 3:18:34 PM	Waiting for phase...				
2/26/2016 3:18:35 PM	1	1	0	On	104 s
2/26/2016 3:18:36 PM	1	1	0	On	105 s
2/26/2016 3:18:37 PM	1	1	0	On	106 s
2/26/2016 3:18:38 PM	0	1	0	On	107 s
2/26/2016 3:18:39 PM	0	1	0	On	108 s
2/26/2016 3:18:40 PM	0	1	0	On	109 s
2/26/2016 3:18:41 PM	0	1	0	On	110 s
2/26/2016 3:18:42 PM	0	1	0	On	111 s
2/26/2016 3:18:43 PM	0	1	0	On	112 s
2/26/2016 3:18:44 PM	0	1	0	On	113 s
2/26/2016 3:18:45 PM	0	1	0	On	114 s
2/26/2016 3:18:46 PM	0	1	1	On	115 s
2/26/2016 3:18:47 PM	0	1	1	On	116 s
2/26/2016 3:18:48 PM	0	1	1	On	117 s
2/26/2016 3:18:49 PM	0	1	0	On	118 s
2/26/2016 3:18:50 PM	0	1	1	On	119 s
2/26/2016 3:18:51 PM	1	0	1	On	120 s
2/26/2016 3:18:52 PM	1	1	0	On	121 s
2/26/2016 3:18:53 PM	0	1	0	On	122 s
2/26/2016 3:18:54 PM	0	0	0	On	123 s
2/26/2016 3:18:55 PM	0	0	1	On	124 s
2/26/2016 3:18:56 PM	0	0	1	On	125 s
2/26/2016 3:18:57 PM	0	0	0	On	126 s
2/26/2016 3:18:58 PM	0	0	0	On	127 s
2/26/2016 3:18:59 PM	0	0	0	On	128 s
2/26/2016 3:19:00 PM	0	0	0	On	129 s
2/26/2016 3:19:01 PM	0	0	0	On	130 s
2/26/2016 3:19:02 PM	0	0	0	On	131 s
2/26/2016 3:19:03 PM	0	0	0	On	132 s
2/26/2016 3:19:04 PM	0	0	0	On	133 s
2/26/2016 3:19:05 PM	0	0	0	On	134 s
2/26/2016 3:19:06 PM	1	1	0	On	135 s
2/26/2016 3:19:07 PM	0	1	0	On	136 s
2/26/2016 3:19:08 PM	0	0	0	On	137 s

Table 6-5: DSS Output Log File for SR 436 and CR 427 (One Cycle) (Continued)

Date Time	Ch0	Ch1	Ch2	Ch3	Interval
2/26/2016 3:19:09 PM	0	0	0	On	138 s
2/26/2016 3:19:10 PM	0	0	0	On	139 s
2/26/2016 3:19:11 PM	1	0	0	On	140 s
2/26/2016 3:19:12 PM	0	1	0	On	141 s
2/26/2016 3:19:13 PM	0	0	0	On	142 s
2/26/2016 3:19:14 PM	1	0	0	On	143 s
2/26/2016 3:19:15 PM	0	0	1	On	144 s
2/26/2016 3:19:16 PM	1	0	1	On	145 s
2/26/2016 3:19:17 PM	1	0	0	On	146 s
2/26/2016 3:19:18 PM	0	0	0	On	147 s
2/26/2016 3:19:19 PM	0	1	1	On	148 s
2/26/2016 3:19:20 PM	1	1	1	On	149 s
2/26/2016 3:19:21 PM	1	0	0	On	150 s
2/26/2016 3:19:22 PM	1	0	1	On	151 s
2/26/2016 3:19:23 PM	1	0	1	On	152 s
2/26/2016 3:19:24 PM	0	0	1	On	153 s
2/26/2016 3:19:25 PM	0	0	0	On	154 s
2/26/2016 3:19:26 PM	0	0	1	On	155 s
2/26/2016 3:19:27 PM	0	1	1	On	156 s
2/26/2016 3:19:28 PM	1	1	1	On	157 s
2/26/2016 3:19:29 PM	0	0	1	On	158 s
2/26/2016 3:19:30 PM	0	0	0	On	159 s
2/26/2016 3:19:31 PM	1	1	1	On	160 s
2/26/2016 3:19:32 PM	1	0	0	On	161 s
2/26/2016 3:19:33 PM	0	1	0	On	162 s
2/26/2016 3:19:34 PM	1	0	0	On	163 s
2/26/2016 3:19:35 PM	2	1	0	On	164 s
2/26/2016 3:19:36 PM	0	1	0	On	165 s
2/26/2016 3:19:37 PM	0	1	0	On	166 s
2/26/2016 3:19:38 PM	1	1	0	On	167 s
2/26/2016 3:19:39 PM	0	1	0	On	168 s
2/26/2016 3:19:40 PM	1	0	1	On	169 s
2/26/2016 3:19:41 PM	1	1	1	On	170 s
2/26/2016 3:19:42 PM	0	0	1	On	171 s
2/26/2016 3:19:43 PM	0	0	1	On	172 s
2/26/2016 3:19:44 PM	0	0	0	On	173 s
2/26/2016 3:19:45 PM	0	0	1	On	174 s
2/26/2016 3:19:46 PM	0	0	1	On	175 s
2/26/2016 3:19:47 PM	1	1	1	On	176 s
2/26/2016 3:19:48 PM	0	1	1	On	177 s
2/26/2016 3:19:49 PM	1	1	0	On	178 s
2/26/2016 3:19:50 PM	1	0	0	On	179 s
2/26/2016 3:19:51 PM	0	1	0	On	180 s
2/26/2016 3:19:52 PM	0	1	0	On	181 s

Table 6-5: DSS Output Log File for SR 436 and CR 427 (One Cycle) (Continued)

Date Time	Ch0	Ch1	Ch2	Ch3	Interval
2/26/2016 3:19:53 PM	1	0	0	On	182 s
2/26/2016 3:19:54 PM	1	0	0	On	183 s
2/26/2016 3:19:55 PM	0	1	0	On	184 s
2/26/2016 3:19:56 PM	0	1	0	On	185 s
2/26/2016 3:19:57 PM	1	1	0	On	186 s
2/26/2016 3:19:58 PM	0	1	0	On	187 s
2/26/2016 3:19:59 PM	1	0	1	On	188 s
2/26/2016 3:20:00 PM	1	1	1	On	189 s
2/26/2016 3:20:01 PM	0	1	0	On	190 s
2/26/2016 3:20:02 PM	1	0	0	On	191 s
2/26/2016 3:20:03 PM	1	1	0	On	192 s
2/26/2016 3:20:04 PM	0	1	1	On	193 s
2/26/2016 3:20:05 PM	0	1	1	On	194 s
2/26/2016 3:20:06 PM	0	1	0	On	195 s
2/26/2016 3:20:07 PM	0	1	1	On	196 s
2/26/2016 3:20:08 PM	1	0	1	On	197 s
2/26/2016 3:20:09 PM	1	0	0	On	198 s
2/26/2016 3:20:10 PM	1	1	0	On	199 s
2/26/2016 3:20:11 PM	1	1	1	On	200 s
2/26/2016 3:20:12 PM	1	1	0	On	201 s
2/26/2016 3:20:13 PM	1	1	1	On	202 s
2/26/2016 3:20:14 PM	0	1	0	On	203 s
2/26/2016 3:20:15 PM	1	0	0	On	204 s
2/26/2016 3:20:16 PM	0	1	0	On	205 s
2/26/2016 3:20:17 PM	1	0	0	On	206 s
2/26/2016 3:20:18 PM	0	1	1	On	207 s
2/26/2016 3:20:19 PM	1	0	0	On	208 s
2/26/2016 3:20:20 PM	0	0	1	On	209 s
2/26/2016 3:20:21 PM	0	0	1	On	210 s
2/26/2016 3:20:22 PM	0	0	0	On	211 s
2/26/2016 3:20:23 PM	1	0	0	On	212 s
2/26/2016 3:20:24 PM	0	1	1	On	213 s
2/26/2016 3:20:25 PM	1	1	1	On	214 s
2/26/2016 3:20:26 PM	1	1	0	On	215 s
2/26/2016 3:20:27 PM	1	0	1	On	216 s
2/26/2016 3:20:28 PM	1	0	0	On	217 s
2/26/2016 3:20:29 PM	1	0	0	On	218 s
2/26/2016 3:20:30 PM	2	0	0	On	219 s
2/26/2016 3:20:31 PM	1	0	0	On	220 s
2/26/2016 3:20:32 PM	Applying decision			Red Arrow	
2/26/2016 3:20:32 PM	Waiting for phase...				
2/26/2016 3:20:33 PM	Waiting for phase...				
2/26/2016 3:20:34 PM	Waiting for phase...				
2/26/2016 3:20:35 PM	Waiting for phase...				

6.3 DSS Testing Conclusions

The decision support system was tested at two different intersections in Seminole County. The UCF research team utilized Seminole County Traffic Engineering Lab where field data was collected in real time mode using peer-to-peer logic in order to map the field controller to the lab controller. Video data was collected at the same time period as the algorithm was tested in order to validate the algorithm decisions. The DSS testing confirmed the applicability and validity of the developed DSS as well as the aforementioned procedure, criteria and logic.

7. CONCLUSIONS

The flashing yellow arrow phase II project provided additional intersection video data that was extracted and utilized in order to refine the model developed in phase I. The additional videos, garnished by FDOT representatives, were an asset to the project and contributed to its success. The usable data of the master database was increased to 38 intersections with locations across the State of Florida. The data extraction process in phase II was completed to match the basic prioritized parameters that were used to refine the developed model in phase I. Additional parameters such as the left-turn timing, left-turn gap, opposing lane utilization and left-turn stop delay were extracted as necessary, broadening the data analysis.

Model refinement required the expansion of the database to increase the domain and improve reliability of the developed model. Total entries for Phases I and II amounted to 1,322 hours of data that were analyzed on a second by second basis. The preliminary analysis of the data pinpointed some of the data sets that had low left-turning volume and other circumstances that required removal from the data set not to affect the modeling process. The cleaning process resulted in the removal of 264 hours. The final total remaining hours used in the statistical analysis were 1,058 hours. Further analysis revealed high variability in the data set which was enhanced through data sub-setting using other parameters in the data set. Several modeling techniques were investigated which included stepwise regression, time series analysis and neural networks. Based on the analysis, neural networks model provided the highest correlation between the independent variables with coefficient of correlation reaching 90%. Neural network analysis is a very powerful tool for non-parametric variables with high variability as they provide superior predictive accuracy to commonly used algorithms. Virtual testing of the decision support system using VISSIM application programming interface (API) confirmed the applicability and validity of the procedure and logic. This was a critical juncture before running a field test.

A custom communications software was developed which has three main functions; control the hardware, display real-time status and execute the proposed FYA algorithm. The UCF research team developed a specific code to retrieve instantaneous channel input data, synchronize opposing thru green phase, analyze traffic information, provide the algorithm decision, and generate a real-time log recording the events. The software was developed using the C# language under Microsoft's™ Visual Studio 2013 development environment.

The proposed algorithm is implemented with the goal of safely optimizing traffic operations. In the case of a red arrow signaled for a left-turn, the opposing thru traffic during the green phase is constantly analyzed in real-time to determine whether it would be optimal to switch the red arrow to a flashing yellow arrow. The decision is made based on a number of parameters which includes: the minimum headway of vehicles in the opposing traffic, the number of lanes to cross, and the number of cycles to be analyzed prior to making the decision. The algorithm determines the time interval between the successive arrivals of vehicles for each lane independently and computes the corresponding headway for each lane by cycle on a second by second. The thresholds used for different crossing number of lanes were obtained from the database of 30,000 cycles collected from the field. If the minimum headway for the corresponding number of lanes is achieved and repeated for certain number of times, for example, at least five times during the analysis period (whether one or two cycles) which is also an input to the algorithm, the decision is made to switch to a flashing yellow mode. Otherwise, a red arrow is decided upon

The decision support system was ultimately tested at two different intersections in Seminole County. The UCF research team utilized Seminole County Traffic Engineering Lab where field data was collected in real time mode using peer-to-peer logic in order to map the field controller to the lab controller. Video data was collected at the same time period as the algorithm was tested in order to validate the algorithm decisions. The DSS testing confirmed the applicability and validity of the developed DSS as well as the aforementioned procedure, criteria and logic. The value of the DSS in making real-time traffic decisions is crucial to improving the performance of the left-turning traffic and can be applied at any flashing yellow arrow system.