

FHWA/IN/JTRP-2000/5

Final Report

**DEVELOPMENT OF CLOSED LOOP SYSTEM
EVALUATION PROCEDURES**

**Eric Nelson
Montasir Abbas
Gary Shoup
Darcy Bullock
Ryan Gallagher**

December 2000

Draft Final Report
FHWA/IN/JTRP-2000/5

DEVELOPMENT OF CLOSED LOOP SYSTEM EVALUATION PROCEDURES

Eric J. Nelson
Research Assistant

Montasir M. Abbas
Research Assistant

Gary E. Shoup
Research Assistant

and

Darcy Bullock
Associate Professor of Civil Engineering

School of Civil Engineering
Purdue University

Joint Transportation Research Program
Project Number: C-36-17WW
File Number: 8-4-49

Conducted in Cooperation with the
Indiana Department of Transportation
and the
Federal Highway Administration

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Federal Highway Administration and the Indiana Department of Transportation. This report does not constitute a standard, specification, or regulation.

Purdue University
West Lafayette, IN 47907

July 2000

1. Report No. FHWA/IN/JTRP-2000/5		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle DEVELOPMENT OF CLOSED LOOP SYSTEM EVALUATION PROCEDURES				5. Report Date December 2000	
				6. Performing Organization Code	
7. Author(s) Eric Nelson, Montasir Abbas, Gary Shoup, Darcy Bullock, R. Gallagher				8. Performing Organization Report No. FHWA/IN/JTRP-2000/5	
9. Performing Organization Name and Address Joint Transportation Research Program Civil Engineering Building Purdue University West Lafayette, Indiana 47907-1284				10. Work Unit No.	
				11. Contract or Grant No. SPR-2326	
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204				13. Type of Report and Period Covered Final Report	
				14. Sponsoring Agency Code	
15. Supplementary Notes Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration, NCP 4D4e0212.					
16. Abstract <p>Modern traffic control systems are complex entities whose performance should be thoroughly quantified prior to deployment. However, many of the advanced features available with this control equipment, such as preemption and real-time control strategies, are typically proprietary in nature, and therefore not incorporated into standard simulation models. Since it is not desirable for the engineer to learn in a field environment, under live traffic conditions, this research presents a rational procedure for evaluating and validating such control strategies in a laboratory setting. This document explores three aspects of traffic signal systems, which include the advanced control settings for single controller diamond interchanges, the impact evaluation of emergency vehicle preemption on signalized corridor operation, and an analysis of the more complex Traffic Responsive (TRP) control strategies available with the modern equipment. Each of these areas have been evaluated using quantitative data obtained from the CORSIM simulation model that communicates with the actual control equipment through the use of a Controller Interface Device (CID). The results for each of the study areas have been tabulated, plotted, and discussed. These case studies serve as models of how INDOT may want to request future traffic signal timing contracts to structure and present the performance of signal timing design alternatives.</p>					
7. Key Words Traffic Signal Controller, Evaluation, Hardware, Simulation			18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Virginia, 22161		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 409	22. Price



INDOT Research

TECHNICAL *Summary*

Technology Transfer and Project Implementation Information

TRB Subject Code: 54-6 Traffic Control Systems
Publication No.: FHWA/IN/JTRP-2000/5, SPR-2326

December 2000
Final Report

Development of Closed Loop System Evaluation Procedures

Introduction

Traffic signals are used by the Indiana Department of Transportation for safely regulating the flow of traffic. Until the late 1970's, traffic signal systems were predominantly fixed time electromechanical systems with deterministic green intervals. Over the past two decades, traffic signal systems have evolved to become a complex distributed control system. Each controller has a microprocessor that sequences and times phases according to local detector demand while simultaneously communicating with an adjacent master controller to maintain a

constant cycle length – and perhaps implement traffic responsive operation. The controllers purchased by INDOT conform to the National Electrical Manufacturer Association (NEMA). These controllers have standard electrical interfaces, but vendors compete on the features and user interface provided by the microprocessor based control system. Consequently, each vendors systems behaves somewhat differently. As a result, it is impossible to evaluate the performance of a closed loop traffic signal system with standard simulation software.

Findings

This research demonstrated why traditional highway capacity manual analysis can not be applied to traffic signal systems and showed that simulation procedures must be used if one

wishes to account for the operation of modern coordinated-actuated traffic signal controllers commonly used by INDOT.

Implementation

Throughout this research, several items were spun-off for implementation. The following paragraphs describe these various implementation efforts.

This research evaluated the feasibility and technical issues associated with using one controller to operate a compressed diamond

interchange. As a result of this work, several informal meetings/workshops have been held with INDOT staff. At a meeting in the Greenfield District in June, it was decided that this procedure would be used at the new compressed diamonds being constructed at the southern end of I-65 scheduled for construction in 2001. Had this research not

been conducted, test equipment and procedures would not have been available to evaluate this novel control procedure.

This research developed vendor neutral procedures for documenting the essential controller parameters and detector mappings necessary for documenting a functional coordinated-actuated traffic signal system design. As new INDOT staff is added or more signal design work is contracted out, the tables and figures documented in the report will be particularly helpful for INDOT as they will illustrate how coordinated-actuated traffic signal system designs should be presented. A pilot project with an INDOT COOP student is currently underway to document a corridor timed with SYNCRO using this procedure.

Developed “big picture” graphs and figures documenting the performance of a traffic signal system. These “big picture” figures illustrate: 1) The travel time along a corridor, 2) Minor movement and side street delay, 3) system delay by hour and 4) number of stops by hour. These graphs are particularly

useful for district traffic engineers for evaluating alternative signal timing plans proposed by either in house staff or consultants. This procedure will also be used by the INDOT COOP student participating in the pilot study.

Finally, in the past, INDOT staff has learned to operate traffic signal systems entirely through on the job training. As a result, some staff are reluctant to try novel procedures that could be beneficial, because of the risk involved in modifying controllers regulating live traffic. The “flight simulator” type environment constructed for closed loop traffic signal systems provides an ideal environment for training both INDOT staff as well as students at Purdue University. This environment provides both visual and quantitative feedback that provides an opportunity for participants to rapidly gain experience (both successes and failures) operating closed loop signal systems, without subjecting the motoring public to those experiments.

Contacts

For more information:

Professor Darcy M. Bullock

Principal Investigator
School of Civil Engineering
Purdue University
West Lafayette, IN 47907-1284
Phone: (765) 494-2226
Fax: (765) 496-1105

Indiana Department of Transportation

Division of Research
1205 Montgomery Street
P.O. Box 2279
West Lafayette, IN 47906
Phone: (765) 463-1521
Fax: (765) 497-1665

Purdue University

Joint Transportation Research Program
School of Civil Engineering
West Lafayette, IN 47907-1284
Phone: (765) 494-9310

Fax: (765) 496-1105

IMPLEMENTATION REPORT

Traffic signals are used by the Indiana Department of Transportation for safely regulating the flow of traffic. Until the late 1970's, traffic signal systems were predominantly fixed time electromechanical systems with deterministic green intervals. Over the past two decades, traffic signal systems have evolved to become a complex distributed control system. Each controller has a microprocessor that sequences and times phases according to local detector demand while simultaneously communicating with an adjacent master controller to maintain a constant cycle length – and perhaps implement traffic responsive operation. The controllers purchased by INDOT conform to the National Electrical Manufacturer Association (NEMA). These controllers have standard electrical interfaces, but vendors compete on the features and user interface provided by the microprocessor based control system. Consequently, each vendors system behaves somewhat differently. As a result, it is impossible to evaluate the performance of a closed loop traffic signal system with standard simulation software.

This research project fabricated devices called Controller Interface Devices (CIDs) for conducting simulation experiments with the actual traffic signal equipment and developed procedures for tabulating that data so that the performance of a closed loop traffic signal system could be readily evaluated. Throughout this research, SAC members have help coordinate the following “implementation” of this research by participating in case studies and critiquing incremental results:

- Evaluating vendor specific features of a particular brand of controller in a safe offline environment where reproducible tests can be carried out. Chapter 3 illustrates the importance of this capability.
- Evaluating the feasibility and technical issues associated with using one controller to operate a compressed diamond interchange. The procedures operating a diamond interchange in such a manner are documented in Chapters 4 and 5. As a result of this work, several informal meetings/workshops have been held with INDOT staff. At a meeting in the Greenfield District in June, it was decided that this procedure would be used at the new compressed diamonds being constructed at the southern end of I-65 scheduled for construction in 2001.
- Developing vendor neutral procedures for documenting the essential controller parameters and detector mappings necessary for documenting a functional coordinated-actuated traffic signal system design. As new INDOT staff is added or more signal design work is contracted out, the tables and figures shown in Chapters 6, 8, 9, and Appendix C will be particularly helpful for INDOT as they will illustrate how coordinated-actuated traffic signal system designs should be presented.
- Developing “big picture” graphs and figures documenting the performance of a traffic signal system. These “big picture” figures illustrate: 1) The travel time along a corridor, 2) Minor movement and side street delay, 3) system delay by hour and 4) number of stops by hour. Chapters 7 and 8 illustrate the travel time and minor movement figures. Chapters 9 illustrates all four classes of figures used to evaluate different closed loop timing options for a corridor in Indianapolis that range from free operation to time of day operation to fully traffic responsive operation. These graphs are particularly useful for district traffic engineers for evaluating alternative signal timing plans proposed by either in house staff or consultants.

Finally, in the past, INDOT staff has learned to operate traffic signal systems entirely through on the job training. As a result, some staff are reluctant to try

novel procedures that could be beneficial, because of the risk involved in modifying controllers regulating live traffic. The “flight simulator” type environment constructed for closed loop traffic signal systems provides an ideal environment for training both INDOT staff as well as students at Purdue University. This environment provides both visual and quantitative feedback that provides an opportunity for participants to rapidly gain experience (both successes and failures) operating closed loop signal systems, without subjecting the motoring public to those experiments.

In closing, the specific steps required to implement a complete hardware-in-the-loop simulation is as follows:

1. Define network geometry. Example definitions are shown in Figures 6-1 and 6-2.
2. Define intersection phasing. Example definitions are shown in Figure 6-3 to 6-5.
3. Identify intersection approaches numbers (example approach numbers shown in Figure 6-6) in CORSIM file. This information is obtained from the order of links connected to the intersection (Record 43 in Figure 6-9).
4. Develop a .CID file that maps the movements on each approach (i.e. Figure 6.6) to a particular phase (i.e. Figure 6.3, 6.4, or 6.5). An example .CID file is shown in Figure 6-7.
5. Use network editor (such as ITRAF) to define and assign detector data to system detector (Record 42). Example detector data are shown in Figure 6-8 and 6-9 and Table 6-1 and 6-2.
6. Configure controllers with “program chart” information typically programmed in the field. Example data is shown in Tables 6-3 to 6-6.
7. Run simulation with Controller Interface Devices (i.e. Figure 3-4).
8. View animation (i.e. Figure 2-7).

9. Optionally, tabulate numerical data from CORSIM into to summary graphs (i.e. Figures 7-2 to 7-5) and tables (i.e. Tables 7-3 to 7-7).
10. Present animation and quantitative data to individuals responsible for implementation.

Although these steps may at first seem onerous, Steps 1, 2, 5, and 6 already have to be done, and are already the most time consuming. Steps 3, and 4 are relatively quick and can be performed in about 2 hours. Steps 7 and 8 are equivalent to the on-street tuning process currently conducted. Steps 9 and 10 are optional, and probably only necessary in special cases.

TABLE OF CONTENTS

<u>DESCRIPTION</u>	<u>PAGE</u>
LIST OF TABLES	v
LIST OF FIGURES	x
CHAPTER 1 – INTRODUCTION	1
Report Motivation	1
Case Studies.....	2
Report Overview	3
CHAPTER 2 – SIMULATION AND EVALUATION PROCEDURES	5
Current Evaluation Procedures	5
Early Return to Main Street Green	7
Analyzing Atypical Conditions	10
Analyzing Oversaturated Conditions	10
Simulation Analysis Procedures.....	11
Applications Using Simulation	17
Implementation Advantages.....	18
CHAPTER 3 – CONCEPTS OF HARDWARE IN THE LOOP SIMULATION.....	19
Chapter Overview	19
Motivation for Hardware-in-the-Loop Simulation	19
Concepts of Hardware-in-the-Loop Simulation	21
Application of Microscopic Simulation Technology.....	26
Sample Analysis of Traffic Responsive Operation	26
Summary of Hardware-in-the-Loop Simulation	32
CHAPTER 4 – CONTROL CONCEPTS FOR ACTUATED DIAMOND INTERCHANGES.....	34
Overview of Diamond Interchanges	34
Introduction to Diamond Interchanges	34
General Diamond Control Concepts	35
Definition of a Phase	36
Single Controller – Three Phase Operation	39

Single Controller – Four Phase Operation	42
Load Bay Assignments	45
Pedestrian Indications.....	45
Operating Both Three and Four Phase Control Logic	46
Conclusions and Implementation Issues.....	47
CHAPTER 5 – HARDWARE CONFIGURATION FOR SINGLE CONTROLLER DIAMOND INTERCHANGES.....	55
Chapter Overview	55
Diamond Case Studies	56
Hardware-in-the-Loop Configuration	57
External Detector Configuration and Examples	59
Interchange Configuration and Detector Settings.....	61
Recap of Real-Time Control Concepts.....	63
Concluding Remarks.....	63
CHAPTER 6 – HARDWARE CONFIGURATION FOR THE EMERGENCY VEHICLE PREEMPTION NETWORK.....	74
Preemption Network.....	74
Controller Configuration and Phasing	74
Hardware-in-the-Loop Configuration	76
External Detector Configurations and Examples.....	77
Configuration of Preemption Detectors	79
Configuring the CID and Control Equipment for Preemption.....	81
Local Detector Configuration.....	82
Configuration of Preemption Detectors	83
Summary of Timing Parameters.....	84
CHAPTER 7 – IMPACT EVALUATION OF EMERGENCY VEHICLE PREEMPTION ON SIGNALIZED CORRIDOR OPERATION	98
Overview of Emergency Vehicle Preemption	98
Introduction of Preemption Concepts	99
Overview of Signal Preemption	100
Prior Studies on Preemption	101
Impact of Preemption on Signal System	102
Evaluation Procedure and Equipment.....	104
Preemption Case Study – Lafayette, IN	106
Statistical Analysis of Results.....	108
Summary of Results.....	110
CHAPTER 8 – TRAFFIC RESPONSIVE ANALYSIS OF THE SR 26 (SOUTH) NETWORK – LAFAYETTE, IN.....	122

Chapter Overview	122
Overview of the System	124
Configuration of System Detectors.....	125
System Detector Mapping.....	129
Overview of System Timing Plans.....	135
Time-of-Day Configuration	136
Traffic Responsive Configuration	137
Traffic Responsive Function Computations.....	140
Traffic Responsive Plan Selection.....	144
Overview of the Study	148
Scenario Results and Cycle Analysis.....	149
Analysis of Quantitative Results.....	155
Summary of Results.....	163
CHAPTER 9 – TRAFFIC RESPONSIVE ANALYSIS FOR THE SR 67 (KENTUCKY) NETWORK – INDIANAPOLIS, IN	202
Chapter Overview	202
Overview of Network and Volume Scenarios	203
System Phasing and Ring Structures.....	206
System CID File and Approach Labels	208
Local and System Detector Configuration.....	209
Mapping of System Detectors	212
Configuration of System Timing Plans	216
Time-of-Day Configuration	217
Traffic Responsive Configuration	217
Traffic Responsive Function Computations.....	220
Traffic Responsive Plan Selection.....	222
Overview of the Study	224
Scenario Results and Cycle Analysis.....	224
Analysis of Quantitative Results.....	234
Summary of Results.....	242
CHAPTER 10 – CONCLUSIONS AND FUTURE RESEARCH.....	289
Summary of Evaluation Procedures.....	289
Summary of Analysis Procedures	289
General Findings and Results.....	290
Future Research	292
LIST OF REFERENCES.....	295
APPENDIX A – EMERGENCY VEHICLE PREEMPTION CYCLE ANALYSIS AND TRANSITIONING RESULTS.....	300

APPENDIX B – SR 67 (KENTUCKY) QUANTITATIVE RESULTS FOR ALL APPROACHES AND MOVEMENTS.....	330
APPENDIX C – SR 26 (SOUTH) TRAFFIC RESPONSIVE STUDY NETWORK AND CONTROLLER PARAMETERS	367

LIST OF TABLES

<u>TABLE</u>	<u>PAGE</u>
2-1: HCM Tables Subjective to Arterial Progression Quality.....	9
2-2: Sample Output Data Extracted from CORSIM Output Files	12
2-3: Example of Statistical Variation in Travel Time (Sec/Veh).....	14
4-1: Detector Type Information for all Operations	53
4-2: Detector Assignments for 3-Phase Control – Single Controller	53
4-3: Detector Assignments for 4-Phase Operation – Single Controller	54
5-1: Intersection Pocket Lengths and Detector Locations.....	72
5-2: Intersection Detector Configuration (CID Logic Only)	72
5-3: Interchange Detector Configuration (Controller)	73
5-4: General Phase Parameters (SR 26 – South).....	73
5-5: Diamond Interchange Coordination Plans and Splits.....	73
6-1: Intersection Pocket Lengths and Detector Locations.....	94
6-2: Intersection Detector Configuration (CID Logic Only)	95
6-3: Intersection Detector Configuration (Controller)	96
6-4: Preemption Detector Configuration (CID & Controller)	96
6-5: General Phase Parameters (SR 26 – South).....	97
6-6: SR 26 (South) Coordination Plans and Splits	97
7-1: Turning Movement Percentages for the Studied Network	112
7-2: Times that Emergency Vehicles are Introduced into Network	112
7-3: Summary of Midday Arterial Travel Times.....	117
7-4: Summary of Midday Minor Movement Delay	118
7-5: Summary of Afternoon Peak Arterial Travel Times.....	119
7-6: Summary of Afternoon Peak Minor Movement Delay	120

7-7: Statistical Significance Tests on Arterial Travel Time	121
8-1: System Entry Volumes (Reference Figure 8-1)	173
8-2: System Turning Percentages (Reference Figure 8-1)	173
8-3: Intersection Pocket Lengths and Detector Locations.....	174
8-4: Intersection Detector Configuration (CID Logic Only)	174
8-5: Intersection Detector Configuration (Controller)	175
8-6: System Detector Configuration (CID Logic Only)	175
8-7: General Phase Parameters (SR 26 – South).....	176
8-8: SR 26 (South) Coordination Plans and Splits	176
8-9: Time of Day Programming Chart (SR 26 – South)	177
8-10: System Detector Mapping (Master Controller).....	177
8-11: Traffic Responsive Programming (System Detectors)	177
8-12: System Detector Function Computations (SR 26 – South).....	178
8-13: System Thresholds for Plan Selection (SR 26 – South)	178
8-14: Traffic Responsive Plan Selection Chart (SR 26 – South).....	178
8-15: SR 26 (South) Pattern Select – Node 1 (1 of 2).....	179
8-16: SR 26 (South) Pattern Select – Node 1 (2 of 2).....	180
8-17: SR 26 (South) Percent In-Sync (%) – All Scenarios	181
8-18: Summary of Arterial Travel Times Subject to Various Conditions	181
8-19: Summary of Minor Movement Delay Subject to Various Conditions.....	182
8-20: Summary of System Delay Subject to Various Conditions	183
9-1: Entry Volumes per Period (VPH) – Case_1	252
9-2: Entry Volumes per Period (VPH) – Case_2.....	252
9-3: Entry Volumes per Period (VPH) – Case_3.....	252
9-4: Entry Volumes per Period (VPH) – Case_4.....	253
9-5: Entry Volumes per Period (VPH) – Case_5.....	253
9-6: Turning Movements per Period (Percentages)	254
9-7: Intersection Pocket Lengths and Detector Locations.....	255
9-8: Intersection Detector Configuration (CID Logic Only)	256
9-9: Intersection Detector Configuration (Controller)	257

9-10: System Detector Configuration (CID Logic Only)	258
9-11: General Phase Parameters (SR 67 – Kentucky)	259
9-12: SR 67 (Kentucky) Coordination Plans and Splits.....	260
9-13: Time of Day Programming Chart (SR 67 – Kentucky)	260
9-14: System Detector Mapping (Master Controller).....	261
9-15: Traffic Responsive Programming (System Detectors).....	261
9-16: System Detector Computations (SR 67 – Kentucky)	261
9-17: System Thresholds for Plan Selection (SR 67 – Kentucky)	262
9-18: Traffic Responsive Plan Selection Chart (SR 67 – Kentucky)	262
9-19: SR 67 (Kentucky) Pattern Select – Node 3 (All Scenarios)	263
9-20: SR 67 (Kentucky) Percent In-Sync (%) – All Scenarios.....	264
9-21: SR 67 (Kentucky) Cumulative Delay Time – All Scenarios (V-M).....	264

APPENDIX TABLES:

A-1: SR 26 (South) Pattern Select – Path_1 (All Scenarios).....	301
A-2: SR 26 (South) Pattern Select – Path_2 (All Scenarios).....	302
A-3: SR 26 (South) Pattern Select – Path_3 (All Scenarios).....	303
A-4: SR 26 (South) Pattern Select – Path_4 (All Scenarios).....	304
A-5: SR 26 (South) Pattern Select – Path_5 (All Scenarios).....	305
A-6: SR 26 (South) Pattern Select – Path_6 (All Scenarios).....	306
A-7: SR 26 (South) Pattern Select – Path_7 (All Scenarios).....	307
A-8: SR 26 (South) Percent In-Sync (%) – All Scenarios.....	308
B-1: Case_1 - Vehicular Delay (V-M) - Free Operation - Part 1 of 2.....	331
B-2: Case_1 - Vehicular Delay (V-M) - Free Operation - Part 2 of 2.....	332
B-3: Case_1 - Standard Deviation of Delay (V-M) - Free Operation	333
B-4: Case_1 - Vehicular Delay (V-M) - Time of Day - Part 1 of 2.....	334
B-5: Case_1 - Vehicular Delay (V-M) - Time of Day - Part 2 of 2.....	335
B-6: Case_1 - Standard Deviation of Delay (V-M) - Time of Day.....	336
B-7: Case_1 - Vehicular Delay (V-M) - Time of Day (2) - Part 1 of 2	337
B-8: Case_1 - Vehicular Delay (V-M) - Time of Day (2) - Part 2 of 2	338
B-9: Case_1 - Standard Deviation of Delay (V-M) - Time of Day (2)	339

B-10: Case_1 - Vehicular Delay (V-M) - Traffic Responsive - Part 1 of 2	340
B-11: Case_1 - Vehicular Delay (V-M) - Traffic Responsive - Part 2 of 2	341
B-12: Case_1 - Standard Deviation of Delay (V-M) - Traffic Responsive.....	342
B-13: Case_2 - Vehicular Delay (V-M) - Time of Day - Part 1 of 2.....	343
B-14: Case_2 - Vehicular Delay (V-M) - Time of Day - Part 2 of 2.....	344
B-15: Case_2 - Standard Deviation of Delay (V-M) - Time of Day.....	345
B-16: Case_2 - Vehicular Delay (V-M) - Traffic Responsive - Part 1 of 2	346
B-17: Case_2 - Vehicular Delay (V-M) - Traffic Responsive - Part 2 of 2	347
B-18: Case_2 - Standard Deviation of Delay (V-M) - Traffic Responsive.....	348
B-19: Case_3 - Vehicular Delay (V-M) - Time of Day - Part 1 of 2.....	349
B-20: Case_3 - Vehicular Delay (V-M) - Time of Day - Part 2 of 2.....	350
B-21: Case_3 - Standard Deviation of Delay (V-M) - Time of Day.....	351
B-22: Case_3 - Vehicular Delay (V-M) - Traffic Responsive - Part 1 of 2	352
B-23: Case_3 - Vehicular Delay (V-M) - Traffic Responsive - Part 2 of 2	353
B-24: Case_3 - Standard Deviation of Delay (V-M) - Traffic Responsive.....	354
B-25: Case_4 - Vehicular Delay (V-M) - Time of Day - Part 1 of 2.....	355
B-26: Case_4 - Vehicular Delay (V-M) - Time of Day - Part 2 of 2.....	356
B-27: Case_4 - Standard Deviation of Delay (V-M) - Time of Day.....	357
B-28: Case_4 - Vehicular Delay (V-M) - Traffic Responsive - Part 1 of 2	358
B-29: Case_4 - Vehicular Delay (V-M) - Traffic Responsive - Part 2 of 2	359
B-30: Case_4 - Standard Deviation of Delay (V-M) - Traffic Responsive.....	360
B-31: Case_5 - Vehicular Delay (V-M) - Time of Day - Part 1 of 2.....	361
B-32: Case_5 - Vehicular Delay (V-M) - Time of Day - Part 2 of 2.....	362
B-33: Case_5 - Standard Deviation of Delay (V-M) - Time of Day.....	363
B-34: Case_5 - Vehicular Delay (V-M) - Traffic Responsive - Part 1 of 2	364
B-35: Case_5 - Vehicular Delay (V-M) - Traffic Responsive - Part 2 of 2	365
B-36: Case_5 - Standard Deviation of Delay (V-M) - Traffic Responsive.....	366
C-1: Entry Volumes per Period (VPH) – (Regular Volumes – Case_1)	381
C-2: Entry Volumes per Period (VPH) – (Event Volumes – Case_2).....	382
C-3: Turning Movements (Percentages – Case_1) – 1 of 4.....	383

C-4: Turning Movements (Percentages – Case_1) – 2 of 4.....	384
C-5: Turning Movements (Percentages – Case_1) – 3 of 4.....	385
C-6: Turning Movements (Percentages – Case_1) – 4 of 4.....	386
C-7: Turning Movements (Percentages – Case_2) – 1 of 4.....	387
C-8: Turning Movements (Percentages – Case_2) – 2 of 4.....	388
C-9: Turning Movements (Percentages – Case_2) – 3 of 4.....	389
C-10: Turning Movements (Percentages – Case_2) – 4 of 4.....	390
C-11: Intersection Pocket Lengths and Detector Locations	392
C-12: Intersection Detector Configuration (CID Logic Only)	393
C-13: Intersection Detector Configuration (Controller).....	395
C-14: System Detector Configuration (CID Logic Only)	395
C-15: General Phase Parameters (SR 26 – South)	397
C-16: SR 26 (South) Coordination Plans and Splits	399
C-17: Time of Day Programming Chart (SR 26 – South).....	399
C-18: System Detector Mapping (Master Controller).....	400
C-19: Traffic Responsive Programming (System Detectors)	400
C-20: System Detector Function Computations (SR 26 – South)	400
C-21: System Thresholds for Plan Selection (SR 26 – South).....	401
C-22: Traffic Responsive Plan Selection Chart (SR 26 – South)	401
C-23: SR 26 (South) / US 52 – Pattern – Typical Day (Run_1)	402
C-24: SR 26 (South) / US 52 – Pattern – Event Day (Run_1).....	403
C-25: SR 26 (South) US 52 – Percent In-Sync (%) – Run_1	404
C-26: SR 26 (South) US 52 – Percent In-Sync (%) – All Runs	404

LIST OF FIGURES

<u>FIGURE</u>	<u>PAGE</u>
2-1: Sample Arterial Analysis Output [Avery & Courage, 1993].....	6
2-2: Highway Capacity Manual Average Intersection Delay Equation	7
2-3: Illustration of Phase Gap-Outs and Force-Offs [Shoup, 1998].....	8
2-4: Illustration of the Early Return to Green Problem [Shoup, 1998]	8
2-5: Input Module Worksheet Arrival Type Parameter (HCM).....	9
2-6: Example of Turning Traffic Impeding the Through Movement	11
2-7: Example of Spillback from an Oversaturated Intersection	11
2-8: Comparison of Cumulative Travel Times (Sec/Veh)	13
2-9: Airline Highway Network.....	14
2-10: Variation in Cumulative Travel Time (Reference Table 2-4)	15
2-11: Comparison of Side Street Delay (Veh-Min)	16
2-12: Comparison of Mainline Number of Stops	16
2-13: Comparison of Cumulative Delay Times (Veh-Min)	17
3-1: Schematic of the Hardware-in-the-Loop Simulation Environment	22
3-2: Hardware-in-the-Loop Simulation Environment (SR-26 Network)	23
3-3: Illustration of the Controller Switchbox Concept	24
3-4: Illustration of the Hardware-in-the-Loop Concept	25
3-5: SR 67 (Kentucky) Network – Mendenhall to JCT I-465 (Ramps).....	27
3-6: SR 67 (Kentucky) System Ring Structures	28
3-7: Total Delay Time (Veh-Min) - Time of Day Vs Traffic Responsive.....	30
3-8: Total Delay Time (Veh-Min) - Time of Day (2) Vs Traffic Responsive	30
3-9: Southbound Travel Time per Period using Traffic Responsive.....	31
4-1: Interchange Phasing and Ring Structures – Separate Controllers	48
4-2: Interchange Phasing and Ring Structures for 3-Phase Operation.....	49

4-3: Diamond Detector Layout - Single Controller (3 & 4-Phase Control)	50
4-4: The Green Intervals of 4-Phase Operation (Single Controller Only)	50
4-5: Interchange Phasing and Ring Structures – (4-Phase Operation)	51
4-6: Load Switch Outputs - Single Controller (4-Phase Operation).....	52
4-7: Diamond Pedestrian Control for a Single Controller	52
5-1: Direct Connect Procedure (No Control Cabinet Required)	65
5-2: Backpanel Mount Procedure (Requires Controller Cabinet).....	65
5-3: System Entry Volumes (Sample Diamond Interchange).....	66
5-4: Diamond Interchange Geometrics and Detector Locations	66
5-5: Diamond Interchange Phasing - Separate Controllers.....	67
5-6: Diamond Interchange Phasing - (3-Phase Operation).....	67
5-7: Typical Diamond Interchange Phasing Diagrams.....	68
5-8: Typical Diamond Interchange Ring Structures	69
5-9: Intersection Approach Labels (Diamond Interchanges).....	70
5-10: External Control File (CID) for Phasing (General Diamond)	70
5-11: Diamond Detector Locations and Numbering	71
5-12: Sample External Detector File (General Diamond).....	72
6-1: SR 26 (South) – System Entry Volumes.....	86
6-2: Intersection Lane Geometry and Configurations (SR 26 – South).....	87
6-3: Intersection Phasing Diagrams (SR 26 – South)	88
6-4: Intersection Ring Structures (Separate Controllers)	89
6-5: Intersection Ring Structures (Single Diamond Controller)	90
6-6: Intersection Approach Labels (Reference 6-7)	91
6-7: External Control File (CID) for Phasing (Reference 6-6).....	91
6-8: Intersection Detector Locations and Numbering (SR 26 – South)	92
6-9: Sample External Detector File (Reference 6-8)	93
6-10: External Preemption Detectors (Apply to 6-9)	93
6-11: Sample Paths Data File for Path #7 [Paths.dat]	94
6-12: Sample Vehicles Data File for Path #7 [Vehicles.dat].....	94
7-1: Studied Paths of Emergency Vehicles.....	113

7-2: Cumulative EB Travel Time Subject to Path #5, Scenario 1.....	114
7-3: Cumulative WB Travel Time Subject to Path #3, Scenario 2.....	114
7-4: Minor Movement Delay Subject to Path #2, Scenario 3.....	115
7-5: WB Number of Stops per Link Subject to Path 1, Scenario 2.....	115
7-6: Typical Impact of Inadequate Slack Time for the EBLT.....	116
8-1: SR 26 (South) Network – Progress to Meijer Parkway.....	164
8-2: Intersection Lane Geometry and Configurations (SR 26 – South).....	165
8-3: Intersection Phasing Diagrams (SR 26 – South).....	166
8-4: Intersection Ring Structures (Separate Controllers).....	167
8-5: Intersection Ring Structures (Single Diamond Controller).....	168
8-6: Intersection Approach Labels (Reference 8-7).....	169
8-7: External Control File (CID) for Phasing (Reference 8-6).....	169
8-8: Intersection Detector Locations and Numbering.....	170
8-9: Sample External Detector File (Reference 8-8).....	171
8-10: Relationship Between Volume and Occupancy [Econolite, 1996].....	172
8-11: Comparison Between Actual Volume and Scaled Volume.....	172
8-12: Comparison Between Actual Occupancy and Scaled Occupancy.....	172
8-13: SR 26 (South) System Cycle Graphs – Pattern 111 to 211.....	184
8-14: SR 26 (South) System Cycle Graphs – Pattern 111 to 311.....	185
8-15: SR 26 (South) System Cycle Graphs – Pattern 111 to 411.....	186
8-16: SR 26 (South) System Cycle Graphs – Pattern 111 to 511.....	187
8-17: SR 26 (South) System Cycle Graphs – Pattern 411 to 111.....	188
8-18: SR 26 (South) System Cycle Graphs – Pattern 511 to 111.....	189
8-19: Cumulative Eastbound Travel Time (S/V) – Pattern 111 to 211.....	190
8-20: Cumulative Westbound Travel Time (S/V) – Pattern 111 to 211.....	190
8-21: Cumulative Eastbound Delay Time (V-M) – Pattern 111 to 211.....	191
8-22: Cumulative Westbound Delay Time (V-M) – Pattern 111 to 211.....	191
8-23: Eastbound Number of Stops per Link – Pattern 111 to 211.....	192
8-24: Westbound Number of Stops per Link – Pattern 111 to 211.....	192
8-25: Side Street Delay Time (V-M) – Pattern 111 to 211.....	193

8-26: Cumulative Eastbound Travel Time (S/V) – Pattern 111 to 311	194
8-27: Cumulative Westbound Travel Time (S/V) – Pattern 111 to 311	194
8-28: Cumulative Eastbound Delay Time (V-M) – Pattern 111 to 311	195
8-29: Cumulative Westbound Delay Time (V-M) – Pattern 111 to 311	195
8-30: Eastbound Number of Stops per Link – Pattern 111 to 311.....	196
8-31: Westbound Number of Stops per Link – Pattern 111 to 311.....	196
8-32: Side Street Delay Time (V-M) – Pattern 111 to 311.....	197
8-33: Cumulative Eastbound Travel Time (S/V) – Pattern 111 to 511	198
8-34: Cumulative Westbound Travel Time (S/V) – Pattern 111 to 511	198
8-35: Cumulative Eastbound Delay Time (V-M) – Pattern 111 to 511	199
8-36: Cumulative Westbound Delay Time (V-M) – Pattern 111 to 511	199
8-37: Eastbound Number of Stops per Link (S/V) – Pattern 111 to 511	200
8-38: Westbound Number of Stops per Link – Pattern 111 to 511.....	200
8-39: Side Street Delay Time (V-M) – Pattern 111 to 511.....	201
9-1: SR 67 (Kentucky) Network – Mendenhall to JCT I-465 (Ramps).....	244
9-2: SR 67 (Kentucky) Intersection Geometrics & Detector Locations.....	245
9-3: Intersection Phasing Diagrams (SR 67 – Kentucky).....	246
9-4: SR 67 (Kentucky) System Ring Structures	247
9-5: Intersection Approach Labels (Reference 9-6)	248
9-6: External Control File (CID) for Phasing (SR 67 – Kentucky).....	248
9-7: Intersection Detector Locations and Numbering.....	250
9-8: Sample External Detector File (SR 67 – Kentucky)	251
9-9: SR 67 (Kentucky) System Cycle Graphs – Case_1.....	265
9-10: SR 67 (Kentucky) System Cycle Graphs – Case_1 (TOD_2).....	266
9-11: SR 67 (Kentucky) System Cycle Graphs – Case_2.....	267
9-12: SR 67 (Kentucky) System Cycle Graphs – Case_3.....	268
9-13: SR 67 (Kentucky) System Cycle Graphs – Case_4.....	269
9-14: SR 67 (Kentucky) System Cycle Graphs – Case_5.....	270
9-15: Cumulative NB Travel Time (S/V) Per Period (TRP) – Case_1	271
9-16: Cumulative SB Travel Time (S/V) Per Period (TRP) – Case_1	271

9-17: Total Delay Time (V-M) Per Period (Free Vs TRP) – Case_1	272
9-18: Total Number of Stops Per Period (Free Vs TRP) – Case_1.....	272
9-19: Cumulative Delay Time (V-M) – (Free Vs TRP) – Case_1	273
9-20: Total Delay Time (V-M) Per Period (TOD Vs TRP) – Case_1	274
9-21: Total Number of Stops Per Period (TOD Vs TRP) – Case_1	274
9-22: Cumulative Delay Time (V-M) – (TOD Vs TRP) – Case_1	275
9-23: Cumulative Delay Time (V-M) – (TOD (2) Vs TRP) – Case_1	275
9-24: Total Delay Time (V-M) Per Period (TOD (2) Vs TRP) – Case_1	276
9-25: Total Number of Stops Per Period (TOD (2) Vs TRP) – Case_1	276
9-26: Cumulative NB Travel Time (S/V) Per Period (TRP) – Case_2	277
9-27: Cumulative SB Travel Time (S/V) Per Period (TRP) – Case_2	277
9-28: Total Delay Time (V-M) Per Period (TOD (2) Vs TRP) – Case_2	278
9-29: Total Number of Stops Per Period (TOD (2) Vs TRP) – Case_2	278
9-30: Cumulative Delay Time (V-M) – (TOD (2) Vs TRP) – Case_2.....	279
9-31: Cumulative NB Travel Time (S/V) Per Period (TRP) – Case_3	280
9-32: Cumulative SB Travel Time (S/V) Per Period (TRP) – Case_3	280
9-33: Total Delay Time (V-M) Per Period (TOD (2) Vs TRP) – Case_3.....	281
9-34: Total Number of Stops Per Period (TOD (2) Vs TRP) – Case_3.....	281
9-35: Cumulative Delay Time (V-M) – (TOD (2) Vs TRP) – Case_3.....	282
9-36: Cumulative NB Travel Time (S/V) Per Period (TRP) – Case_4	283
9-37: Cumulative SB Travel Time (S/V) Per Period (TRP) – Case_4	283
9-38: Total Delay Time (V-M) Per Period (TOD (2) Vs TRP) – Case_4.....	284
9-39: Total Number of Stops Per Period (TOD (2) Vs TRP) – Case_4.....	284
9-40: Cumulative Delay Time (V-M) – (TOD (2) Vs TRP) – Case_4.....	285
9-41: Cumulative NB Travel Time (S/V) Per Period (TRP) – Case_5	286
9-42: Cumulative SB Travel Time (S/V) Per Period (TRP) – Case_5	286
9-43: Total Delay Time (V-M) Per Period (TOD (2) Vs TRP) – Case_5.....	287
9-44: Total Number of Stops Per Period (TOD (2) Vs TRP) – Case_5.....	287
9-45: Cumulative Delay Time (V-M) – (TOD (2) Vs TRP) – Case_5.....	288

APPENDIX FIGURES:

A-1: SR 26 (South) System Cycle Graphs – 1_Preempt (Path_1).....	309
A-2: SR 26 (South) System Cycle Graphs – 2_Preempts (Path_1)	310
A-3: SR 26 (South) System Cycle Graphs – 3_Preempts (Path_1).....	311
A-4: SR 26 (South) System Cycle Graphs – 1_Preempt (Path_2).....	312
A-5: SR 26 (South) System Cycle Graphs – 2_Preempts (Path_2).....	313
A-6: SR 26 (South) System Cycle Graphs – 3_Preempts (Path_2).....	314
A-7: SR 26 (South) System Cycle Graphs – 1_Preempt (Path_3).....	315
A-8: SR 26 (South) System Cycle Graphs – 2_Preempts (Path_3).....	316
A-9: SR 26 (South) System Cycle Graphs – 3_Preempts (Path_3).....	317
A-10: SR 26 (South) System Cycle Graphs – 1_Preempt (Path_4).....	318
A-11: SR 26 (South) System Cycle Graphs – 2_Preempts (Path_4).....	319
A-12: SR 26 (South) System Cycle Graphs – 3_Preempts (Path_4).....	320
A-13: SR 26 (South) System Cycle Graphs – 1_Preempt (Path_5).....	321
A-14: SR 26 (South) System Cycle Graphs – 2_Preempts (Path_5).....	322
A-15: SR 26 (South) System Cycle Graphs – 3_Preempts (Path_5).....	323
A-16: SR 26 (South) System Cycle Graphs – 1_Preempt (Path_6).....	324
A-17: SR 26 (South) System Cycle Graphs – 2_Preempts (Path_6).....	325
A-18: SR 26 (South) System Cycle Graphs – 3_Preempts (Path_6).....	326
A-19: SR 26 (South) System Cycle Graphs – 1_Preempt (Path_7).....	327
A-20: SR 26 (South) System Cycle Graphs – 2_Preempts (Path_7).....	328
A-21: SR 26 (South) System Cycle Graphs – 3_Preempts (Path_7).....	329
C-1: SR 26 (South) & US 52 (Sagamore) – Study Network.....	368
C-2: SR 26 (South) / US 52 (Sagamore) Intersection Geometrics.....	370
C-3: Phasing Diagrams for Lafayette System (SR 26 & US 52)	373
C-4: Intersection Ring Structures (SR 26 & US 52)	375
C-5: Intersection Approach Labels (Reference C-6)	376
C-6: External Control File (CID) for Phasing (Reference C-5)	377
C-7: Intersection Detector Locations and Numbering	378
C-8: Sample External Detector File (Reference C-7).....	380

C-9: SR 26 (South) System Cycle Graphs – Typical Day	405
C-10: SR 26 (South) System Cycle Graphs – Typical Day	406
C-11: SR 26 (South) System Cycle Graphs – Event Day	407
C-12: SR 26 (South) System Cycle Graphs – Event Day	408

CHAPTER 1 – INTRODUCTION

Report Motivation

Modern traffic signal systems typically consist of coordinated-actuated controllers that revert all unused green time back to the arterial. Such strategies were developed to improve the overall performance of the system by allowing each intersection to respond to its own volume demand, while maintaining some level of coordination from one intersection to the other. This reduces the overall travel time and delay for the arterial movements. However these actuated parameters, which help minimize the overall system delay, also make the start of the main street green more difficult to predict, since it is dependent on the demands of the minor movements. Therefore, insufficient volumes on these approaches would allow the green to prematurely begin for the arterial movements, potentially increasing the total number of stops downstream.

This is one of the many perplexities associated with modern coordinated-actuated signal systems, and is why some type of rational evaluation procedure should be used to aid in the analysis of such networks. Often times, improvements made to these systems are difficult to determine, since they are frequently compared to the timing plans of the existing system, which were implemented several years prior, and no longer accurately reflect the current traffic patterns. Therefore, there should be some type of evaluation methodology that would allow the engineer to see the differences in the overall system performance, given slight changes in some of the controller parameters.

This study used a procedure commonly referred to as hardware-in-the-loop simulation, which allows the actual controller equipment to communicate with a simulation program (CORSIM) that then calculates the various Measures of Effectiveness (MOE's). This allows the analyst to make changes in the actual control equipment, that would then impact the operation of the relative intersection in the model. Such an approach permits users to examine all the vendor specific features inside the control equipment, so that they will have a more realistic view on how the system would perform in the field. It would also provide the analyst with additional insight into how the system will respond to a particular set of volume scenarios, prior to the implementation of the system.

Although the CORSIM simulation package includes an internal model that contains most of the typical actuated control parameters available on modern equipment, it was not relevant for this research, since this study focuses primarily on analyzing issues associated with pattern changes and cycle transitions. Therefore all of the information obtained from this research was from the performance of the actual control equipment, which responded to a simulation model of the actual network being examined. Hence, one could now quantitatively evaluate the performance of a system using a variety of case scenarios that contain before and after data, thereby making the validation of a particular operation easier to justify.

Case Studies

This document consists of three main areas that were examined in order to better understand the significance of various issues associated with modern traffic control systems. These areas include the advanced control concepts for single controller diamond interchanges, the impact evaluation of emergency vehicle preemption on a signalized corridor operation, and an analysis on some of the more advanced real-time control parameters available with the current

control equipment. The diamond interchange study focuses primarily on getting the reader acquainted with the controller hardware, and the importance of an efficient operation, while the preemption study evaluates the impact that various levels of transitioning have on the overall performance of the system. The remainder of the document examines some of the more advanced parameters associated with Traffic Responsive (TRP) procedures, in order to determine how the equipment responds to a variety of traffic patterns.

Report Overview

The objective of this research is to develop procedures that can be used to aid in the analysis and operation of modern closed-loop signal systems, while increasing awareness on some of the control issues associated with these networks. It is believed that the procedures contained herein will help mitigate some of the misfortunes that are encountered during the deployment of these systems, by means of good evaluation procedures that will help one better understand the operation of the system, and explain why it is operating in such a manner, given certain circumstances.

This report describes the research effort that was developed in order to address the main objectives, based on the issues that were introduced in the previous section. Chapter 2 examines the various simulation and evaluation methodologies that are used for the various cases in the research and also discusses why the Highway Capacity Manual (HCM) procedures are not ideal for coordinated-actuated signal systems. Chapter 3 surveys the various theories behind hardware-in-the-loop simulation, and explains how such procedures were helpful with this analysis. Chapter 4 investigates the main concepts behind diamond interchange control strategies, while Chapter 5 applies the hardware-in-the-loop technology to an interchange, in order to demonstrate how such

procedures can be used to evaluate the advanced detector logic and phasing associated with these interchanges.

The remainder of this Report is directed towards analyzing the transitioning that occurs as a result of system disturbances (preemption) or standard pattern changes that are common with both the Time-of-Day (TOD) and Traffic Responsive (TRP) methodologies. Chapter 6 explores the configuration for the preemption study, which was prepared using hardware-in-the-loop simulation, while Chapter 7 analyzes the results obtained from the study. Chapter 8 uses the same network (preemption) and slightly modifies it, in order to analyze some of the more advanced parameters associated with the Traffic Responsive (TRP) control strategies, while Chapter 9 applies such procedures to a different network, where the traffic patterns change on a more gradual basis. Chapter 10 summarizes the conclusions that were obtained from this research, while providing suggestions for future work that would help better improve the performance of these arterial networks as a system.

CHAPTER 2 – SIMULATION AND EVALUATION PROCEDURES

Current Evaluation Procedures

The creation and deployment of traffic signal system timing plans is a very complex task. Modern technologies, such as actuated traffic signal controllers, have greatly improved efficiency of the intersection, but they have also made the operation more difficult to design and analyze, since the intersection phase times are no longer fixed. Hence, it is not possible to accurately analyze a fully actuated intersection, using the traditional procedures in the Highway Capacity Manual (HCM).

One operating objective of a traffic signal system is to operate a group of intersections at near optimal efficiency. Coordinating the system, or producing the maximum bandwidth in one direction is relatively simple for a fixed-time system. However, when one is trying to accommodate the other direction as well, the problem becomes more difficult, and obtaining the optimal cycle length becomes more critical. There are a variety of software packages available that can help find optimal timing plans for the system (Passer II-90, TRANSYT-7F, NO-STOP). However, the majority of these programs are for fixed-time systems since they do not account for actuation and varying demand volumes. These programs and Highway Capacity Software (HCS) do not account for the stochastic volumes and varying green time allocations encountered in the field. This is one of the flaws with the procedure and is the main reason why simulation based procedures should be used for such analysis.

Since the operation of modern coordinated-actuated signal systems is not deterministic, current analysis and test procedures do not allow one to predict how arterial traffic signal systems will perform in the field. This typically results in a less than desirable operation when timing plans are initially deployed. Simulation has a number of advantages over the current HCM analysis procedures because it allows the engineer to model a coordinated-actuated system more precisely and identify the potential problems.

Many of the computer analysis programs provide output like that shown in Figure 2-1. Notice how this figure lacks graphical insight and simplicity, with no indication of how the signals operate as a system. The HCM procedures define the average intersection control delay equation as shown in Figure 2-2. The equation is intended to estimate the average delay per vehicle based on the average green splits at the intersection. However, with the advancements in traffic control hardware, mainly actuated features, there is concern that this procedure does not accurately account for the variation in the green times typically encountered with modern coordinated-actuated systems.

SIGNAL TIMING OPTIMIZATION REVIEW METHOD (STORM)
PASSER II TIMING PLAN SUMMARY

Run Identification: Optimize phasing

Artery: P2 OPT PH
Title: CENTRAL AVE
File Name: C:\AAPEX\DATA2\CENTRAL2.POF

INTERSECTION PERFORMANCE SUMMARY

INT NO	CROSS STREET	PHASE	CRITICAL V/C	CYCLE INDICATOR	DELAY SEC/VEH	% STOPS	OFFSET
1	A STREET	WTE G	95	1.12	39.2	98 107	1
2	B STREET	FW G	79	0.93	20.1	75 29	2
3	C STREET	RE G	79	0.93	20.7	34 74	2
4	D STREET	ETW LT	89	1.05	37.3	93 98	3
5	E STREET	FW G	79	0.93	20.8	79 36	3
6	F STREET	RE G	79	0.93	19.4	18 92	3

		Problem Intersections						
	Units	Value	#	Dir	Movt	Prot	Lanes	V/C
Cycle Length	sec	95	1	NB	THRU	-	2	95
Efficiency	%	.36						
Attainability	%	.80						
Stops	%	79						
Delay per veh	sec	27.3						
Total Delay	veh-hrs	168.0						
Fuel Consumption	gal	349.8						
Max Cycle Indicator		1.12						

Figure 2-1: Sample Arterial Analysis Output [Avery & Courage, 1993]

$$d = d_1 \times PF + d_2 + d_3$$

$$d_1 = \frac{0.5C[1 - (g/C)]^2}{1 - (g/c)[\min(X, 1.0)]}$$

$$d_2 = 900T[(X - 1) + \sqrt{(X - 1)^2 + 8kIX / Tc}]$$

- d* = control delay (sec/veh),
*d*₁ = uniform delay (sec/veh),
*d*₂ = incremental delay (sec/veh),
*d*₃ = residual demand delay (sec/veh) (see NRC Appendix 9-VI),
PF = uniform delay adjustment for quality of progression,
c = capacity of lane group (veh/hr),
X = v/c ratio for lane group with v representing demand flow rate,
C = cycle length (sec),
g = effective green time for lane group,
T = duration of the analysis period (hr)
k = incremental delay adjustment for actuated control, and
l = incremental delay adjustment for filtering by upstream signals

Figure 2-2: Highway Capacity Manual Average Intersection Delay Equation

Early Return to Main Street Green

When the green times on the side streets fluctuate on a per cycle basis, then the relative start of green is constantly changing, as shown in Figure 2-3. This is because any unused green time reverts back to the arterial during coordination. This results in certain signals starting (receiving the green) earlier than expected which creates the “early return to green” problem that is shown in Figure 2-4. These variations in the start of green directly impact the quality of progression on the arterial. This can make a significant difference in the arrival types at downstream intersections, which must be defined using the HCM procedure, as evident in Figure 2-5. As seen from Figure 2-2, the PF factors (function of delay) vary significantly, depending on the arrival type that is determined. This can have a significant impact on the amount of delay that is estimated at an intersection, sometimes by greater than two Level-of-Service (LOS) levels.

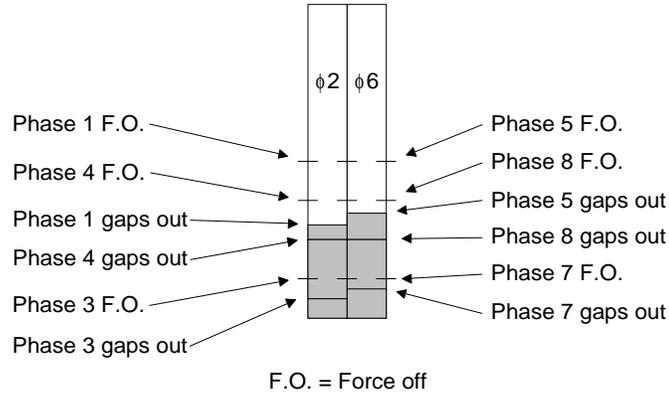


Figure 2-3: Illustration of Phase Gap-Outs and Force-Offs [Shoup, 1998]

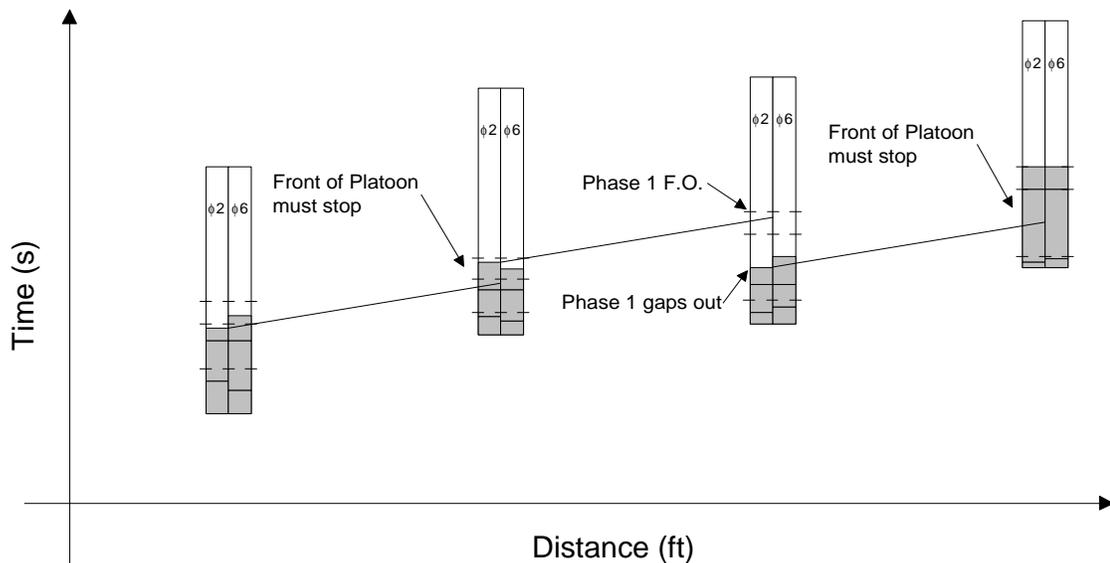


Figure 2-4: Illustration of the Early Return to Green Problem [Shoup, 1998]

Currently the HCM has no procedure for estimating the PF factors that should be used for the design of coordinated-actuated controller timings (Table 2-1). Many of the diagrams generated with current signal design packages are based on fixed-time procedures, which do not represent the actuated conditions that actually occur in the field. This is mainly attributed to the “early return to green” that was previously addressed. Hence an early release of vehicles at one intersection will likely result in the platoons getting stopped at adjacent or other

downstream intersections. This typically results in a poor level of progression, as seen in Figure 2-4. Although the HCM now provides approximate procedures for estimating the average green times for actuated controllers, it is unlikely that any analytical models will be developed for modeling a series of coordinated-actuated control parameters being used by modern signal systems.

Pedestrian Button		Arr. Type
Y or N	Min. Timing	

Figure 2-5: Input Module Worksheet Arrival Type Parameter (HCM)

HCM TABLE 11-5. RELATIONSHIP BETWEEN ARRIVAL TYPE AND PLATOON RATIO (R_p)

ARRIVAL TYPE	RANGE OF PLATOON (R_p)	DEFAULT VALUE (R_p)	PROGRESSION QUALITY
1	≤ 0.50	0.333	Very Poor
2	>0.50 and ≤ 0.85	0.667	Unfavorable
3	>0.85 and ≤ 1.15	1.000	Random Arrivals
4	>1.15 and ≤ 1.50	1.333	Favorable
5	>1.50 and ≤ 2.00	1.667	Highly Favorable
6	>2.00	2.000	Exceptional

HCM TABLE 11-6. UNIFORM DELAY (d_i) PROGRESSION ADJUSTMENT FACTOR (PF)

GREEN RATIO (g/C)	ARRIVAL TYPE (AT)					
	AT-1	AT 2	AT 3	AT 4	AT 5	AT 6
0.20	1.167	1.007	1.000	1.000	0.833	0.750
0.30	1.286	1.063	1.000	0.986	0.714	0.571
0.40	1.445	1.136	1.000	0.895	0.555	0.333
0.50	1.667	1.240	1.000	0.767	0.333	0.000
0.60	2.001	1.395	1.000	0.576	0.000	0.000
0.70	2.556	1.653	1.000	0.256	0.000	0.000
Default, f_p	1.00	0.93	1.00	1.15	1.00	1.00
Default, R_p	0.333	0.667	1.000	1.333	1.667	2.000

- NOTES:
1. $PF = (1 - P) f_p / (1 - g/C)$.
 2. Tabulation is based on default values of f_p and R_p .
 3. $P = R_p * g/C$ (may not exceed 1.0).
 4. PF may not exceed 1.0 for AT 3 through AT 6.

Table 2-1: HCM Tables Subjective to Arterial Progression Quality

Analyzing Atypical Conditions

Even if the HCM were to estimate actuated controllers by using average green times, it is unlikely that there will ever be an approach for analyzing other scenarios dealing with cycle transition or other problems that are not steady state. Some of the examples examined in this research which fit in this category are preemption (emergency vehicle, railroad, or bus) and transitions resulting from a Time-of-Day (TOD) or Traffic Responsive (TRP) program changes. Generally, preemption takes the affected intersections out of coordination, at which time the transitioning period is not steady state until coordination is again obtained. The same is true for other cases as well, since pattern changes typically result in cycle length changes. While these changes are occurring, the system is not running any defined cycle. The HCM procedures are not applicable for such situations.

Analyzing Oversaturated Conditions

It is important to note that the stochastic properties affecting the HCM analysis procedures are not limited just to traffic control hardware operation, but also to vehicular traffic flows, which usually vary over time and often result in temporary oversaturated conditions. A typical example would be a left-turn lane spilling back and impeding the through movement, as shown in Figure 2-6. Such an occurrence could then potentially spillback and impede other upstream intersections, as evident in Figure 2-7. In this instance, the spillback was the result of an oversaturated downstream intersection. Current HCM procedures do not account for such criteria, as each intersection is analyzed independently, and does not consider what is occurring upstream or downstream. This is perhaps the most critical flaw of the HCM procedure and is why simulation based procedures are highly recommended for such applications. These procedures, used as part of this research, are discussed in the subsequent section.

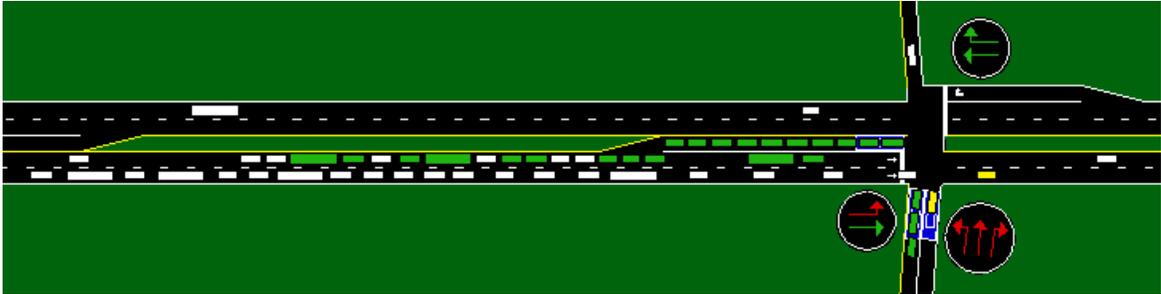


Figure 2-6: Example of Turning Traffic Impeding the Through Movement

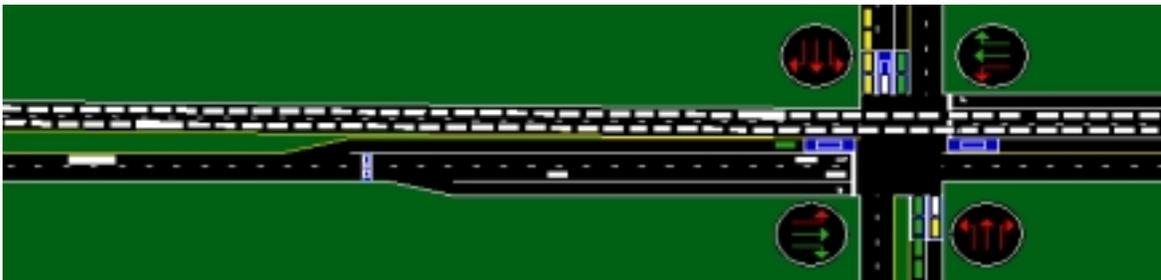


Figure 2-7: Example of Spillback from an Oversaturated Intersection

Simulation Analysis Procedures

In order to overcome some of the limitations associated with the deterministic formulas and accurately account for the stochastic properties of an arterial signal system, microsimulation traffic packages are essential [Husch, 1998], [Kaman Sciences, 1997], [Access Engineering, 1998]. The HCM indicates that simulation models can be used to estimate the LOS for a given network, but currently provides no procedures for analysis to follow. Such procedures could be of great benefit to practicing engineers as they would provide the practitioners with a standard analysis of such systems which include (but are not limited to) coordinated-actuated and real-time adaptive control systems.

Current microsimulation models, such as CORSIM, SimTraffic, and VisSIM, simplify the analysis of such systems by supplying large amounts of movement specific data such as travel time, delay time, number of stops, etc. In

addition to providing a wealth of data, these models are also capable of analyzing control systems consisting of a variety of complex attributes such as actuated control, brief duration of oversaturated conditions, signal preemption, and cycle transition algorithms often associated with pattern changes. This research presents a procedure that accounts for the stochastic properties present with both the vehicular traffic and the traffic control systems.

The graphical reporting procedure used for the majority of this research looks at the cumulative arterial travel time and the cumulative arterial delay time, each of which are in relation to the locations of the signalized intersections for the network [Shoup, 1998]. The cumulative travel and delay times were calculated by compiling multiple traffic simulation runs and tabulating the average individual link travel and delay time for the arterial along with their corresponding standard deviation. The averages are then tabulated to calculate the cumulative arterial travel and delay times with respect to the actual intersection locations. Table 2-2 shows an example of the typical output that can be extracted from CORSIM.

SUMMARY OF MOE'S (NORMALIZED):								EASTBOUND PROGRESSION (THRU MOVEMENT)						
EASTBOUND		Vehicle		Vehicle Minutes			Ratio	Sec/Yeh		Yeh-Min			Average	
Link	Length	Miles	Trips	Move Time	Delay Time	Total Time	Move Total	Total Time	Delay Time	Queue Time	Stop Time	Stops (PCT)	Vol. (YPH)	Speed MPH
101,1	2500	582.3	1230	776.5	4646.9	5423.3	0.14	265.1	227.3	5002.5	3711.4	62.7	1133	11.5
1,2	700	147.1	1111	196.5	1671.1	1867.6	0.11	101.2	90.6	1427.0	1270.7	53.0	1089	9.5
2,3	780	128.5	870	171.3	1117.2	1288.5	0.13	89.1	77.3	914.4	711.2	44.3	928	12.1
3,4	1470	166.5	598	222.0	82.8	304.8	0.73	30.6	8.3	13.7	11.2	17.5	718	32.9
4111	2500	287.3	607	383.1	76.6	459.6	0.83	45.4	7.6	0.2	0.0	0.0	485	37.5
3600	7950	1311.6	4416	1749.3	7594.5	9343.8	0.31	127.3	103.5	7357.7	5704.4	41.9	936	17.6

Table 2-2: Sample Output Data Extracted from CORSIM Output Files

This data can then be placed in a graphical format as shown in Figure 2-8, in order to better illustrate the overall operation. The graph shows the arterial travel time for a given direction. Such graphs are designed to indicate where each of the signalized intersections are located, along with how travel time or delay is impacted by each of the intersections. The graph in Figure 2-8 allows the analyst to easily comprehend the cumulative travel time for the arterial and compare it to a variety of scenarios. In this case Traffic Responsive is being

compared to the traditional Time-of-Day operation. This figure makes it easy to identify the critical locations on the arterial, since such locations are found by locating the steep slopes on the graphs. Such slopes indicate an abrupt change in travel time (for this case), which suggests a potential problem.

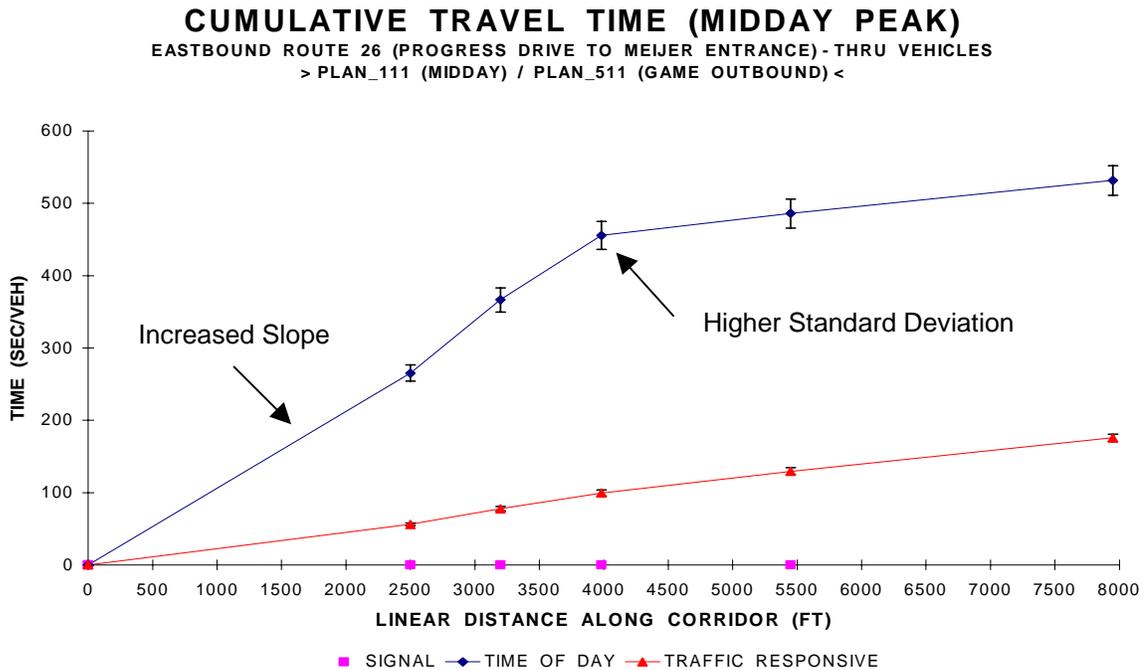


Figure 2-8: Comparison of Cumulative Travel Times (Sec/Veh)

Noting such critical locations on the graphs is important to the analyst, since it often signifies that further investigation may be needed. Generally these slopes are also accommodated by a greater variation in the error bars as shown in Figure 2-8. This indicates that there is less certainty in the relative measure of effectiveness (MOE) being examined. Great variability in an MOE is also an indicator that there is a problem. Table 2-3 illustrates how statistical variations can be quite significant between the various runs, which is apparent when looking at the variations of link 12-7. This typically means that the link is very near saturation. Figure 2-9 shows the network represented by Table 2-3, while Figure 2-10 is the corresponding graphical output, in travel time. From Figure 2-10 one can easily view the decrease in certainty by the increase in the width of

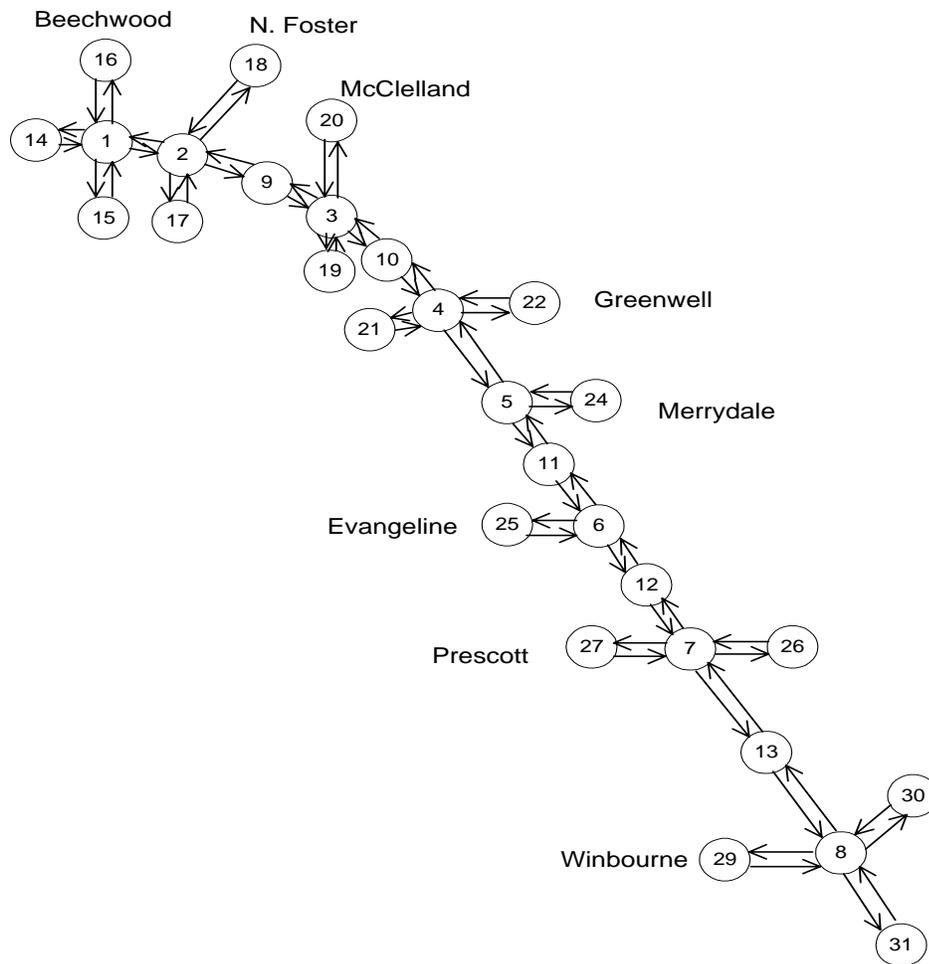


Figure 2-9: Airline Highway Network

Start Node	End Node	Run 01	Run 02	Run 03	Run 04	Run 05	Run 06	Run 07	Run 08	Run 09	Run 10
14	1	21.9	23.7	22.7	22.6	22.6	23.9	21.0	25.3	22.2	22.7
1	2	21.5	19.4	21.9	21.1	19.8	19.9	19.8	19.4	19.9	20.7
2	9	18.8	18.3	18.8	18.5	18.5	18.2	18.6	17.7	18.2	18.7
9	3	17.7	19.4	19.4	19.0	20.0	19.1	20.2	21.0	20.1	19.6
3	10	15.2	15.6	15.6	15.6	15.7	15.7	15.9	16.0	15.6	15.8
10	4	31.3	33.6	30.4	27.7	30.4	28.7	30.1	28.4	32.7	32.5
4	5	29.2	31.4	30.0	31.3	30.8	31.3	29.5	29.4	30.8	29.8
5	11	17.4	17.6	18.9	17.8	18.2	17.7	17.7	17.6	18.3	17.7
11	6	19.2	19.6	20.8	19.0	19.4	19.5	19.9	19.0	20.1	18.7
6	12	17.7	18.4	18.4	18.6	18.1	19.1	29.8	18.7	18.3	18.6
12	7	60.9	117.8	118.8	137.6	117.8	108.6	180.0	107.8	84.1	118.9
7	13	31.6	31.6	31.9	31.4	32.1	31.8	31.6	32.1	32.2	32.4
13	8	34.3	34.7	35.5	34.8	35.6	34.0	34.4	35.5	34.4	35.5

Table 2-3: Example of Statistical Variation in Travel Time (Sec/Veh)

the error bars, which begins at Node 7 (Prescott). Since the graph is cumulative, these bars will continue to expand downstream (Southbound), due to the decreased certainty in travel time.

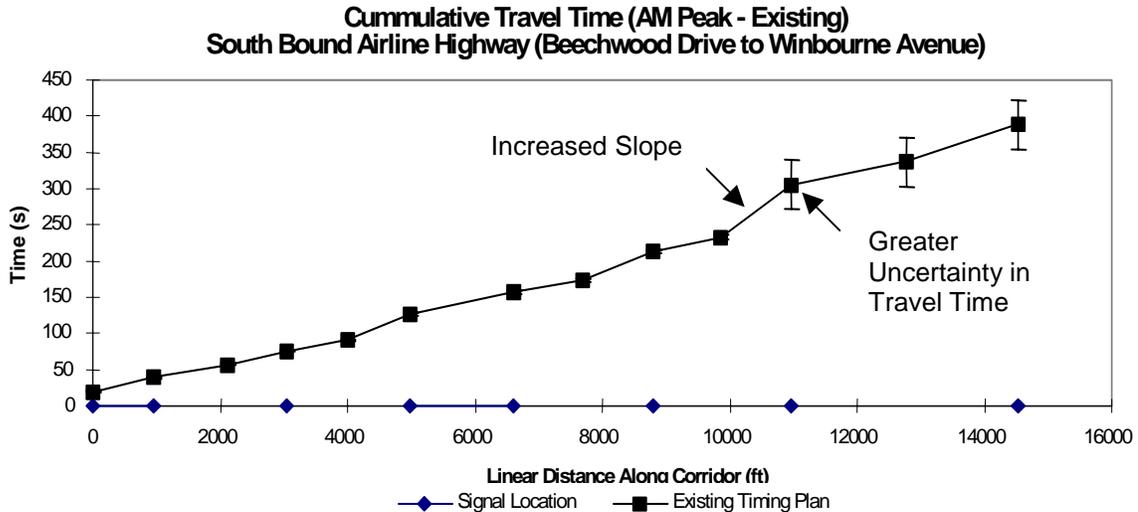


Figure 2-10: Variation in Cumulative Travel Time (Reference Table 2-4)

Although most of the examples here focused on cumulative travel time, there are other MOE's that can be examined. Figure 2-11 to Figure 2-13 are just a few of these. Figure 2-11 shows an example of side street delay while Figure 2-12 shows the number of stops that occur for each link on the arterial in the Eastbound direction relative to existing conditions. Figure 2-13 illustrates the cumulative delay time in the Westbound direction for the relative scenarios. Notice that in nearly all cases, the existing conditions performed best indicating that lack of coordination can increase the relative MOE values.

Similar graphic procedures discussed here can also be used for other MOE's that can be extracted from the output files. Examples include queue time, stop time, speeds, and emission estimates for HC, CO, and NOX. These possibilities are typically constrained by the amount of information available in the simulation output files. The graphs shown here will be used throughout this research, in order to help analyze the data obtained from the simulation.

SIDE STREET DELAY TIME (AFTERNOON RUSH)

STATE ROUTE 26 (PROGRESS DRIVE TO MEIJER ENTRANCE) - ALL VEHICLES
> 2 PREEMPT(S) AT 60 SEC AND 150 SEC (PATH_ID - 110,4,3,2,1,101) <

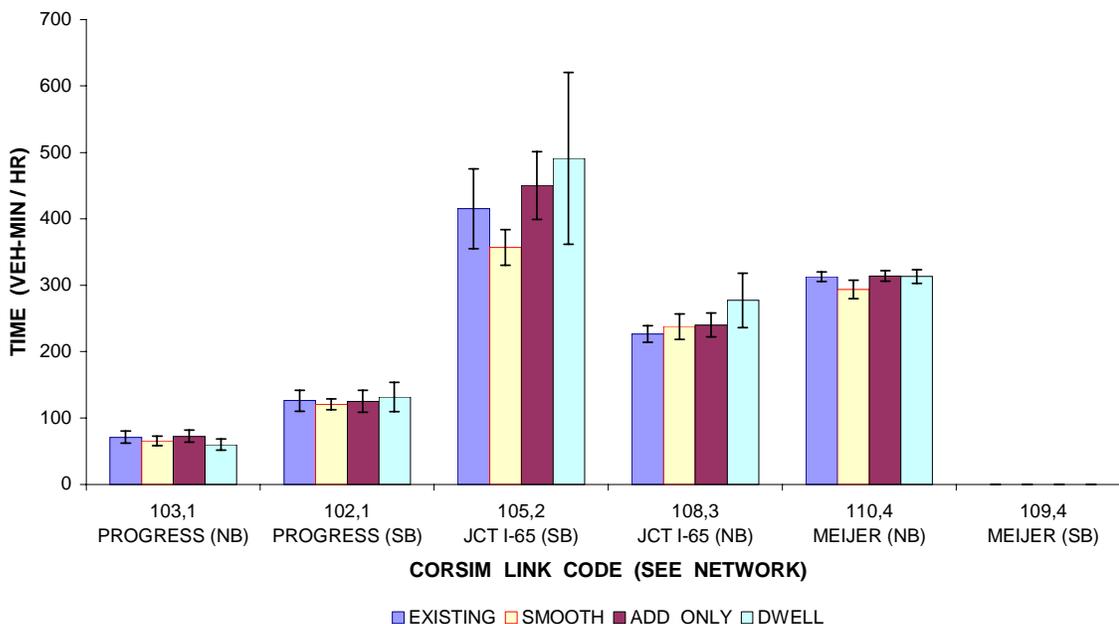


Figure 2-11: Comparison of Side Street Delay (Veh-Min)

NUMBER OF STOPS / LINK (AFTERNOON RUSH)

EASTBOUND ROUTE 26 (PROGRESS DRIVE TO MEIJER ENTRANCE) - THRU VEHICLES
> 2 PREEMPT(S) AT 60 SEC AND 150 SEC (PATH_ID - 110,4,3,2,1,101) <

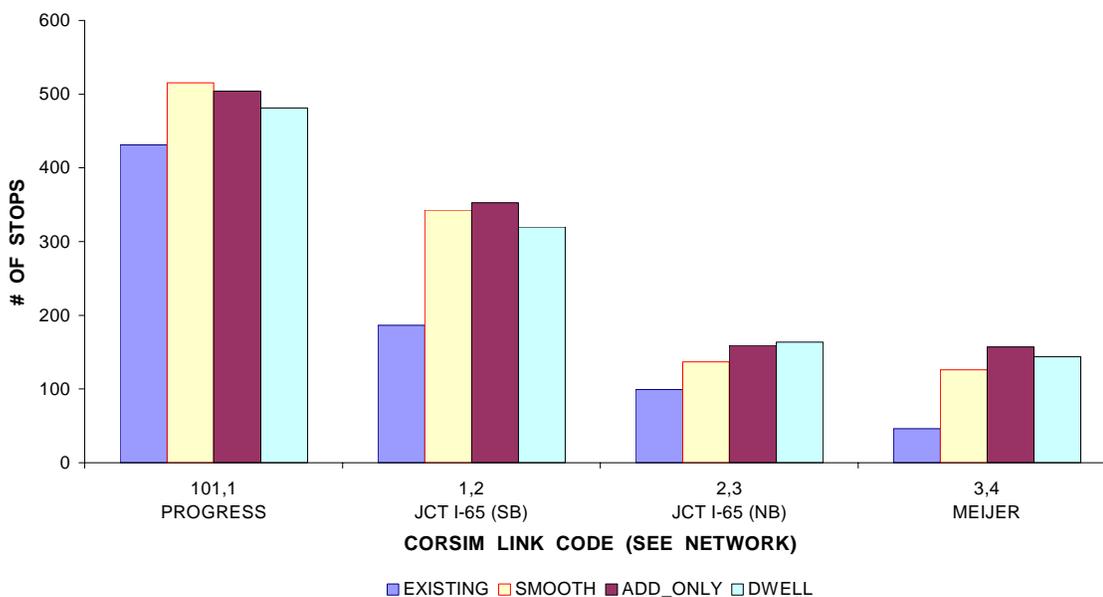


Figure 2-12: Comparison of Mainline Number of Stops

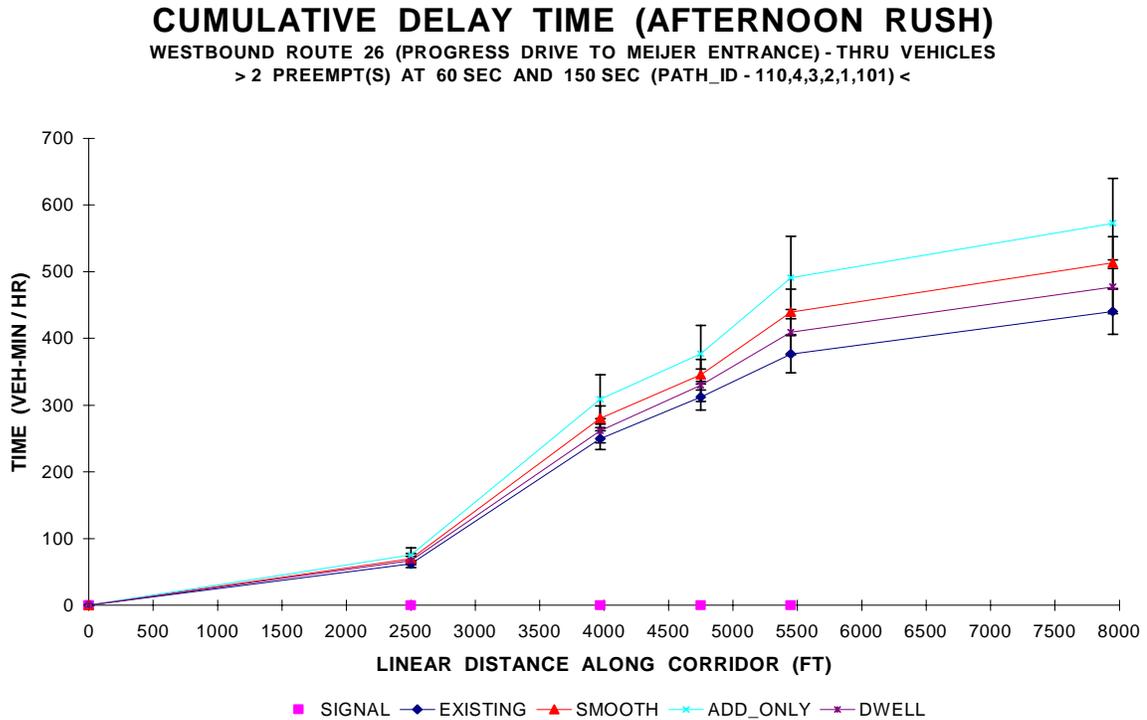


Figure 2-13: Comparison of Cumulative Delay Times (Veh-Min)

Applications Using Simulation

Some of the applications that can be used with simulation models include the tuning of offsets, the experimentation with the permissive periods under coordinated operation, the quantification of the overall system performance, and detailed animation which is helpful for illustrating problems to the public or client. In addition these models typically incorporate the intersection geometry in the analysis. The common features often include the number of lanes per approach, length of turning bays, placement of detectors, and skewed intersections. Some operational features include the modeling of protected only or protected-permissive left-turns, split phase operation, and lagging left-turning movements. Coordination is also feasible to model and can be changed on a per period basis at which time the entry volumes can also be changed.

Implementation Advantages

Based on the discussions in this chapter, simulation offers many advantages over the existing HCM procedures. The evaluation of arterial signal systems proposed in this research provides a rational procedure for quantifying and graphically representing the overall performance of a system. Such a process is very important when designing a new timing strategy as it can be used to validate the viability of a new timing strategy and identify problem areas that are not always apparent with the HCM procedures because of spillback or improperly tuned offsets.

With the HCM procedure comparisons, the proposed timing plans are typically compared to existing conditions by comparing the quantitative values at each intersection without a graphic comparison on how the system operates as a whole. In contrast, simulation procedures discussed herein can better provide a path-based graphic comparison of different system plans, which can then be used to validate new plans, if they perform better than existing conditions. Since these procedures allow the analyst to examine the system as a whole, such comparisons are particularly useful for determining overall system performance.

CHAPTER 3 – CONCEPTS OF HARDWARE IN THE LOOP SIMULATION

Chapter Overview

In recent years, there have been two parallel research paths for developing advanced traffic signal systems. They include the real-time traffic adaptive system research, supported largely by the United States Department of Transportation (USDOT), and the smaller scale closed-loop systems developed primarily by traffic signal system vendors. Simulation models have been developed for evaluating USDOT supported projects, and those results have been reported in the literature. However, even though there have been several TRP systems deployed, most of the vendor developed systems have not undergone such rigorous evaluations. This is an area of significant concern, since deployment of efficient closed-loop signal systems is one of the most cost effective Intelligent Transportation System (ITS) investments that a state or urban area can make. In order to make good deployment decisions, rational quantitative evaluation procedures are required to evaluate feasible options.

Motivation for Hardware-in-the-Loop Simulation

Over the past several years, there has been extensive public and private sector activity in the development of TRP and traffic adaptive control procedures. Internationally, systems like SCAT and SCOOT have seen broad application. In the United States, several vendors have implemented an array of traffic responsive features in their signal systems. The United States Department of Transportation (USDOT) has also sponsored an aggressive program for the research and field deployment of new traffic adaptive algorithms. Moreover,

cities throughout the world continue to deploy a variety of traffic responsive and traffic adaptive control algorithms.

The common feature behind all of these systems is that they use some type of vehicle detection to change the display of signal indications according to some prescribed logic that is designed to optimize certain system Measures of Effectiveness (MOE's). However, virtually all of the signal systems in commercial production implement their control logic on unique computing platforms. Hence, the algorithms are usually considered proprietary and are typically not available to the engineering community for conducting rigorous scientific evaluations.

Computing power has recently reached the point where microscopic network simulations of an entire network are now feasible. As indicated in the previous chapter, microscopic simulation packages are available, which model the vehicle movement and basic coordinated-actuated signal logic. However, because of the proprietary nature of the various traffic responsive and traffic adaptive algorithms, there is essentially no available software package that can be used for quantitatively evaluating the performance of alternative algorithms, or to serve as a design tool for "tuning" system parameters prior to deployment.

As a result, the only studies that agencies have available to them, in order to aid with the design and decision-making process, are vague "before-and-after" studies conducted with either probe vehicles or system detectors. Many of these studies use the old system, with outdated timings as the "before" case, and so it becomes unclear if the benefits are simply associated with the most recent timings, or the new traffic responsive / adaptive algorithm. Furthermore, because of the natural stochastic variation of traffic, and huge costs associated with systematically collecting system performance data, few, if any of the studies present rigorous statistical comparisons.

This chapter will examine an evaluation procedure developed for quantifying the impact of traffic responsive operation on modern closed-loop signal systems. It will review the concepts behind hardware-in-the-loop simulation and explain the application of this simulation procedure, along with how it can be used to evaluate closed-loop systems. It will also summarize the development of hardware-in-the-loop simulation procedures, while examining procedures for tabulating the quantitative data. This chapter will conclude by discussing how such equipment can be used to upgrade the traffic engineering profession's design, analysis, and operation of modern traffic signal systems.

Concepts of Hardware-in-the-Loop Simulation

To address this systematic evaluation problem, there are several efforts in the United States that are being made to integrate microscopic simulation programs with the traffic control hardware, in order to help better study the performance of vendor specific algorithms [Bullock, 1998], [Bullock, 1999], [Engelbrecht, 1999], [Husch, 1999], [Koonce, 1999], [Nelson, 2000]. Figure 3-1 schematically depicts the typical hardware-in-the-loop architecture, which consists of the three main components shown below:

- A Controller Interface Device (CID). This device provides the interface from the traffic controller to the computer running the microscopic simulation. The interface is typically based upon the discrete voltage levels used to drive the load switches and monitor loop detectors.
- A software interface module to provide the linkage between the CID and a microscopic simulation program. Since the software runs under Windows, this interface is typically implemented in a dynamic link library (DLL) software module.
- A microscopic simulation engine that is responsible for moving vehicles through a defined network and tabulating MOE's. The simulation engine

does not implement any control logic. Instead, external signal state indications (RED, AMBER, and GREEN) are obtained from actual control equipment which is connected to the simulation computer. The traffic signal control equipment is stimulated by detector calls placed by the simulation program via the CID.

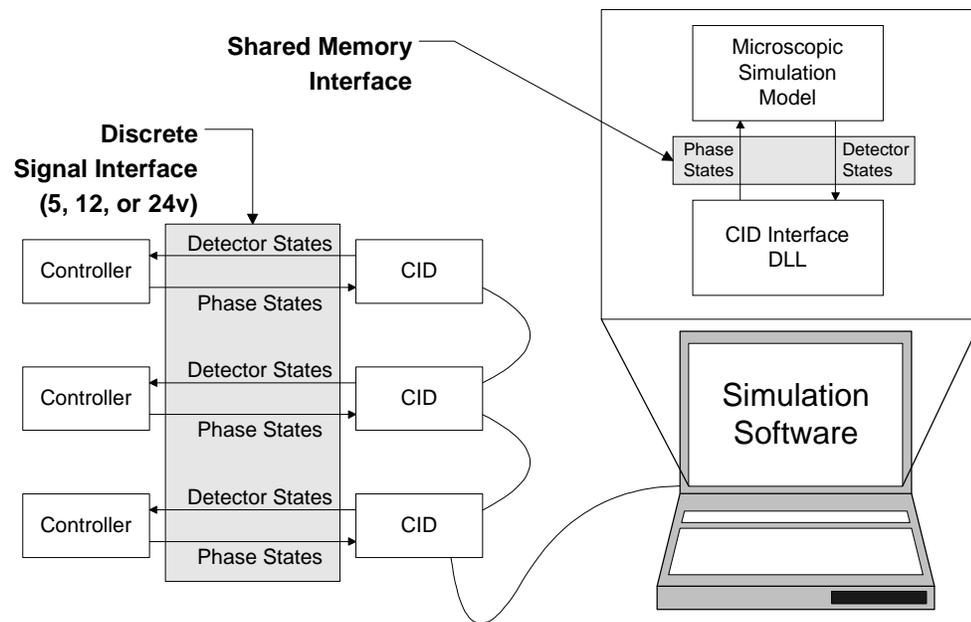


Figure 3-1: Schematic of the Hardware-in-the-Loop Simulation Environment

Since the control equipment ultimately controls the load switches and monitors detector calls, this discrete signal interface is the lowest common denominator that all controllers must have. Hence, this architecture provides a common evaluation framework that a variety of control systems can be interfaced with for conducting scientifically rigorous and reproducible evaluations. Although not shown in Figure 3-1, a typical simulation would have each controller connected to either a closed-loop master or a central control system, which would then run the traffic responsive algorithm.

Figure 3-2 shows a photograph of both the control equipment and the CID units, which were used to evaluate a three intersection system on SR 26 (South)

in Lafayette, IN. As seen from the figure, Controllers 1 and 2 are housed in a traditional controller cabinet, where all of their discrete signals are terminated in the cabinet backpanel. The corresponding CIDs were then interfaced to the backpanels using alligator clip harnesses. Controller 3 was interfaced to the CID using a direct-connect cable. Looking at Figure 3-2, it can be seen how the direct-connect procedure has the obvious advantage of using less equipment. However, it is important to note that this configuration is not as flexible, since custom cables must be constructed for each of the controller types.

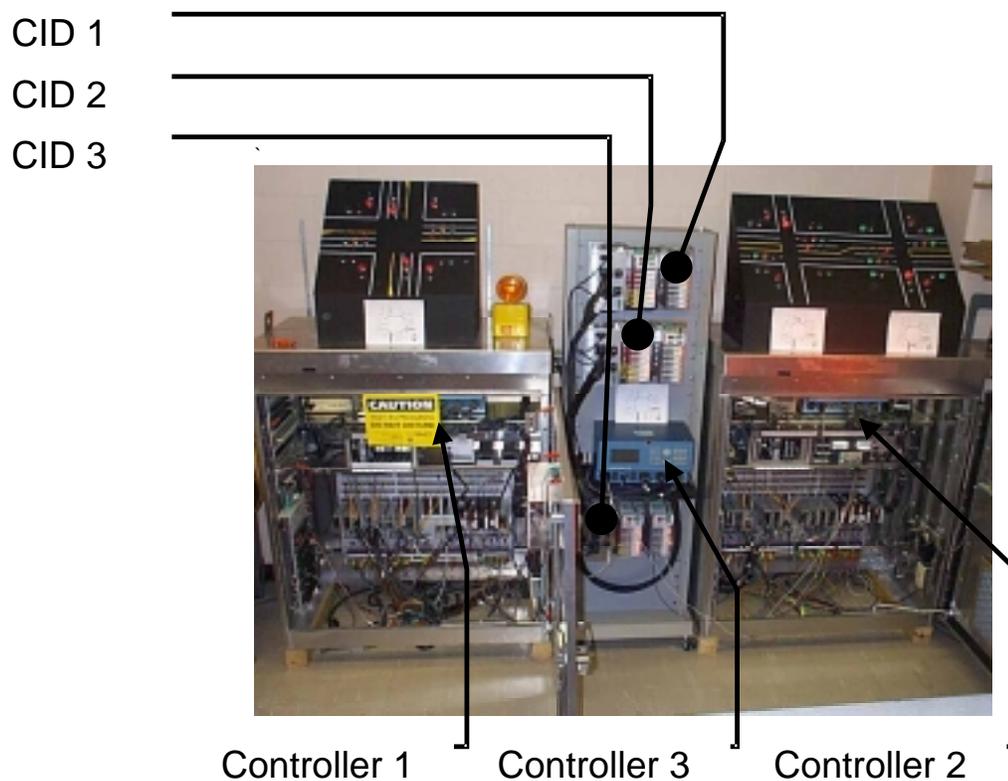


Figure 3-2: Hardware-in-the-Loop Simulation Environment (SR-26 Network)

Other procedures using a defined communication protocol [Husch, 1999] can also be used for interfacing control equipment with the simulation software. These procedures are typically based upon the NEMA TS II Type 1 interface [NEMA, 1998], which use much smaller and cheaper interface devices (CID's). However, such communication-based procedures typically restrict the diversity of

the control equipment that can be included in the simulation. For example, in the United States neither the 170 nor the 2070 currently support the NEMA TS II Type 1 interface protocol.

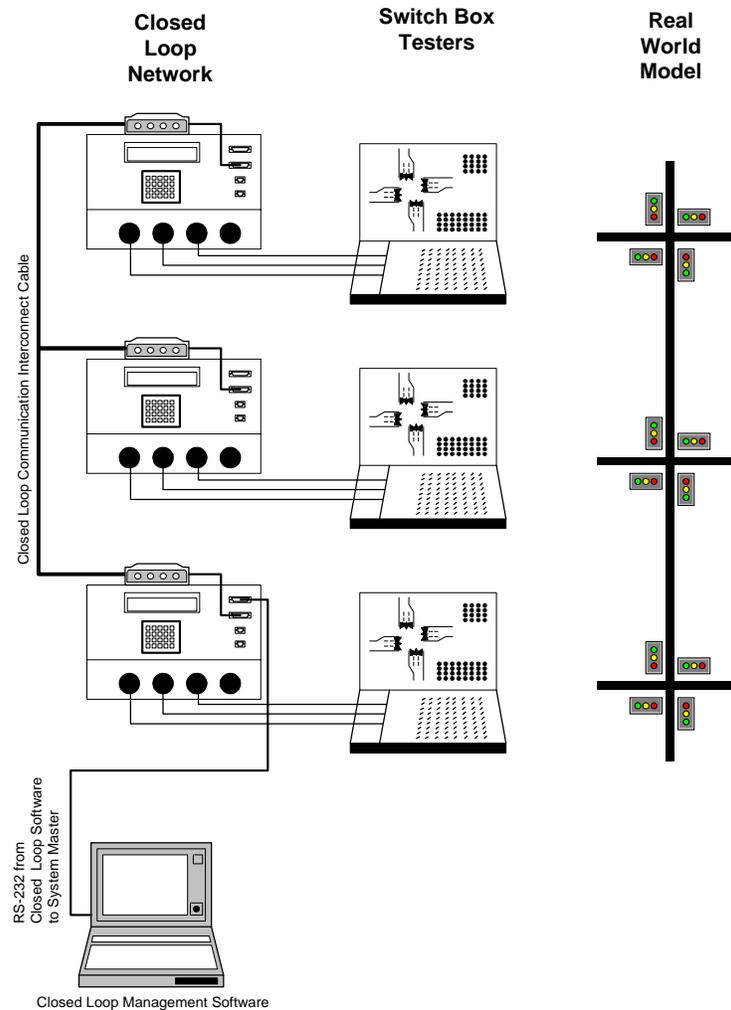


Figure 3-3: Illustration of the Controller Switchbox Concept

Finally, it is important to note that this evaluation procedure should not be confused with the traditional switchbox testers shown in Figure 3-3, which allow engineers to verify that desired controller features are operating as expected. When using only switchbox based testers, it would be impossible to simulate all the discrete detector actuations associated with a small arterial, much less corridors with more signals or higher volumes. Furthermore, without a simulation

program tabulating the MOE's, it would be impossible to conduct quantitative studies on the overall performance of the arterial. Hence, the configuration using the CIDs, shown in Figure 3-4, will instead be used, since this configuration allows the hardware equipment (controllers) to communicate with the simulation, as will be seen in the subsequent section.

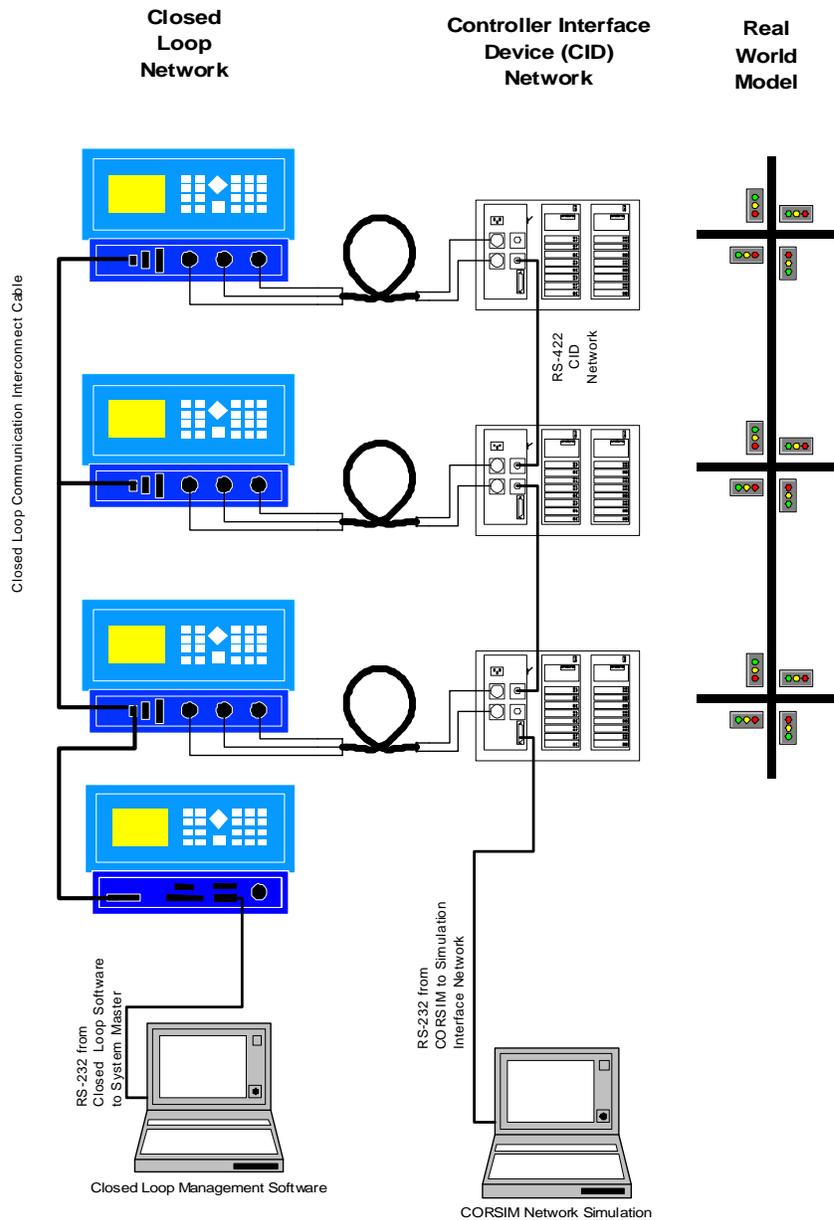


Figure 3-4: Illustration of the Hardware-in-the-Loop Concept

Application of Microscopic Simulation Technology

In order to make the evaluation system, shown in Figure 3-1 or Figure 3-4, useful for evaluating alternative control algorithms, it is essential that the CID's be interfaced with a robust microscopic simulation program. The microscopic simulation is responsible for "moving" all vehicles through a user defined network following prescribed vehicle kinematics. This movement is performed by recalculating the position of each vehicle at a deterministic frequency, typically between 1 and 10 Hz. During each recalculation, vehicle accelerations in the simulation are updated in response to signal indications obtained from the CID and adjacent vehicles in the network. During each simulation interval, the appropriate detector states are updated, via the CID.

To ensure that the occupancy calculated by the traffic controllers closely models field conditions, the duration of the presence detectors is inversely proportional to the velocity of the vehicle actuating the detector. Since the simulation tabulates vehicle positions over the entire simulation period, the resulting data obtained from the program tends to be extremely detailed. Hence it is essential that some aggregation be performed, in order to help better understand the overall impact from alternative control measures. To help aid in the analysis, it is crucial to present the analytical data in a graphical format that is easy to understand [Shoup, 1999].

Sample Analysis of Traffic Responsive Operation

To illustrate some of the information that can be obtained using hardware-in-the-loop simulation, a five intersection arterial on the Southwest side of Indianapolis, IN was analyzed, as shown in Figure 3-5. The analysis was performed with the equipment shown in Figure 3-4, plus two additional controllers and CIDs not shown in the photograph. The basic ring structures for each of the intersections is shown in Figure 3-6. Hourly turning movement counts from

6:00am to 6:00pm were obtained, and each hourly demand was coded into the network, so that a 12 hour period could be accurately simulated. Since microscopic simulation is stochastic in nature, each control scenario was replicated 5 times, for a total simulation time of about 60 hours per strategy.

Figure 3-7 to Figure 3-9 show some of the sample data that was obtained from the SR 67 (Kentucky) test network, shown in Figure 3-5. Notice that Figure 3-7 depicts a simulation conducted with one set of demand volumes, while Figure 3-8 shows the outcome when an alternative set of demand volumes was used in the simulation. Figure 3-9 is an hourly travel time (Sec/Veh) graph of the Traffic Responsive (TPR) operation, which provides insight into the specific time periods along a Southbound path that was experiencing heavy congestion for this particular scenario. As seen from the figure, there are potential concerns between the hours of 8:00am and 9:00am, as the Southbound travel time was nearly tripled, relative to the other periods.

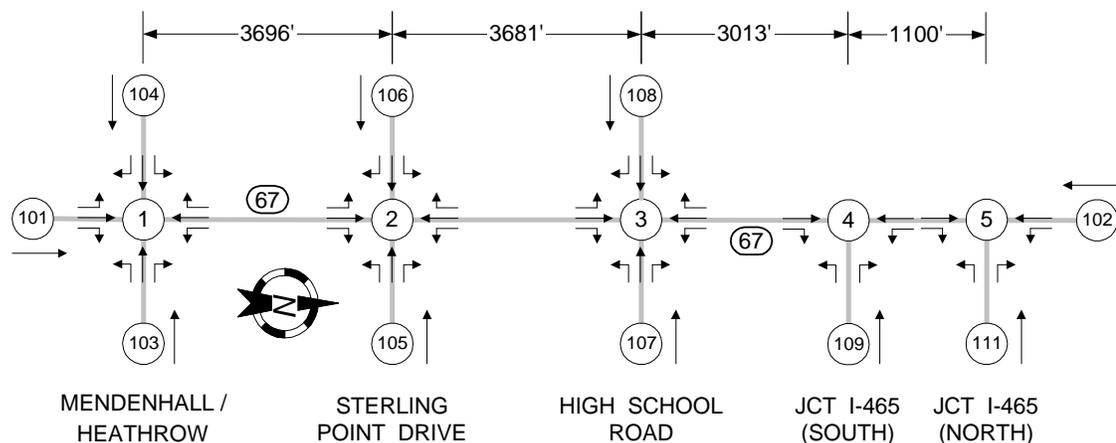


Figure 3-5: SR 67 (Kentucky) Network – Mendenhall to JCT I-465 (Ramps)

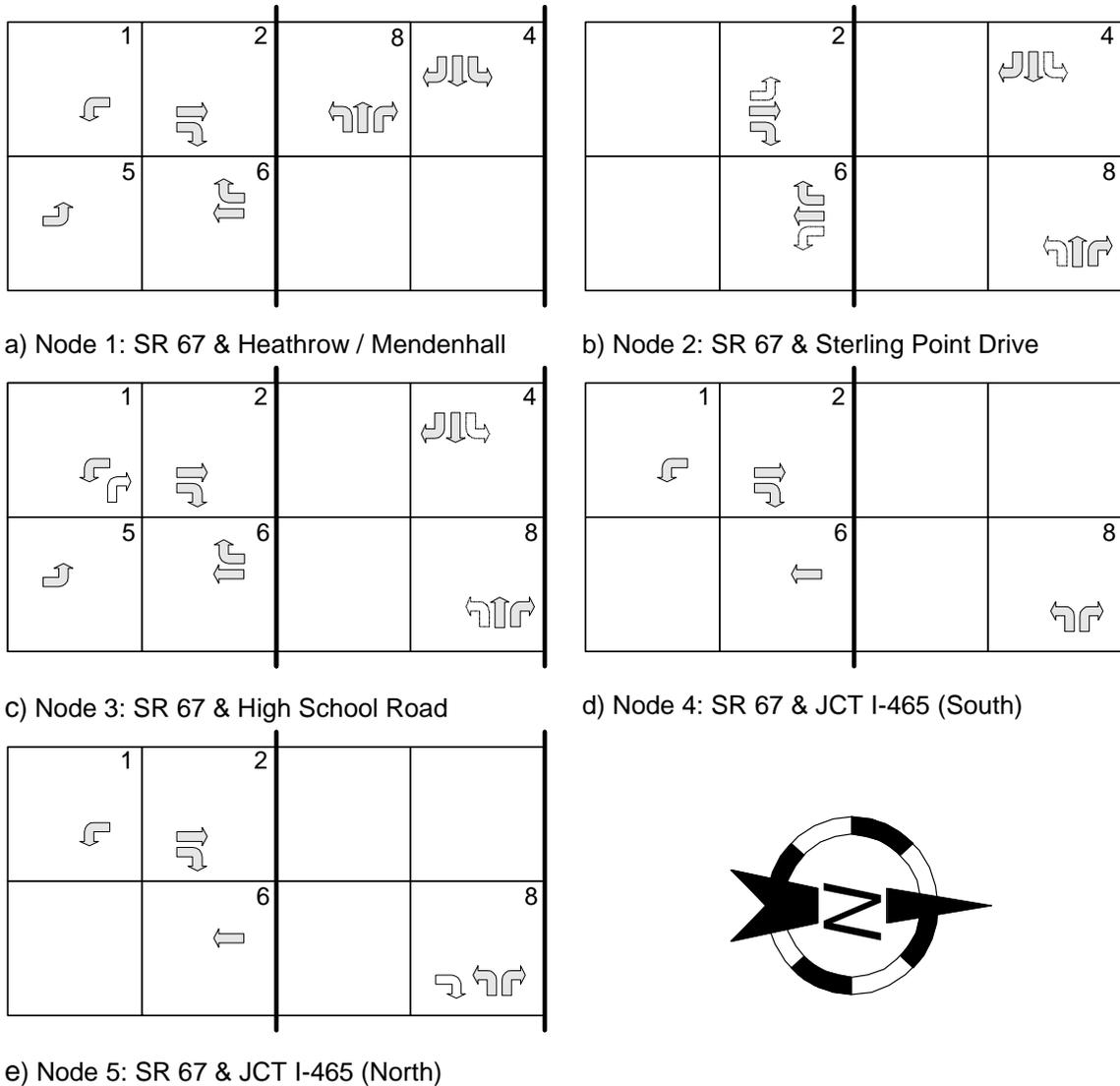


Figure 3-6: SR 67 (Kentucky) System Ring Structures

Figure 3-7 and Figure 3-8 each have a different volume scenario, and show more of the “big picture” by comparing the traditional Time-of-Day (TOD) measures (schedules) to the more advanced Traffic Responsive (TRP) procedures. Each bar in the figures depict the total system delay time (Veh-Min) on a per period (1 hour) basis. In can be seen that Figure 3-7 illustrates a case where TRP plan selection performed slightly worse throughout most of the day, but performed better during the early evening peak hour between 2:00pm and 4:00pm, since the Traffic Responsive (TRP) procedure responded to evening

peak flows that started earlier than the time-based (TOD) system was scheduled for. In general, this is the expected performance of a traffic responsive system:

- TRP performance will slightly lag that of a well timed Time-of Day (TOD) system, since the traffic responsive procedure requires additional time to recognize changes in the traffic patterns and then transition to the appropriate coordination pattern.
- TRP performance will perform significantly better than time-based (TOD) systems if the traffic responsive procedures are properly calibrated to respond to traffic demand that can not be predicted by the traditional time-based procedures.
- The hours of 7:00am to 9:00am, in Figure 3-7, illustrate this slight lagging performance. Similarly, the hours 2:00pm to 4:00pm illustrate the benefit of TRP recognizing that the peak hour has started earlier than expected and then adjusting accordingly.

In contrast, Figure 3-8 illustrates a case where traffic responsive performs significantly worse than the TOD schedule. This is because the TRP algorithm was either too slow or failed altogether to trigger the appropriate timing plans. For example, during the hours of 8:00am and 9:00am, the delay with the TRP was nearly double that of the TOD operation. Similarly, during 2:00pm and 3:00pm, the delay is approximately 30% worse with the TRP procedure. Hence, this degraded TRP performance is an important point to note. Although Figure 3-7 clearly shows the potential benefits of a well calibrated traffic responsive system, Figure 3-8 shows that poor calibration can result in overall performance that is significantly worse than that of a TOD system.

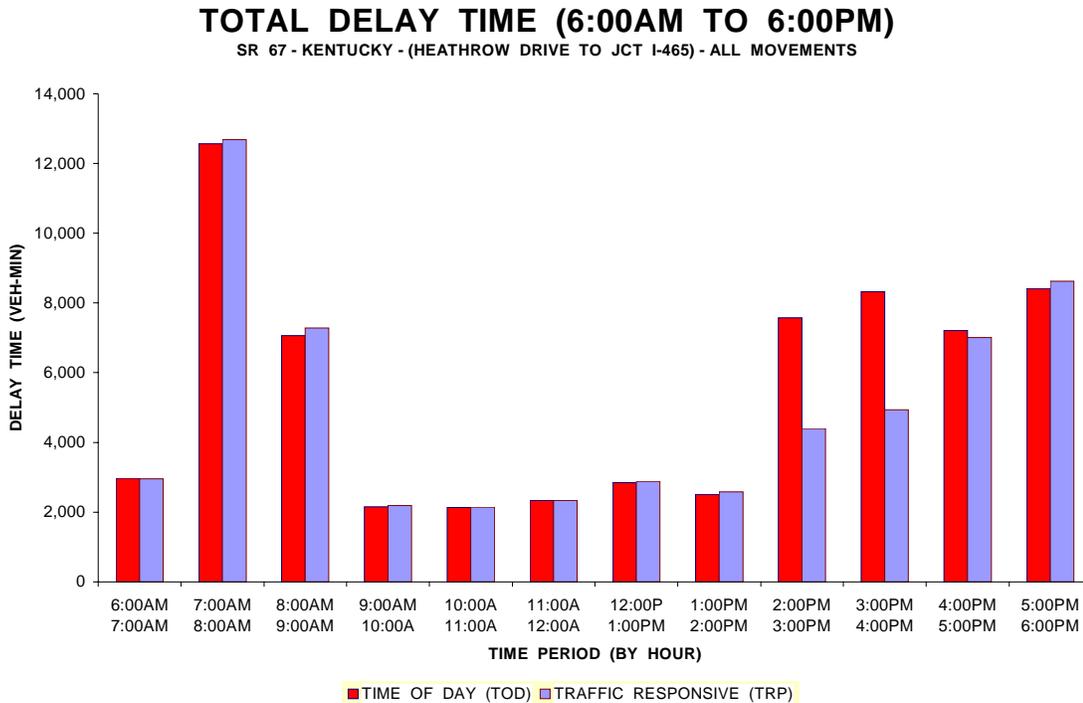


Figure 3-7: Total Delay Time (Veh-Min) - Time of Day Vs Traffic Responsive

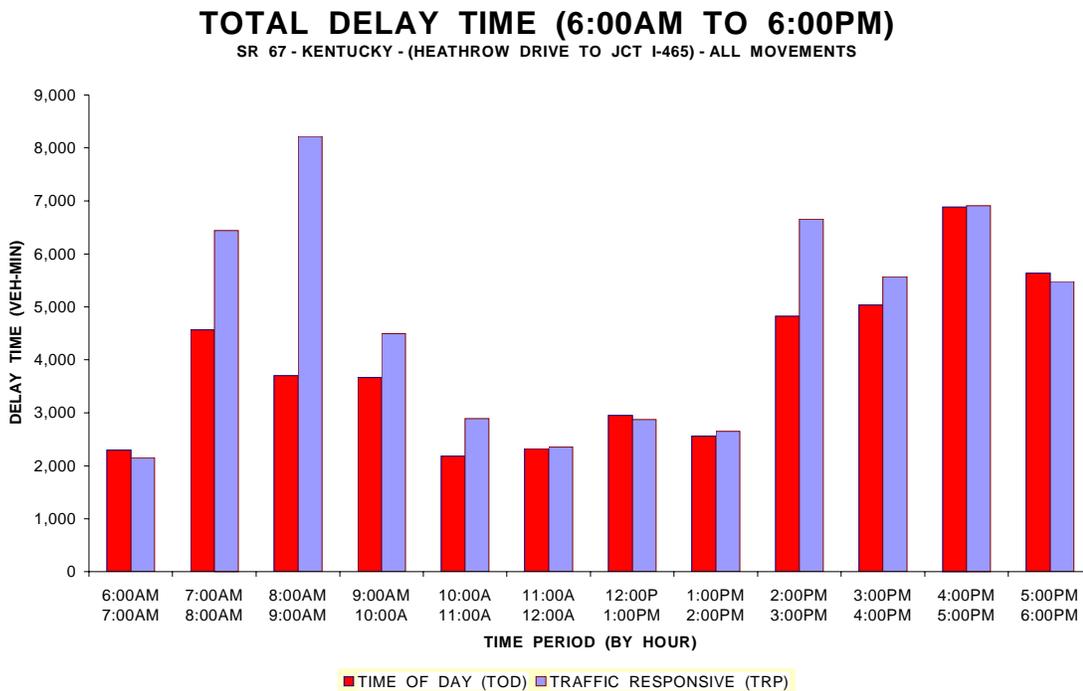


Figure 3-8: Total Delay Time (Veh-Min) - Time of Day (2) Vs Traffic Responsive

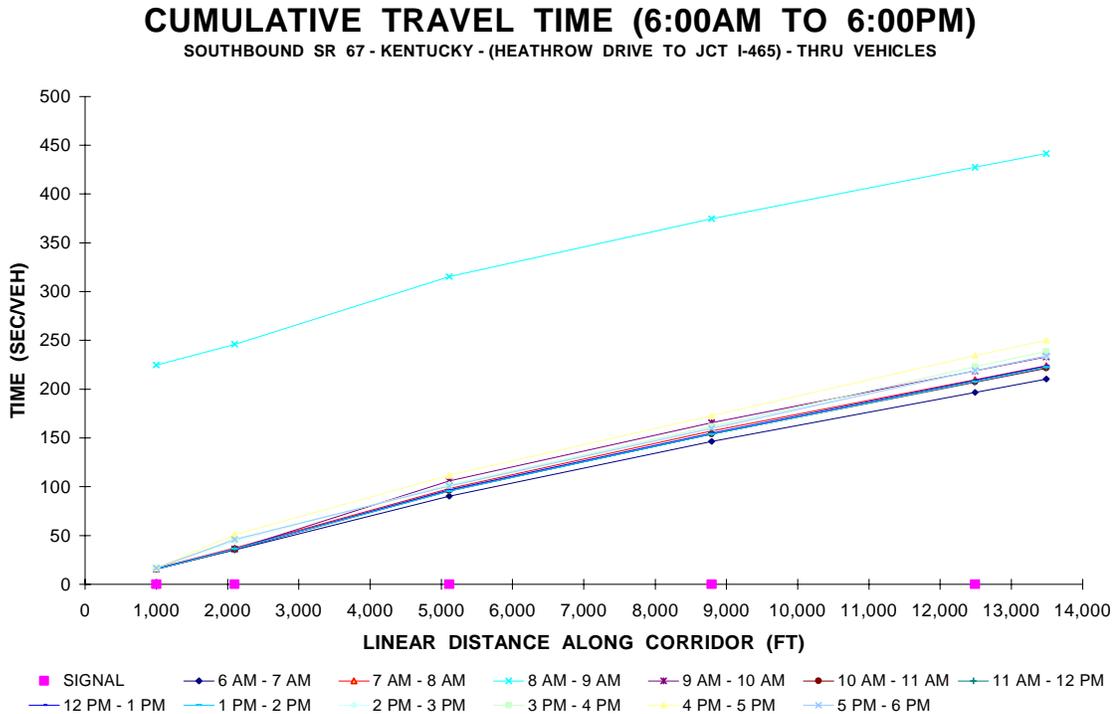


Figure 3-9: Southbound Travel Time per Period using Traffic Responsive

Although Figure 3-7 and Figure 3-8 illustrate the network level performance, they do not provide much insight into where the problems are for signal timing improvements can be made. Figure 3-9 illustrates the travel time (average) that it takes for a typical vehicle to proceed Southbound along the arterial for each of the 1 hour intervals [Shoup, 99]. In general, the cumulative travel times in that direction are on the order of 200 seconds. However, during the morning peak hour, between 8:00am and 9:00am, the Southbound travel time is much greater, somewhere on the order of 450 seconds. By inspection, one can see that virtually all of the delay is introduced at the first intersection, which is shown as a square on the horizontal axis at 1,000 feet.

An engineer reviewing the plans would then look into potential causes, which can range anywhere from a short green interval or an overflowing left-turn lane which impedes the through movement. In this case, the problem was the latter. A short left-turn phase, that resulted from the wrong traffic responsive plan

be selected. This resulted in spillback which then impeded the majority of the Southbound movement for that particular period. Since the Southbound system detectors were located after this junction, there was not enough demand that could clear the intersection (left-turn spillback), in order to activate the appropriate plan. The subsequent chapters will look at this network and related issues in greater detail.

Summary of Hardware-in-the-Loop Simulation

Although the above example comparisons were brief, they were intended to illustrate that hardware-in-the-loop evaluation procedures can be used to characterize the operational performance of a signal system during both steady state as well as the transition periods. Microscopic simulation programs have been available for many years. However hardware-in-the-loop simulation procedures have only recently become feasible because of improved computing platforms and the use of the CID to interface traffic signal controllers to the simulation. By using hardware-in-the-loop simulation, scientifically rigorous and reproducible evaluations can now be performed. Such methodologies have the following applications:

- Using a combination of simulation software and controller interface devices (CID's), the field equipment can now be evaluated in a shop or laboratory environment under traffic conditions that approximate those expected in the field. Since the motoring public is not very receptive to online TRP tuning errors (Figure 3-8), such procedures are particularly important to ensure that a TRP system has no major problems before it is deployed in the street.
- The quantitative MOE's obtained from a Simulation / CID environment provides a mechanism for evaluating alternative control algorithms that can not be simulated. For example, the SCOOT and SCAT algorithms are proprietary and can not be simulated in traditional simulation models.

However, the hardware-in-the-loop procedure allows a simulation program to be connected to either system with only a functional description of the algorithms operation.

- It is now possible to explore and quantify the impact that the multitude of actuated control, traffic responsive, and traffic adaptive parameters have on system performance, without experimenting under live traffic conditions. Many of these features promise to provide significant improvements in operating efficiency. However, without evaluating them in a structured and reproducible environment, it is currently unfeasible to develop rational design procedures for deploying them.
- A “Flight Simulator” type experience can be constructed for training newer personnel. Such an environment would allow for experience-based learning exercises that demonstrate various “what-if” scenarios. Such a system has application in a variety of educational efforts, including college engineering curricula, continuing professional education, and the training of technicians that are responsible for the daily operation and maintenance of these systems.

CHAPTER 4 – CONTROL CONCEPTS FOR ACTUATED DIAMOND INTERCHANGES

Overview of Diamond Interchanges

The design of signal timings for diamond intersections is well documented in the literature and there are a variety of software packages to assist one in generating the timing plans. However, the actual implementation of diamond intersection control procedures on modern dual ring actuated controllers is not documented in the literature, primarily because early implementations used vendor specific features on modern controllers. Consequently, none of the implementation procedures were transferable. In recent years, vendors have greatly increased the flexibility of their traffic controller and now provide configurable ring structures, overlaps, detector modes, and detector mapping. This paper synthesizes current practice and defines procedures for implementing both Three Phase and Four Phase diamond control logic using common features on modern traffic controllers. The procedures introduced in this paper should allow this important area to mature and gain widespread implementation, leading to more efficient traffic signal operation at signalized diamond interchanges.

Introduction to Diamond Interchanges

A diamond interchange is defined as a two-way surface street intersecting two adjacent one-way streets [Capelle, 1961], [DeCamp, 1993]. Most frequently these interchanges are defined where the ramps, or frontage roads, of a freeway cross an arterial at grade. In areas where frontage roads are commonly used, the spacing between intersections is on the order of 60 meters, which usually

causes concern about the interior storage, particularly for the interior left-turn bays. To address this limited storage problem, TTI Four Phase is typically prescribed [TTI, 1998]. When the ramp intersections are widely spaced, say on the order of 200 meters, the more traditional Three Phase operation is typically used [TTI, 1998]. These spacing distances are only approximate guidelines, the actual selection of the specific phasing patterns is also influenced by the intensity of the interior turning movement, particularly at intermediate distances.

The actual phasing concepts and design procedures used for selecting specific phase sequences and timings are well documented in the literature [Fambro, 1988], [Herrick, 1992], [Kim, 1992], [Lom, 1992], [Messer, 1987], [Munjal, 1971]. The purpose of this chapter is to document how one actuated controller can be used to implement either Three Phase or Four Phase control logic on modern traffic signal control equipment [NEMA, 1992]. The following sections describe alternative ring structures, overlap mappings, coordination procedures, and the accommodation of pedestrians.

General Diamond Control Concepts

The most common procedure used for implementing diamond intersection control is to use two controllers, one controller at each ramp. Figure 4-1 illustrates this control concept. Figure 4-1a shows the typical phase numbering scheme, while Figure 4-1b shows the ring structure for the left intersection and Figure 4-1c shows the ring structure for the right intersection. If no background coordination cycle is specified, each intersection operates independent of the other one. If there is significant arterial traffic (Phases 2 and 6), this uncoordinated operation is not very efficient. Consequently, these two adjacent controllers are typically coordinated using a background cycle. If a background cycle is specified, then the arterial through phases are typically the coordinated movements (Phases 2 and 6). When a background cycle is specified, the

relative offset of the end of the coordinated phase is typically zero, or close to zero, in order to provide a reasonable level of two-way progression through the interchange. When near zero offsets are used, the operation of the diamond interchange is roughly characterized as Three Phase [TTI, 1998].

For widely spaced ramps with a low to moderate intensity of interior left-turns (Phases 1 and 5), using two coordinated-actuated controllers works quite well. However, as the spacing between the intersections is reduced and the intensity of the interior left-turns is increased, then it becomes very important obtain precise synchronization between both intersections such that traffic entering the interchange can move through both intersections without being stopped in the middle and spilling back [TTI, 1998]. The conventional actuated controller coordination procedures provide only one predictable point in the cycle, which is the barrier at the end of the coordinated phases [NEMA, 1992]. Notice that in Figure 4-1b, the barrier (shown as a thick black vertical line) is at the end of Phases 1 and 6 while in Figure 4-1c it is at the end of Phases 2 and 5. This can be problematic when left-turn storage is of concern. Subsequent sections of this chapter will present a brief history of diamond control concepts, followed by detailed discussions of how one actuated controller can be used to control both ramps of an interchange in order to provide a high level of coordination.

Definition of a Phase

Historically, much of the confusion regarding the operation of traffic signals in general and diamond interchanges in particular has been caused by the traffic engineering profession's evolving definition of a "phase." In the early days of traffic signal control, there were a limited number of electromechanical contacts for controlling signal indications. Consequently, multiple movements were often controlled by a single contact. As a result, a "phase" would often imply that one or more movements were being controlled simultaneously. For

example, in Figure 4-1b the interval where both through movements were running might be Phase A, while the interval where the interior left and the adjacent through movement were running could be called Phase B. Similarly Phase C would be the ramp movement. In fact many of the early fixed-time diamond concepts used similar terminology [TTI, 1998].

However, in modern NEMA controllers [NEMA, 1992], the convention is now to assign each movement to a specific load switch, which would be controlled by an independently timed “Phase” or “Overlap”. For example, following the convention in Figure 4-1a and Figure 4-1b, the left interior left-turn would be Phase 1, while the left interior through movement would be Phase 6. Similarly the left exterior through movement would be Phase 2, while the ramp would be Phase 4. This terminology problem is pervasive at intersections of all levels of complexity ranging anywhere from two-phase signals, which are typically implemented with four phases (2, 4, 6, and 8), to the complex phasing associated with diamond interchanges.

Since the Highway Capacity Manual still uses this legacy definition of phase, many designers use this legacy definition of a phase [HCM, 1997]. However, the engineers and technicians responsible for implementing the timing use the more modern NEMA definition of a phase [NEMA, 1992]. Needless to say, this continues to create significant confusion. In order to understand the remainder of the chapter, the term “phase” will be used in the following context:

- “Three Phase” and “Four Phase” are legacy terms that refer to operating concepts for diamond interchanges, which do not have any direct correlation with terms and procedures used by modern NEMA controllers.
- Phase y, where y is a number between 1 and 16 indicates a specific movement is controlled by Phase y in a controller. For example, Phase 2

in Figure 4-1a refers to the Eastbound through movement for the West approach to the diamond interchange.

Similarly, the term “Overlap” has evolved as the traffic engineering profession has developed. In order to understand the remainder of the paper, the term “Overlap” will be used in the following context:

- “Internal Overlap” is a legacy term defining a specific transition interval in “Four Phase” control, which does not have any correlation with overlaps defined on modern traffic controllers [Fambro, 1988]. Details of this operation are discussed in the “Four Phase” section of this chapter.
- Overlap z, where z is a letter between A and F, refers to a specific movement controlled by Overlap z in a controller. An overlap is slightly different than a phase because an Overlap is typically timed and controlled by two or more phases.

Finally, although the term “interval” is relatively unambiguous, for the purposes of this paper, both an “interval” and a “green interval” will be defined as follows:

- An Interval is a period of time where no indications change. For example, assuming all phases have identical amber and all red times defined, in Figure 4-1b, there are nine distinct intervals

	Phase 2	Phase 1	Phase 6	Phase 4
Interval 1	G	R	G	R
Interval 2	A	R	G	R
Interval 3	R	R	G	R
Interval 4	R	G	G	R
Interval 5	R	A	A	R
Interval 6	R	R	R	R
Interval 7	R	R	R	G
Interval 8	R	R	R	A
Interval 9	R	R	R	R

The “green interval” is a period of time where none of the green indications change. For example, in Figure 4-1b, there are three distinct green intervals, mainly Phases 2 & 6, 1 & 6, and Phase 4.

Single Controller – Three Phase Operation

As discussed previously, the most common procedure for controlling a diamond interchange is using two controllers running a common cycle operating with end of green offsets that are the same (or close). Figure 4-1 illustrates this concept. Two important observations should be made when reviewing Figure 4-1b and Figure 4-1c.

- On the left intersection, Phase 6 always runs during Phase 2 and Phase 1. If Phase 6 was controlled by an overlap, then a single ring could be used to control the left intersection. For purposes of this study, we will call the left interior movement Overlap A.
- On the right intersection, Phase 2 always runs during Phase 6 and Phase 5. If Phase 2 was controlled by an overlap, then a single ring could be used to control the right intersection. For purposes of this study, we will call the right interior movement Overlap B.

Based upon these observations, Figure 4-2a shows the phase mappings when overlaps are used to control the interior through movements. Similarly, Figure 4-2b shows the most constrained 3-Phase operation (three barriers represented by the three thick black vertical lines). Notice that the top ring (row) controls the left intersection and the bottom ring controls the right intersection. In Figure 4-2b, the phasing is very tightly constrained because the three barriers lock together the arterial through, the interior left-turns, and the ramp movements. This means that all movements at both the left and right intersections must occur at the same time. Also, notice in both Figure 4-2a and Figure 4-2b, that the dark arrows represent movements controlled by phases

while the hollow arrows represent movements controlled by overlaps. Overlap A is green when either Phase 1 or Phase 2 is green. Similarly, Overlap B is green when either Phase 5 or Phase 6 is green.

Figure 4-2c shows a slightly less constrained operation that is most commonly implemented since it uses the default NEMA barriers and the rings do not have to be reconfigured. In this particular case, the interior left-turns can gap out independently. Figure 4-2d, removes one more barrier, so if ramp volumes are unbalanced, the ramp with the lighter volume can gap-out earlier thereby providing the extra time to the arterial. Finally, Figure 4-2e removes all barriers. If there is no background cycle (no coordination) then both intersections operate independently. Such operation is analogous to using two controllers (Figure 4-1), except overlaps are used ($A=1+2$, $B=5+6$) instead of the additional ring.

Figure 4-3 illustrates the basic detector numbering scheme while Table 4-1 defines the types of detectors, and Table 4-2 defines the phases that each of the detectors call along with their configured operating modes. In terms of detection, the following comments summarize the important issues:

- The ramps are labeled Overlap C and Overlap D. The specific reason for this will be discussed with “Four Phase” operation.
- All ramps and through movements (Phases 2, 4, 6, and 8) use stopbar detectors that prevent vehicles from becoming trapped between the advance detectors and the stopbars. These detectors become inactive after the standing queue is discharged since the advance (raceway) detectors are more efficient at detecting gaps.
- All ramps and through movements (Phases 2, 4, 6, and 8) use the advance detectors to improve efficiency so excessive green is not wasted waiting for a detector to gap-out. The efficiency is gained with these

detectors since they are situated such that the last vehicle enters the intersection just as the advance detector gaps-out.

Although Table 4-2 defines a lot of detectors, this arrangement is not substantially different than an optimal arrangement had separate controllers been used. Furthermore, it would not necessarily be more expensive to implement once emerging wide area detection technology is widely deployed. Finally, it should be clear to the reader that the number of detectors could be substantially reduced if all of the advance detectors were eliminated and the stopbar detectors changed to standard detectors. However, such a change would reduce the operating efficiency of the diamond interchange, irrespective of the number of controllers used. In summary, the advantages of using one controller for operating a diamond intersection in this manner is:

- Only one traffic control cabinet is required instead of two. This results in a reduction in equipment costs by about \$6000. In practice the cost reductions are less than \$6000, since longer conduit and wiring runs would be required.
- There is no need to prescribe a fixed cycle length in order to obtain coordination at the interchange. As a result, when demand is low, the diamond operates with a low cycle length. Conversely, as demand gets higher, the cycle length increases, limited by the maximum phase times. In contrast, when two controllers are used, the cycle length must be explicitly changed by either a TOD event or traffic responsive procedure.

The disadvantages of using a single controller in this manner is:

- If the cabinet has a failure and goes into flash, then both intersections are impacted, instead of only one.
- If non-zero end of green offsets for the coordinated arterial phases (Figure 4-2e) are required, then the configuration of the coordinated parameters is

more difficult, since the offset must be implemented by changing the relative force-off points, instead of just changing an offset. This is because many controllers do not provide a mechanism for implementing this special “ring-lag” feature.

Single Controller – Four Phase Operation

As the interior left-turning volumes increase, and the spacing between junctures decrease, then the interior storage for the left-turns becomes the critical concern. To address this limited storage, 4-Phase operation is typically prescribed (Figure 4-4). This operating concept can be thought of as tightly coordinating two intersections so that the four exterior movements (Phases 2, 4, 6, and 8) can be sequentially serviced in a “split phase” fashion, with two special “transition” green intervals. Figure 4-5 documents the specific phase mappings (Figure 4-5a), the abstract ring structure (Figure 4-5b), and a ring with some typical phase timings (Figure 4-5c).

To understand this operation, we will step through all six green intervals in Figure 4-4, starting with the second green interval (Figure 4-4, Phases 2 and 5). Whenever “green intervals” are discussed in this section, the reader should reference Figure 4-4. During green interval 2, the exterior through traffic (left intersection, Phase 2) is progressed through the second intersection by calling Phase 5. Note that since Overlap B has Phase 5 as a parent, the through movement adjacent to Phase 5 at the right intersection is also green. A detailed diagram of the ring operation is shown in Figure 4-5c. In Figure 4-5c Phases 2 and 5 are shown as shaded arrows while Overlap B is shown a hollow arrow.

The third green interval (Figure 4-4, Phases 4 and 5) maintain the same green indications at the right intersection, but displays a green for the ramp at the left intersection. The operation of the third and fourth green intervals, contain

some subtle nuances, which often cause confusion for the novice. Notice that ramp indications are controlled by an overlap, as indicated by the hollow arrows in Figure 4-5c. The specific overlap assignments are documented as part of Figure 4-5a. Since there is a relatively predictable travel time across the interchange, it is desirable to terminate green interval 3 at a point such that the exterior through movement, starting at the right intersection during green interval 4, arrives at the left intersection just as green interval 5 is starting. Consequently, green interval 3 must terminate at the point where there is just enough residual demand to utilize the ramp green time in green interval 4. This termination of green interval 3, while there is still demand on the ramp helps to improve the overall efficiency of the interchange. The duration of green interval 4 is fixed and approximately equal to the travel time between the ramps.

This termination of green interval 3 while there is still residual ramp demand, is typically done with an advance detector (Detector 4 in Figure 4-3). When detector 4 gaps out, green interval 3 terminates and there is just enough time in the fixed green interval 4 to handle the vehicles between Detector 4 and the stopbar. For very tight diamonds this practice works quite well since the travel time across the interchange is quite short. However, as the ramp spacing increases, the upstream detector distance on the ramp becomes excessive. In those cases, this procedure can still be used, but with less efficiency since the detector must be within a few hundred feet of the stopbar. When this occurs, the ramp time in green interval 4 is not used as efficiently as the prior case.

In the fifth green interval, the state of the right intersection does not change, but the left intersection changes to display the left-turn (Figure 4-4, Phase 1) and the accompanying Overlap A. As discussed in the preceding paragraph, green interval 4 is timed so that green interval 5 starts just as the platoon of vehicles arrives. Consequently, the precise timing of green interval 4 is very important, in order to ensure uninterrupted flow during green interval 5. In

fact, it is the fixed-time green interval 4 (and green interval 1 by symmetry) that requires that only one controller be used if the interchange is actuated. Realize that Phases 3 and 7 are used to time these fixed intervals. For simplicity, these intervals have been circled on the interval diagram shown in Figure 4-4.

The operation of green intervals 6 and 1 are analogous to the operation of green intervals 3 and 4 previously described. Although there are six green intervals shown in Figure 4-4, this operation has historically been referred to as 4-Phase, since there are essentially four major movements: Eastbound Arterial, Southbound Ramp, Westbound Arterial, Northbound Ramp. Transition green intervals 1 and 4 reclaim some efficiency by starting traffic across the interchange under tightly controlled conditions. Figure 4-5b documents the ring structure for implementing the control of a diamond interchange with one controller. In addition to the ring structure, it is important to examine the associated detector mappings documented in Table 4-3. However, since detectors are mapped to phases, and not intervals, the following discussion will be made on an individual phase basis.

In the top ring, Phase 2 can be called by the stopbar (2_S) or advance detectors (2_A) on Phase 2, or by the stopbar (A_S) or advance detectors (A_A) on the approach controlled by Overlap A. In the bottom ring, Phase 5 can be called either by the standard detector (5_S) in the left-turn pocket or by the detector (B_S) in the adjacent lane controlled by Overlap B. Phase 4, is called by the advance (raceway) detector (C_A), on the ramp. Notice that detector C_A calls both Phases 4 & 3. Once Phase 4 is started, it times until the advance detector (C_A) gaps out. Since it is an advance detector, there will still be some vehicles on the ramp requiring green time. To help service the remaining vehicles, the fixed-time transition interval (Figure 4-4, Phase 3) that was called by detector C_A or C_S, follows Phase 4. Since the intersection is symmetrical, the remainder of the detectors will not be discussed in detail.

On a final note, traditionally the difficult part of configuring 4-Phase operation is the configuration of the ramp detectors, along with those detectors adjacent to the left turn. Table 4-3 is not the final word on detector mappings. In fact, additional efficiency can be realized by reconfiguring these detectors by time-of-day. For example, if light ramp volumes can usually be handled using only the time in Phase 3, then the technician may elect to wire the advance detector (C_A) to two separate channels. The first channel would be configured the same as shown in Table 4-3, but without a call to Phase 4. The second channel would be configured only to call Phase 4, which would run in non-lock mode, perhaps with a 2.0 second delay on time, in order to prevent calls from passing traffic, but to call the phase when a queue is detected.

Load Bay Assignments

Figure 4-5 shows Overlaps C and Overlaps D controlling the ramps. Overlaps must be used for 4-Phase operation since each of the corresponding displays are timed by multiple phases. However, in order to keep the phase numbering consistent with 3-Phase (Figure 4-2), it is recommended that Overlap C be assigned to Load Bay 4 and Overlap D assigned to Load Bay 8. This arrangement is shown in Figure 4-6. This helps keep the cabinet wiring of the signal displays consistent for both the 3-Phase and 4-Phase operations.

Pedestrian Indications

In general, pedestrian walkways should be configured as shown in Figure 4-7, with the actuated indications. The timing of the pedestrian phases running concurrently with the arterial through movements (P_2 and P_6) is typically not a problem do to the relatively short width of the ramps. However, a pedestrian crossing the arterial (P_4 and P_8) concurrent with the ramps can be problematic, particularly if one is trying to maintain coordination. To reduce the

possibility of exceeding coordination splits and causing an intersection to drop out of coordination, it is desirable to use a form of pedestrian overlaps that permit the pedestrian intervals to be timed over two phases. In the example shown in Figure 4-7, it would be desirable for a P_4 pedestrian actuation to call pedestrian Phases 4 and 3, and time the appropriate pedestrian intervals over both Phases 4 and 3 (Figure 4-5c). Likewise, it would be desirable for a P_8 pedestrian actuation to call pedestrian Phases 8 & 7 and time the appropriate pedestrian intervals over both Phases 8 and 7 (Figure 4-5c).

Operating Both Three and Four Phase Control Logic

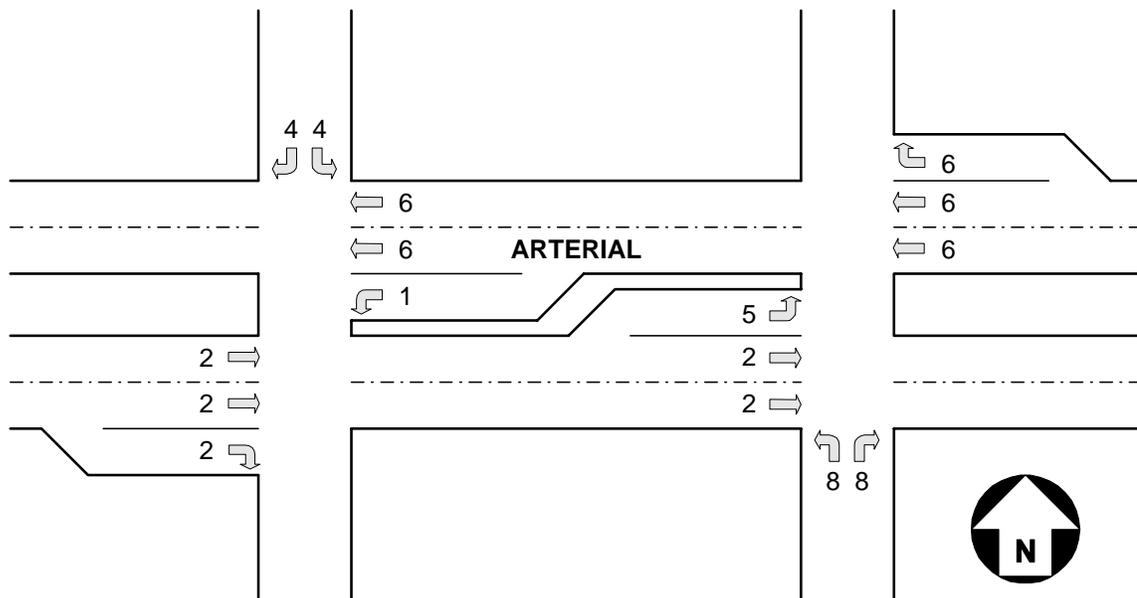
As long as there are no interior storage problems, 3-Phase operation tends to have slightly lower delay. It also makes it easier to obtain two-way progression bands on the arterial. Consequently, some agencies have used 4-Phase operation during peak periods and switch to 3-Phase operation during the off-peak or late night hours. Although there are some driver expectancy concerns when phase sequences are changed by Time-of-Day (TOD), such a procedure is often times more efficient.

The ring structure for 3-Phase operation uses six phases (Figure 4-2c) while the ring structure for 4-Phase operation uses eight phases (Figure 4-5c). If an agency would like to implement a diamond control procedure that uses both 3-Phase and 4-Phase control, changeable by Time-of-Day (TOD), then a controller with 14 phases would be desirable. Six of the phases would be used to code 3-Phase logic, while eight phases would be used to code the 4-Phase logic. A coordination or Time-of-Day (TOD) plan is used to selectively omit the phases not required. Hence, if phases and ring structures are carefully organized and programmed, then it would be possible to implement a ring structure that permits switching between 3-Phase and 4-Phase operation with only 12 phases, by using two of the phases in both of the operations.

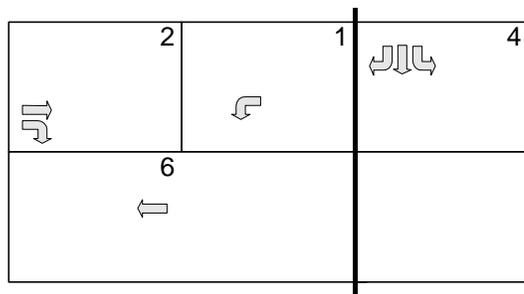
Conclusions and Implementation Issues

This paper has documented the issues associated with actuating both 3-Phase and 4-Phase (TTI) operation. It also presented the conceptual ring structure and the detector mapping necessary to successfully implement these operations. Although several traffic controller vendors have developed proprietary controller configurations for implementing actuated diamond control, none have been widely accepted, since each vendor typically has their own unique set of terminologies and assumptions. Hence, the hardware-in-the-loop simulation was used to aid in the analysis of such parameters and functionalities, as will be seen in the following chapter.

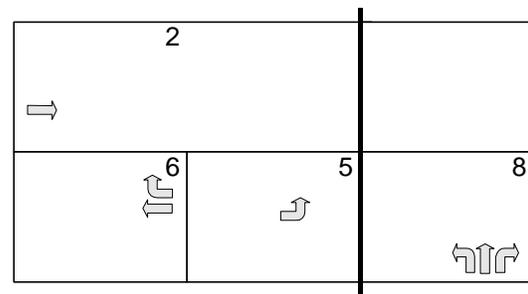
The material presented in this chapter is in a vendor neutral format, which should be helpful to the profession by providing a consistent ring structure and terminology that can be used for designing and implementing diamond intersection control on any NEMA TS II controller. All NEMA TS II controllers can implement the 3-Phase configuration shown in Figure 4-2c, and most can implement any of the four configurations shown in Figure 4-2b to Figure 4-2e. All NEMA TS II controllers can implement the 4-Phase configuration shown in Figure 4-5a, however some may have difficulty matching the numbering depicted in Figure 4-5b. Most vendors allow the sequence of phases in their rings to be restructured and can successfully implement the 4-Phase configuration as shown. However, some controllers may require the remapping of some phases.



a) Diamond Interchange Phase Mappings (Separate Controllers)

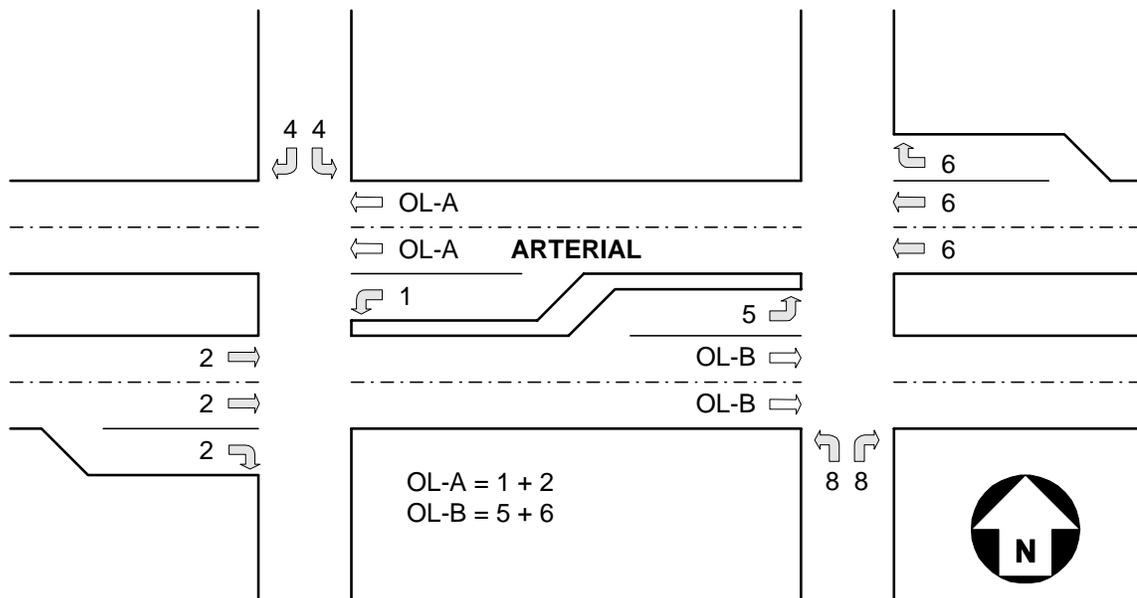


b) Ring Structure for Left Intersection

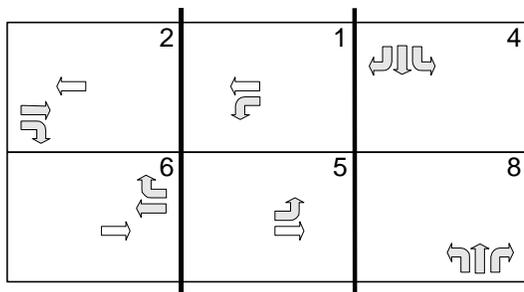


c) Ring Structure for Right Intersection

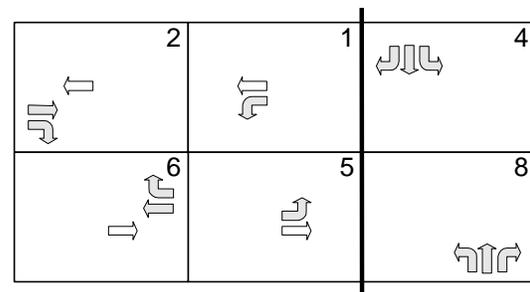
Figure 4-1: Interchange Phasing and Ring Structures – Separate Controllers



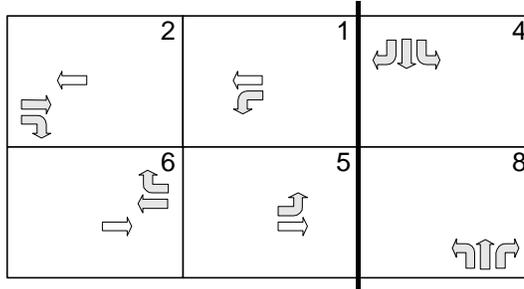
a) Diamond Interchange Phase Mappings (Single Controller)



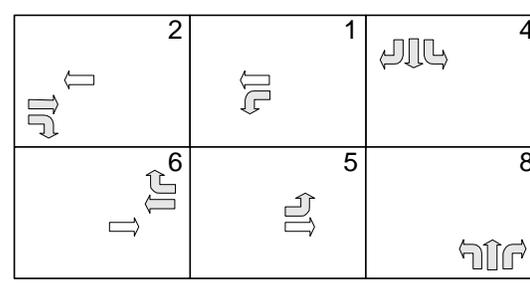
b) Three Phase Ring Structure (3 Barriers)



c) Three Phase Ring Structure (2 Barriers)



d) Three Phase Ring Structure (1 Barriers)



e) Three Phase Ring Structure (No Barriers)

- Grey Arrows: Indications Driven by a Phase
- Hollow Arrows: Indications Driven by an Overlap

Figure 4-2: Interchange Phasing and Ring Structures for 3-Phase Operation

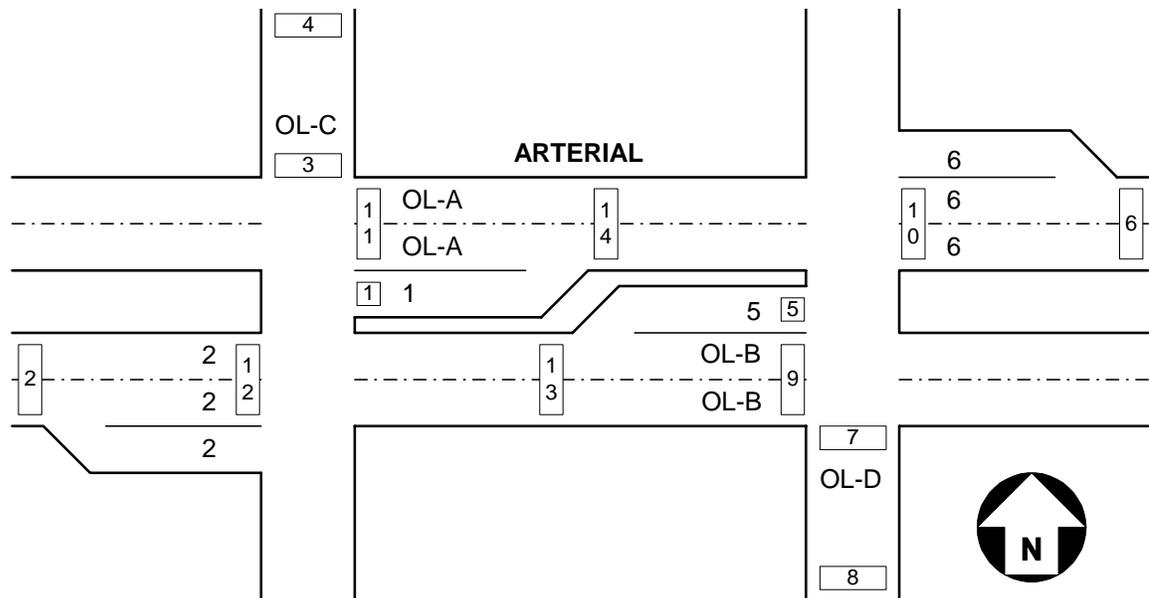


Figure 4-3: Diamond Detector Layout - Single Controller (3 & 4-Phase Control)

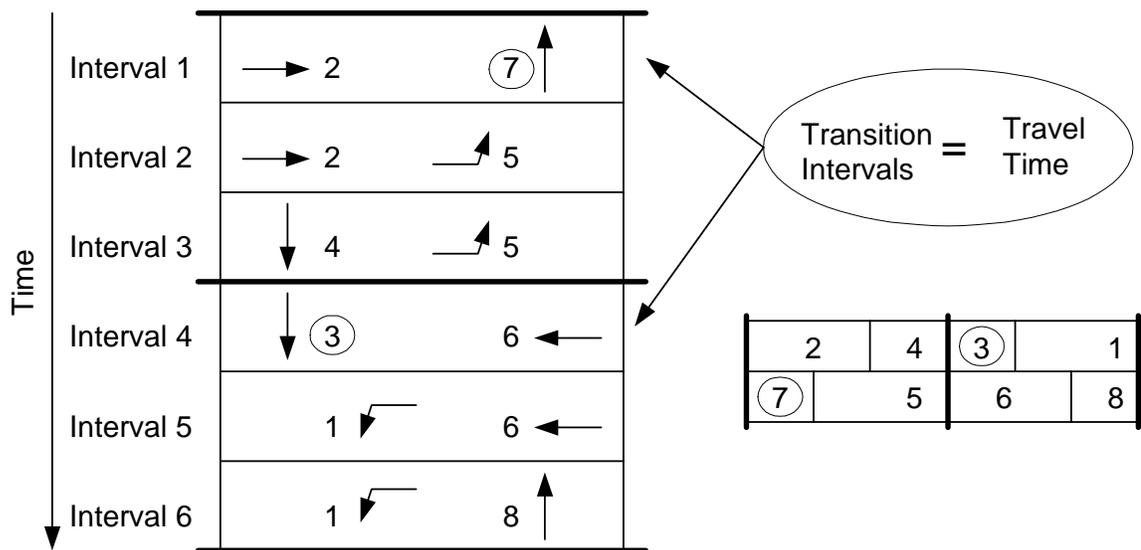
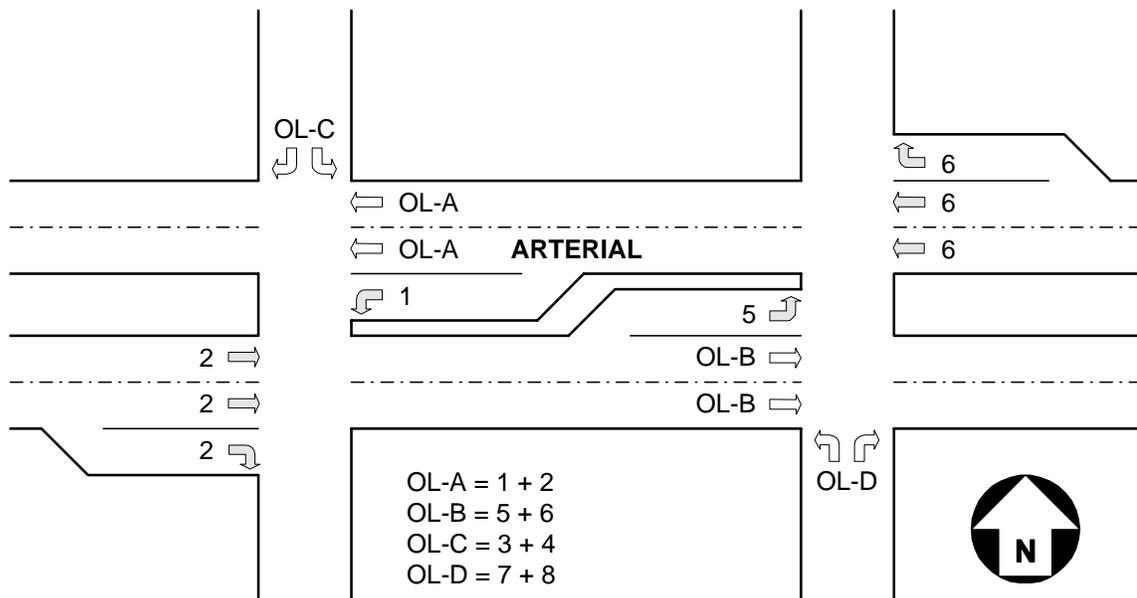
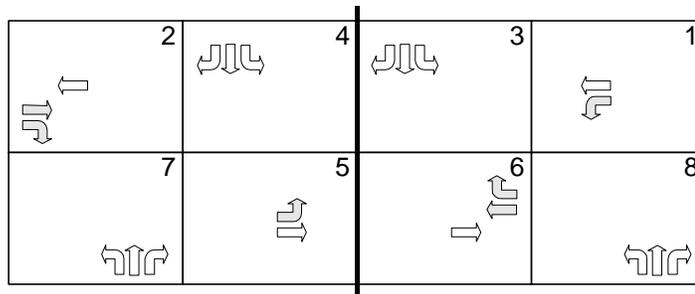


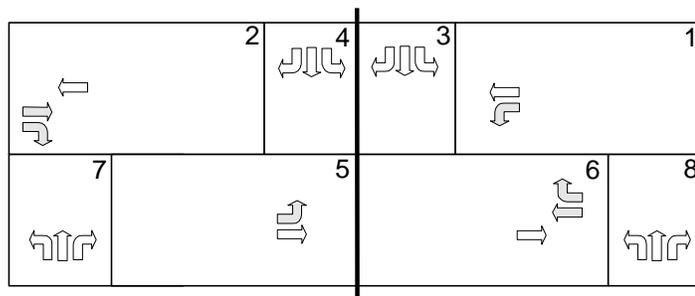
Figure 4-4: The Green Intervals of 4-Phase Operation (Single Controller Only)



a) Diamond Interchange Phase Mappings (Single Controller)

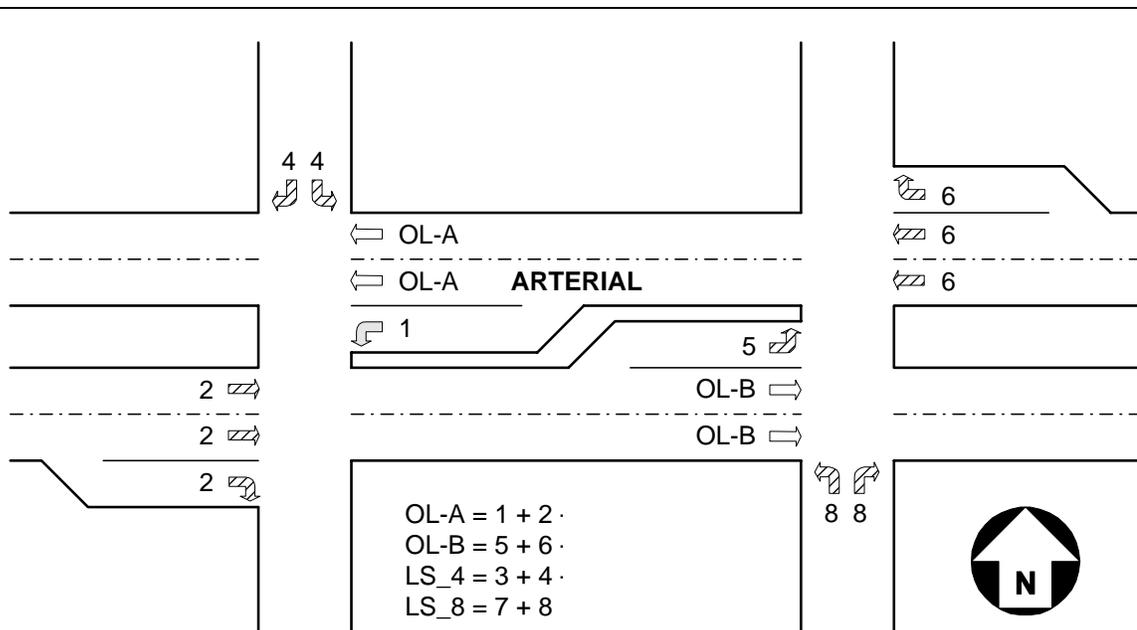


b) Ring Structure for 4-Phase Operation



c) Ring structure with Typical Phase Timings

Figure 4-5: Interchange Phasing and Ring Structures – (4-Phase Operation)



- OL-C is Mapped to Load Switch 4
- OL-D is Mapped to Load Switch 8

Figure 4-6: Load Switch Outputs - Single Controller (4-Phase Operation)

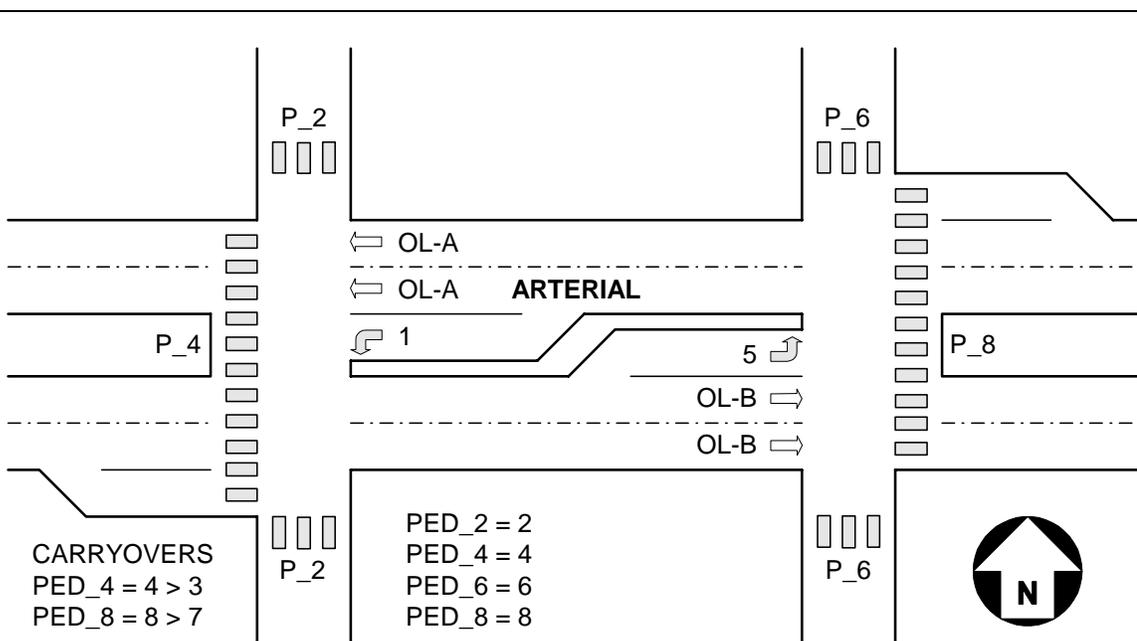


Figure 4-7: Diamond Pedestrian Control for a Single Controller

DETECTOR TYPE	DESCRIPTION
STANDARD (NORMAL)	NORMAL EXTEND / CALLING DETECTOR (CALLS DURING GREEN ARE EXTENDED IF TIME IS PROGRAMMED).
STOP BAR	CALLING DETECTOR (PLACES CALL ONLY DURING RED WHICH IS HELD UNTIL THE DETECTION ZONE IS EMPTY).
STOP BAR W/ EXTEND	SAME AS ABOVE HOWEVER THE CALL IS DROPPED ONLY AFTER THE EXTEND TIMER (RESET) TIMES OUT.

Table 4-1: Detector Type Information for all Operations

DET	NUM	1	2	3	4	5	6	7	8	OPR	DETECTOR TYPE
1_S	1	X								N/L	STANDARD (NORMAL)
2_S	12		X							N/L	STOP BAR
2_A	2		X							N/L	STANDARD (NORMAL)
5_S	5					X				N/L	STANDARD (NORMAL)
6_S	10						X			N/L	STOP BAR
6_A	6						X			N/L	STANDARD (NORMAL)
A_S	11		X							N/L	STOP BAR
A_A	14		X							N/L	STANDARD (NORMAL)
B_S	9						X			N/L	STOP BAR
B_A	13						X			N/L	STANDARD (NORMAL)
C_S	3				X					N/L	STOP BAR
C_A	4				X					N/L	STANDARD (NORMAL)
D_S	7								X	N/L	STOP BAR
D_A	8								X	N/L	STANDARD (NORMAL)

NOTE: N/L INDICATES DETECTORS DO NOT LATCH OR LOCK THE CALL.

NOTE: ALL DETECTORES ARE NON-LOCKED AND RUN IN PRESENCE MODE.

Table 4-2: Detector Assignments for 3-Phase Control – Single Controller

DET	NUM	1	2	3	4	5	6	7	8	OPR	DETECTOR TYPE
1_S	1	X								N/L	STOP BAR W/ EXTEND
2_S	12		X							N/L	STOP BAR
2_A	2		X							N/L	STANDARD (NORMAL)
5_S	5					X				N/L	STOP BAR W/ EXTEND
6_S	10						X			N/L	STOP BAR
6_A	6						X			N/L	STANDARD (NORAML)
A_S	11	X	X							N/L	STOP BAR
A_A	14		X							N/L	STANDARD (NORMAL)
B_S	9					X	X			N/L	STOP BAR
B_A	13						X			N/L	STANDARD (NORMAL)
C_S	3			X						N/L	STOP BAR W/ EXTEND
C_A	4			X	X					LOCK	STANDARD (NORMAL)
D_S	7							X		N/L	STOP BAR W/ EXTEND
D_A	8							X	X	LOCK	STANDARD (NORMAL)

NOTE: ALL DETECTORS RUN IN PRESENCE MODE.

NOTE: N/L INDICATES DETECTORS DO NOT LATCH OR LOCK THE CALL.

Table 4-3: Detector Assignments for 4-Phase Operation – Single Controller

CHAPTER 5 – HARDWARE CONFIGURATION FOR SINGLE CONTROLLER DIAMOND INTERCHANGES

Chapter Overview

As discussed in the previous chapter, diamond interchanges are an area of major concern and coordination between the ramps, particularly during the peak periods, is crucial in order to ensure safe and efficient operation. Modeling these interchanges with a simulation package, such as CORSIM, is not possible since each intersection in the model would require its own controller. This study looked at running the diamond using a single controller so that both 3-Phase and 4-Phase (TTI) operation can be analyzed. Since CORSIM can not model both ramps as one, hardware-in-the-loop analysis was used to more accurately model the interchange as a single entity. This procedure allows one to configure the geometric layout of the interchange in CORSIM so that both ramps can be controlled using the methodologies previously discussed.

Hardware-in-the-loop simulation is exactly as the name implies, hardware in the middle of a loop that links the simulation (CORSIM), to the actual control equipment, as discussed in Chapter 3. This hardware, which allows the communication to occur, is commonly referred to as a Controller Interface Device (CID), which is shown in Figure 5-1. The CID is responsible for reading in the simulated detector calls, and mapping them to the appropriate detector inputs on the control equipment. For this study, there was one CID that was linked directly to the controller itself. This is commonly referred to as “direct connect” since all the components inside the controller cabinet are bypassed. The example shown

in Figure 5-1 is “direct connect” since the CID is directly linked to the traffic signal controller. Notice how there are no other components in the figure.

The other approach for linking up the CID is shown in Figure 5-2. Notice however, that in this case each of the individual I/O's (Input/Output) are linked directly to the appropriate pins on the cabinet backpanel. The backpanel is then linked to the controller, which would produce the same results as the “direct connect” procedure shown in Figure 5-1. In both cases, the CID is essentially responsible for reading in the detector calls from the simulation and then sending back the phase indications (from the controller) to the appropriate approaches within the model. Such a procedure essentially fools the control equipment into thinking that it is running the actual intersection on the street, where in reality it is just controlling the simulation, which is simply a model of conditions on the street.

Diamond Case Studies

For this research there were two case studies that were conducted using the actual volumes and turning percentages at each of the interchanges. Both studies, used the hardware-in-the-loop simulation, which modeled each of the ramps as one entity (single controller). This was done so that both the 3-Phase and 4-Phase operations can be analyzed. Recall that the general logic behind these operations, and when to use them was discussed in the previous chapter. This section will focus on explaining the setup and configuration that was used to configure an interchange of this type and give some case studies where the diamond control logic was applied.

The case studies used for this research include SR 26 (South) at JCT I-65 in Lafayette, IN and SR 37 (Harding) at JCT I-465 in Indianapolis. For both studies the actual geometric layout and detector locations were implemented in the model. The spacing between these interchanges was 780 and 450 feet,

respectively. The SR 26 (South) interchange was analyzed first and then the same study was performed in Indianapolis on SR 37 (Harding) interchange due to the tighter spacing. Since only one controller was used for these studies, only one CID was required. Passer III-98 (TTI), was used to generate the timing plans for all the interchanges that were studied. There were many TTI (Texas Transportation Institute) 3-Phase and 4-Phase scenarios that were analyzed using a variety of cycle lengths.

Hardware-in-the-Loop Configuration

This section will focus of configuring the hardware to run variations of the 3-Phase and 4-Phase (TTI) logic with the actual control equipment linked to CORSIM. Figure 5-3 shows a typical diamond configuration (network) that was used for analysis. In this case the spacing was 500 feet, however, this can vary and have no impact on the actual hardware configuration. Figure 5-4 shows the basic geometric layout for each of the junctions. For this case there are dual left-turns off the ramps and single left-turn lanes on the arterial. Notice the placement of the detectors when examining these figures.

As discussed in the pervious chapter, Figure 5-5 shows the phase numbering used to operate the interchange with separate controllers while Figure 5-6 shows the configuration necessary to run the interchange with a single controller only (3-Phase). Notice that for the second case the interior through movements were replaced with overlaps since each phase can only be used once. This is also apparent in Figure 5-7, which shows the phasing diagrams for each of the cases. Also, notice the squares around the numbers on the arterial. This represents a single entry protected only operation, which indicates that vehicles can only make a left-turn on a green arrow only. The ramp phases are placed inside a circle indicating a standard dual-entry operation, however in this

case there is no parent dual entry phase since the opposing through movement does not exist.

The phasing and left-turn types can also be validated by examining the ring structures shown in Figure 5-8 for each of the scenarios. Looking at both figures, it can be seen that the left turns are protected-only simply because there are no dashed left arrows that appear in Phases 2 or 6. This indicates that left turns are not permitted during the green interval, and can be verified by examining either part of Figure 5-8 (a or b). Notice that both intersections in this figure have two rings (rows) that make up the structure. However, in Figure 5-8a it takes two rings for a single junction, while in Figure 5-8b it is accomplished using a single ring, with each ring representing a juncture at the interchange. The top ring seen in Figure 5-8b is for the left junction while the bottom ring is for the right junction. This is apparent when examining Figure 5-7. The hollow arrows found in Phases 2 and 6 represent the overlaps that are being used to replace the second ring in both parts of Figure 5-8a.

Figure 5-9 shows the approach labels that are needed for the configuration of the CID file that is shown in Figure 5-10. This file tells CORSIM which approaches use the phase indications that are read back from the controller via the CID. As seen from this file, the phase indications are referenced by the node (found in Figure 5-9), the approach number (also shown in this figure), the type of movement (left, through, or right), and finally, the phase type (protected, permitted, protected-permitted). For example, looking at the first line (under phases) it can be seen that the Eastbound through and right movements for Node 2, Approach 1 are tied to controller Phase 2 which is protected-only. This process continues down the list.

Following this format, it can be seen that Approach 2 at Node 2 consists of both a left and a through movement. Looking at Figure 5-10 it can be seen that

both movements are protected-only and are tied to Phases 1 and 9, respectively. Note here that Phase 9 actually represents Overlap A while Phase 10, found at the through movement for Node 3, Approach 1, represents Overlap B. When examining Node 2, Approach 3, it can be seen that the Southbound ramp movement consists of a left, through, and right movement. Notice again how all of these movements are protected-only and are tied to Phase 4. This same procedure applies to all of the approaches for Node 3 as well. Looking down this list it can be seen that the phasing exactly matches that shown in Figure 5-7b.

From the file shown in Figure 5-10, it can also be determined that communication is occurring through COM 2, while CID 1 has a Base ID address of 1. Recall that one CID is needed for each controller in the network. Since only one CID is required for this study, the Base ID address was simple to configure. Generally each CID requires two ID addresses, one for the Phase Group (Output) and the other for the Detector Group (Input). Hence this CID would use ID addresses 1 and 2 with the Base ID being Number 1. If other CID's were needed, the Base ID addresses would typically increase in increments of two (1, 3, 5, etc), since each CID requires two independent addresses. This is better illustrated in upcoming chapters. Notice that Nodes 2 and 3 are linked to CID 1. This allows both junctions to be controlled by the same controller.

External Detector Configuration and Examples

Figure 5-11 shows the complete detector configuration and numbering for both of the junctions. If one eventually wished to run both 3-Phase and 4-Phase operation, then all of the detectors shown in the figure would be highly recommended. Realize that all of these detectors are actuated in real-time as they each have their own output to the external equipment. Figure 5-12 shows how each of these detectors are referenced in CORSIM. Record Type 42 is reserved for external detectors. Looking at the files, the first two columns make

up the link while the third number designates the location of the detector. The Number 7 (Column 3) means that the detector is located in a left-turn lane while the Number 8 indicates that the detector is located in a through lane. The fourth column indicates the setback distance for the detector in tenths of feet. Those rows without a number indicate that the detector is located at the stopbar.

The fifth column of Figure 5-12 represents the detector station number. It can contain up to four numbers ranging anywhere from 101 to 9999. Realize that the first two numbers represent which CID the detector is assigned to, while the second two numbers indicate the assigned input on the CID that the detector will communicate with. The CIDs used for this study hold up to 32 detectors, however only the first 20 can be used under the Mode 2 of the NEMA TS II Type 1 specification used for this research. Since no more than seven intersections were modeled with the hardware-in-the-loop-simulation, the typical range may be between 101 and 720. Therefore all station numbers are three digits, rather than four (as seen in Figure 5-12), since there are less than 10 CIDs that were used for all of the study locations.

Looking at Figure 5-12, it can be seen that all of the station numbers in column five begin with the Number 1. This is expected since there was only one CID used for the interchange. The sixth column represents the length of the detector. However, like the setback distance, this number is also in tenths of feet. The last and final column (7), which appears after the detector length, indicates the operational mode of the detector. A blank at this location represents presence mode while a Number 1 indicates that the detector is operating in pulse mode. When examining Figure 5-12, it can be seen that all detectors run in presence mode since the Number 1 is not present for any of the detectors after the detector length column.

In order to help recap this information, the first line in Figure 5-12 will be examined. Reading this line, the code indicates that the through detector Number 2 has a setback distance of 300 feet and is assigned to CID 1. The length of the detector is 6 feet and runs in presence mode. Looking at Figure 5-11a, this detector can be easily identified. Following this same procedure with the second line of Figure 5-12, it can be seen that through detector Number 12, has no setback distance, which means that it is located at the stopbar. It can also be determined that this detector is assigned to CID 1 and has a length of 36 feet. Like all of the other detectors shown in this file, it also runs in presence mode. The remainder of the detectors shown in Figure 5-11 can be located (Figure 5-12) by following this very same procedure.

The last two lines (Record Type 43) in Figure 5-12, show how the approach labels (Figure 5-9) are determined. The first number represents the corresponding node, while the remainder of the pairs identify the approach labels. Thus, the first pair (1-2) is Approach 1, while the next pair (3-2) is Approach 2, and the last pair (5-2) is the third approach for Node 2. Looking at this record type it can be seen that there are only three pairs for each node. This makes sense since there are only three approaches for each junction of a diamond interchange. Notice how they match up with the approach labels shown in Figure 5-9. Realize that these approach labels can be changed by simply changing the order of the pairs shown for the relative node of Record Type 43.

Interchange Configuration and Detector Settings

Table 5-1 shows the turning bay pocket lengths along with the length of all stopbar detectors by lane group (left, through, right). It also shows the length of the raceway detectors along with the relative distance that they are setback from the stopbar. Notice how this information matches that found in both Figure 5-11 and the coding in Figure 5-12, which was just discussed. Table 5-2 shows all of

the detectors along with the relative station identification number and the mode that each detector is operating in. For this study the detector numbers are essentially the station identification number without the CID reference number (1). Again, notice that all detectors run in presence mode.

Table 5-3 shows the configuration for each of the detectors that are shown in Figure 5-11. Included in this table is the detector number, operational mode (locking or non-locking detection), detector delay, along with the relative phases that they call. The detector type or operational specification is also documented in this table. From this table it can be seen that the raceway detectors are all normal detectors that operate in non-lock mode. The stopbar detectors on the ramp, along with the left-turn detectors, operate as stopbar detectors with an extension timer so that they do not drop the calls until after a sufficient gap in traffic has been detected. A standard stopbar detector, which is the remainder of the detectors shown in this table, would drop the call the instant the first gap in traffic was detected.

Detectors 4 and 8 are in lock mode so that the relative phases can be called during 4-Phase operation. Under 3-Phase control, these detectors operate as standard extension detectors once Detectors 3 or 7 time out. See the previous chapter for further information about these detector configurations. Table 5-4 shows the general timing parameters that were used for the 3-Phase control while Table 5-5 shows the timing plan that was used for the volume scenario shown in Figure 5-3. All of these parameters are programmed directly into the traffic controller. Recall that these parameters were discussed in previous chapters. After reviewing this chapter it will become apparent that Table 5-1 to Table 5-5 summarizes all the phasing and detector information found in Figure 5-10 to Figure 5-12.

Recap of Real-Time Control Concepts

Based on the concepts discussed in this chapter, one should realize that a vehicle traveling Eastbound towards the interchange will first hit Detector 2 which is tied to Phase 2, as seen from Table 5-3. Next the vehicle would hit Detector 12, which should be deactivated if the light is green, since it is a calling detector only. Once it clears the left diamond, it will cross raceway Detector 13 which calls Phase 6 (Table 5-3). Realize that Phase 6 is called since the interior through movement at the right junction is Overlap B. Since detectors can not call overlaps, Phase 6 is called which thereby holds the overlap. Lastly this vehicle would cross Detector 9, which is again deactivated if the light is green, at which time the vehicle would have cleared the interchange.

Using this Eastbound path just examined, and looking at Figure 5-9, it can be seen that this vehicle will be using Node 2, Approach 1 and Node 3, Approach 1. Looking at Figure 5-10 it can see that the vehicle will view the Phase 2 signal at the left junction, and the Overlap B signal at the right junction. Had the vehicle decided to turn left at the right junction it would have instead put a call in Detector 5 which is tied to Phase 5. Since Phase 5 is protected only, the vehicle would be required to wait for an arrow since it is left-on-green arrow only. Looking at Figure 5-11 it can be confirmed that the vehicle would cross mainline Detectors 2, 12, 13, and 9 or 5.

Concluding Remarks

This concludes both the hardware and software configuration that was used for this study. Future sections will build on these hardware-in-the-loop concepts, in order to analyze more complicated networks that use procedures similar to those discussed herein. The following chapter will examine the hardware configuration that was used to analyze the impact evaluation of emergency vehicle preemption on signalized corridor operation, recognizing that

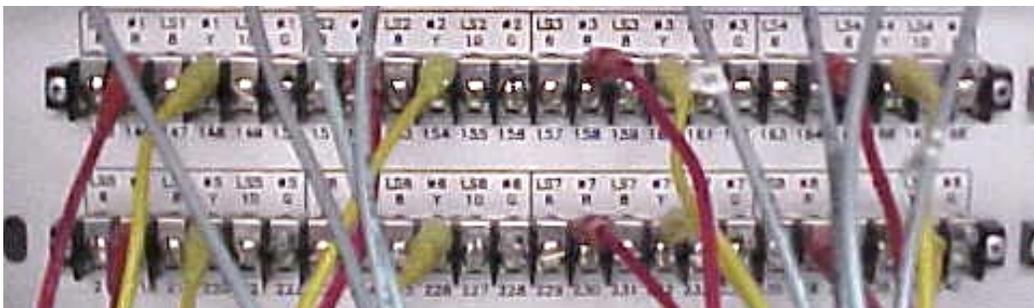
this network also includes a diamond interchange, which applies much of the same logic that was discussed in this chapter. Note that questions regarding the operational configuration of the diamond are answered in the previous chapter.



Figure 5-1: Direct Connect Procedure (No Control Cabinet Required)



a) CID and Signal Controller (No Feasible Connection)



b) Controller Cabinet Backpanel (Must Connect Clips Here)

Figure 5-2: Backpanel Mount Procedure (Requires Controller Cabinet)

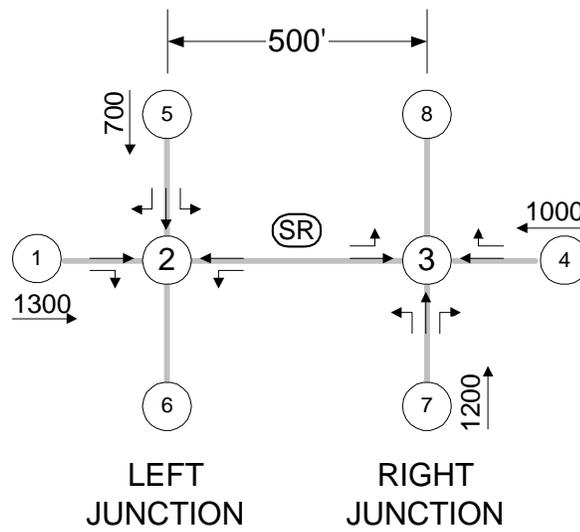
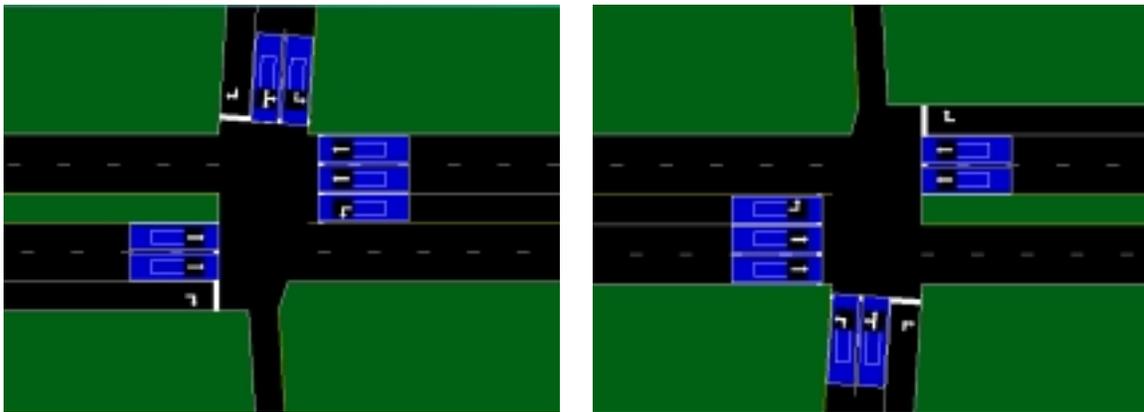


Figure 5-3: System Entry Volumes (Sample Diamond Interchange)



a) Node 2: General Diamond (Left Junction)

b) Node 3: General Diamond (Right Junction)

Figure 5-4: Diamond Interchange Geometrics and Detector Locations

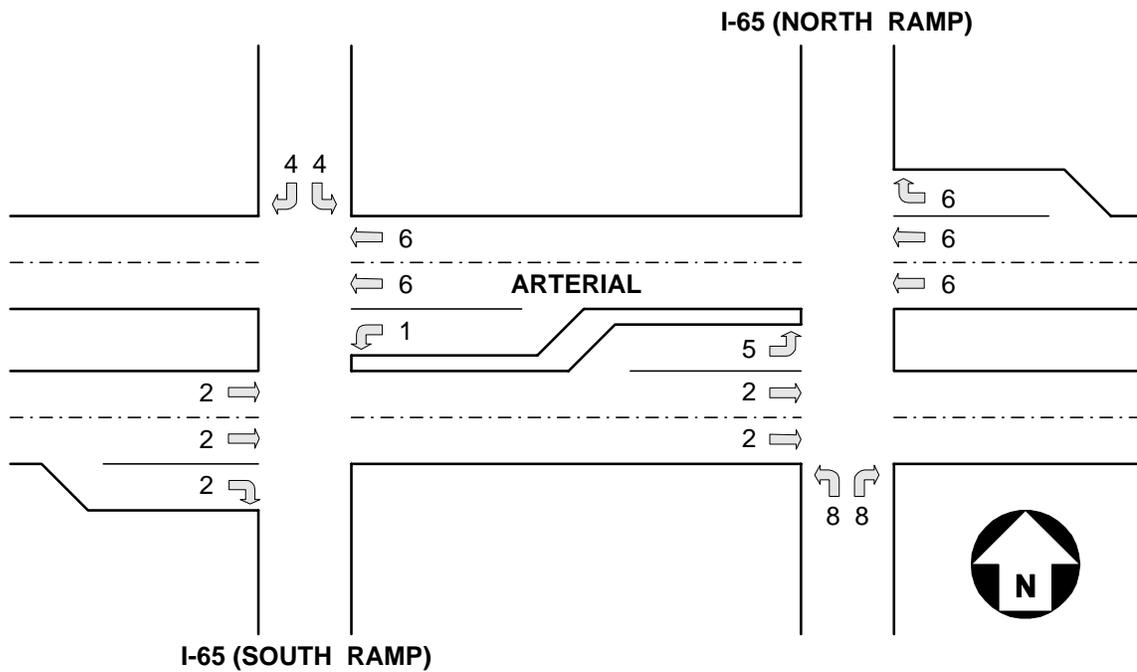


Figure 5-5: Diamond Interchange Phasing - Separate Controllers

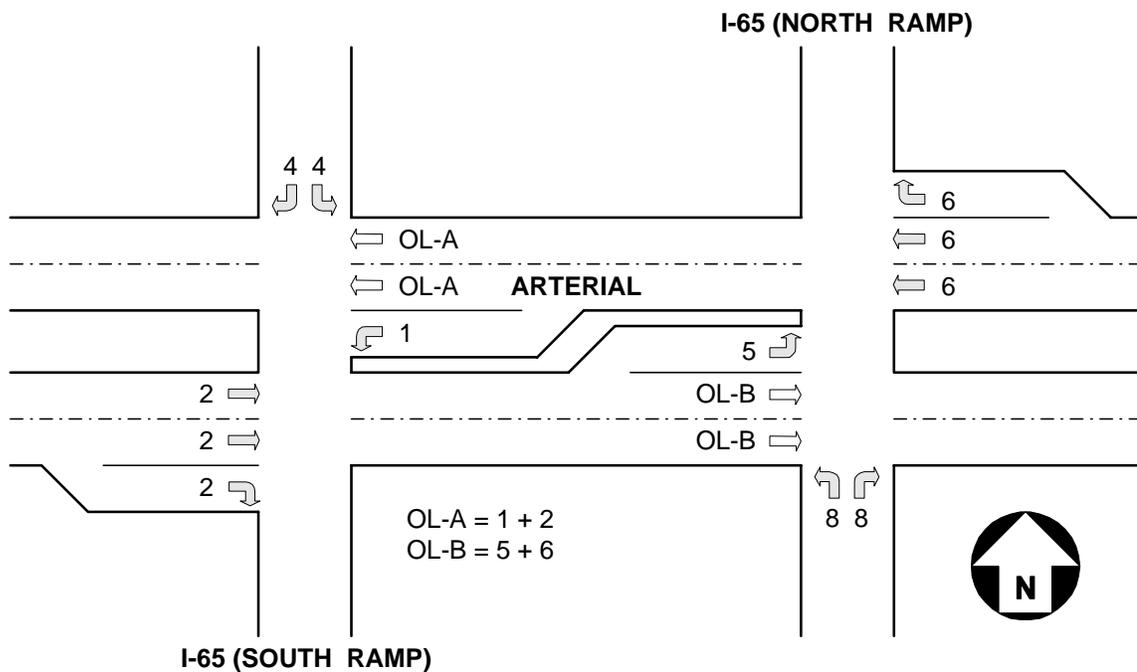
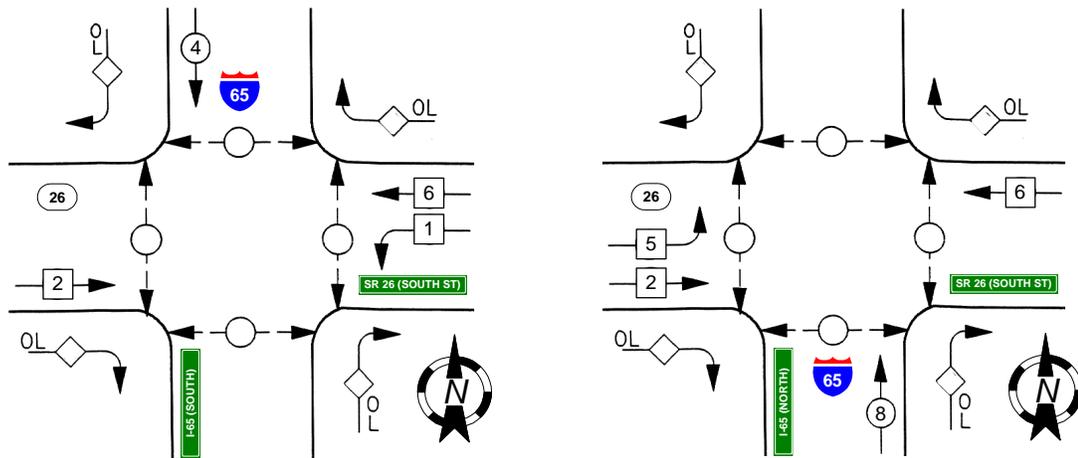
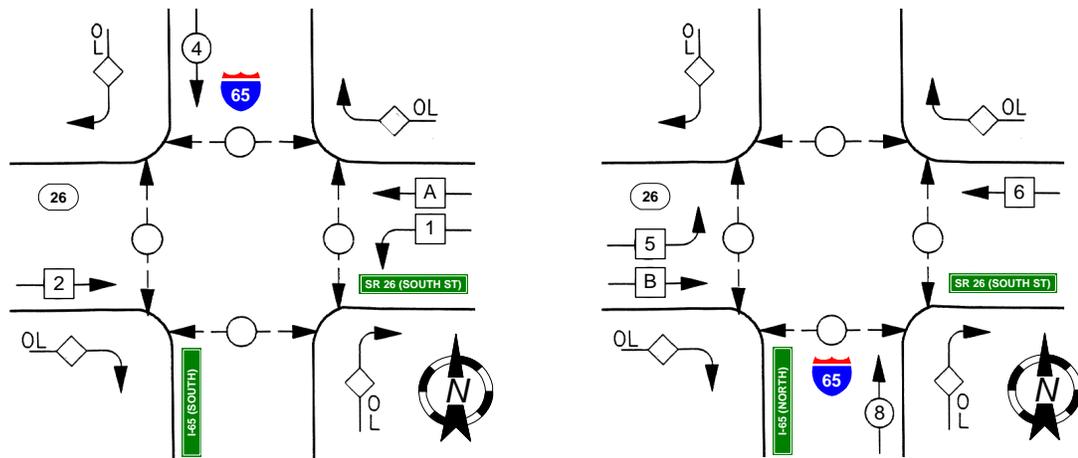


Figure 5-6: Diamond Interchange Phasing - (3-Phase Operation)

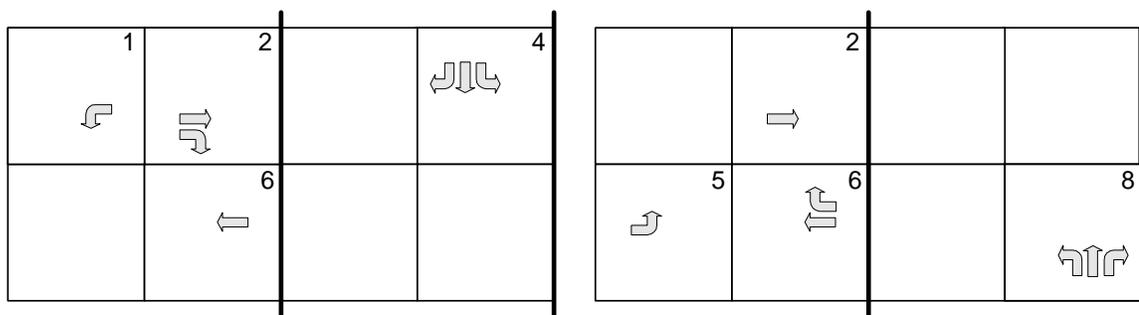


a) Interchange Phasing for Separate Controllers

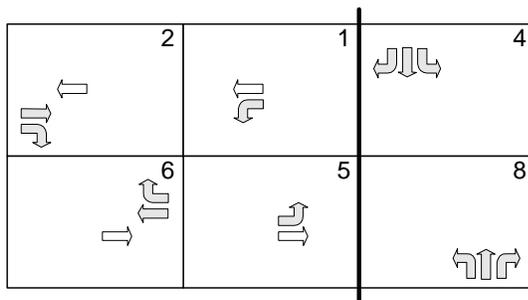


b) Interchange Phasing for a Single Controller

Figure 5-7: Typical Diamond Interchange Phasing Diagrams



a) Interchange Ring Structure with Separate Controllers



b) Interchange Ring Structure with a Single Controller

Figure 5-8: Typical Diamond Interchange Ring Structures

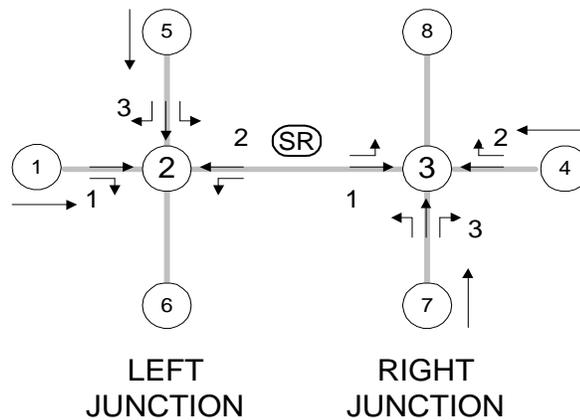
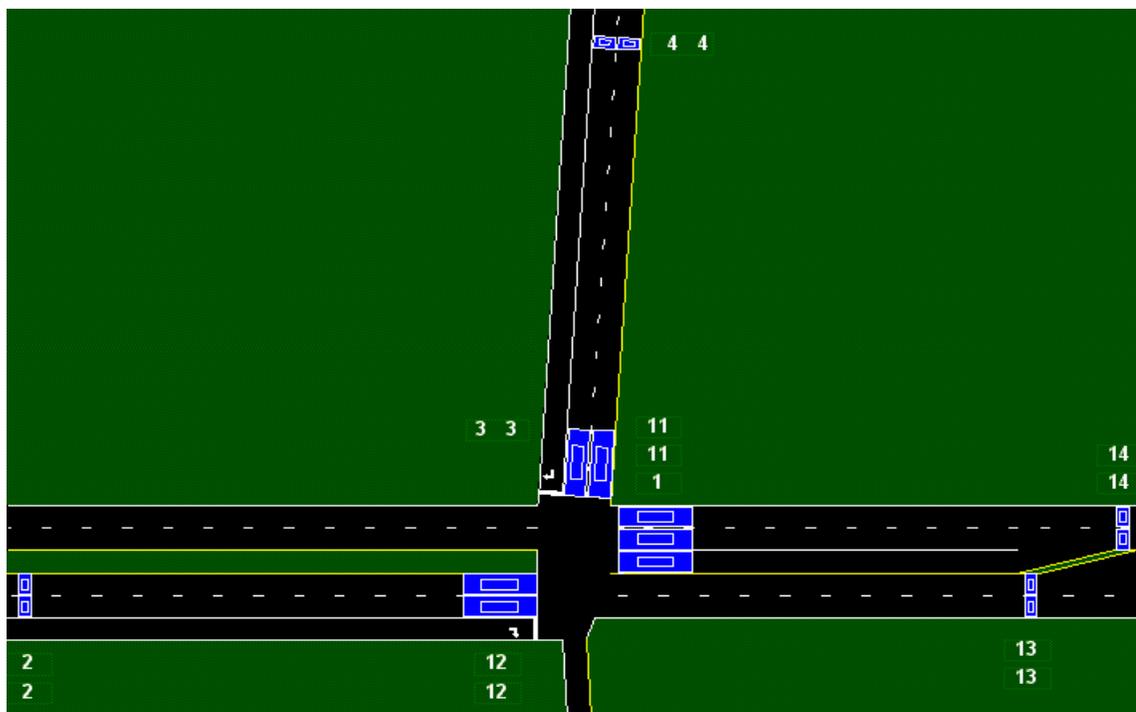


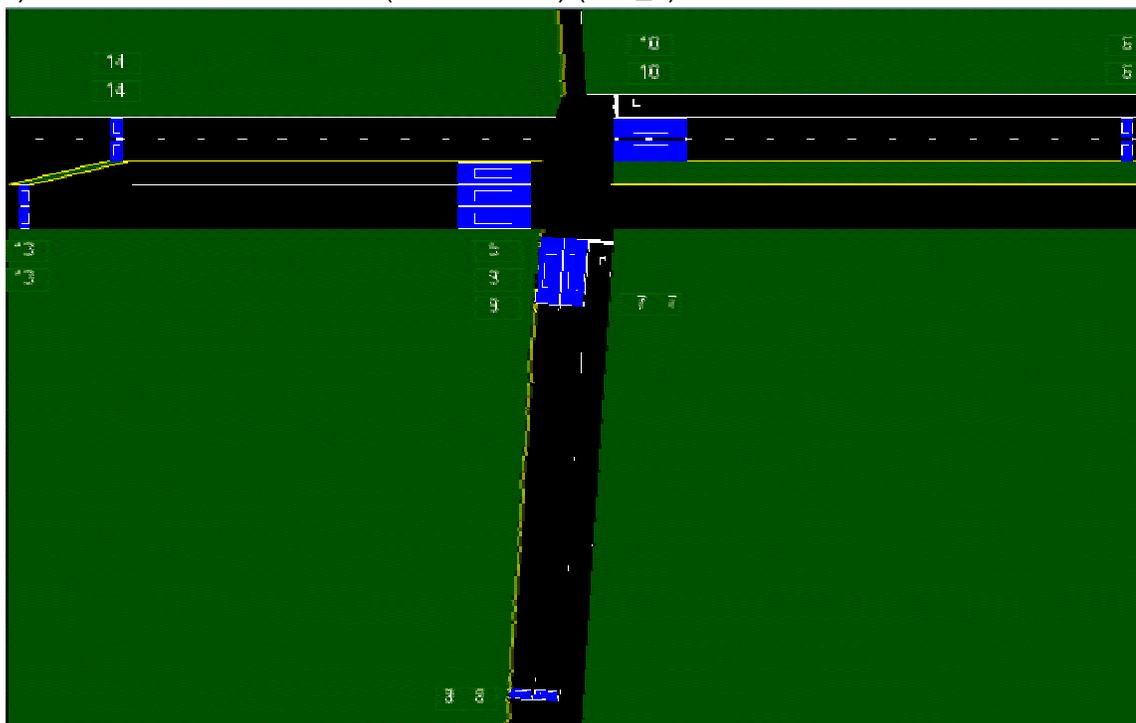
Figure 5-9: Intersection Approach Labels (Diamond Interchanges)

COM [PortID]	2, 2, T, 9, Prot
2	2, 3, L, 4, Prot
CIDdef [CID, Base ID]	2, 3, T, 4, Prot
1, 1	2, 3, R, 4, Prot
NodeAssign[Node, CID]	3, 1, L, 5, Prot
2, 1	3, 1, T, 10, Prot
3, 1	3, 2, T, 6, Prot
Phases [Node, Approach, L/T/R,	3, 2, R, 6, Prot
Phase#, Pro/Per/PP]	3, 3, L, 8, Prot
2, 1, T, 2, Prot	3, 3, T, 8, Prot
2, 1, R, 2, Prot	3, 3, R, 8, Prot
2, 2, L, 1, Prot	

Figure 5-10: External Control File (CID) for Phasing (General Diamond)



a) Node 2: General Diamond (Left Junction) (CID_1)



b) Node 3: General Diamond (Right Junction) (CID_1)

Figure 5-11: Diamond Detector Locations and Numbering

1	2	8	3000	102	60					42
1	2	8		112	360					42
2	3	8	3000	113	60					42
2	3	8		109	360					42
2	3	7		105	360					42
3	2	8	3000	114	60					42
3	2	8		111	360					42
3	2	7		101	360					42
4	3	8		110	360					42
4	3	8	3000	106	60					42
5	2	8	2450	104	60					42
5	2	8		103	360					42
7	3	8	2450	108	60					42
7	3	8		107	360					42
2	1	2	3	2	5	2				2 43
3	2	3	4	3	7	3				2 43

Figure 5-12: Sample External Detector File (General Diamond)

GENERAL DIAMOND		POCKET LENGTHS (FT)		STOP BAR DETECTOR LENGTHS (FT)			RACEWAY DETECTORS (FT)	
INT	MOVE	LEFT	RIGHT	LEFT	THRU	RIGHT	THRU	DIST
2	EB	--	320	--	36	--	6	300
2	WB	200	--	36	36	--	6	300
2	SB	--	350	36	--	36	6	245
3	EB	200	--	36	36	--	6	300
3	WB	--	320	--	36	--	6	300
3	NB	--	350	36	--	36	6	245

NOTE: "PREV" DENOTES THAT THE TURNING BAY BEGINS AT THE PREVIOUS INTERSECTION.

Table 5-1: Intersection Pocket Lengths and Detector Locations

INT	MOVE -MENT	DET NUM	STAT ID	PUL PRS	INT	MOVE -MENT	DET NUM	STAT ID	PUL PRS
2	EBTH	2	102	PRS	3	EBLT	5	105	PRS
2	EBTH	12	112	PRS	3	EBTH	13	113	PRS
2	WBLT	1	101	PRS	3	EBTH	9	109	PRS
2	WBTH	14	114	PRS	3	WBTH	6	106	PRS
2	WBTH	11	111	PRS	3	WBTH	10	110	PRS
2	SBLT	4	104	PRS	3	NBLT	8	108	PRS
2	SBLT	3	103	PRS	3	NBLT	7	117	PRS

NOTE: INTERSECTION 2 & 3 DETECTORS ARE TIED TO THE SAME CONTROLLER (DIAMOND).

Table 5-2: Intersection Detector Configuration (CID Logic Only)

INT	MOVE -MENT	DET NUM	LOCK / N-LCK	DELAY (SEC)	CALL PHASE	DETECTOR TYPE
2	EBTH	2	N-LCK	--	2	STANDARD (NORMAL)
2	EBTH	12	N-LCK	--	2	STOP BAR (CALLING)
2	WBLT	1	N-LCK	--	1	STOP BAR W/ EXTEND
2	WBTH	14	N-LCK	--	2	STANDARD (NORMAL)
2	WBTH	11	N-LCK	--	2	STOP BAR (CALLING)
2	SBLT	4	LOCK	--	4	STANDARD (NORMAL)
2	SBLT	3	N-LCK	--	4	STOP BAR W/ EXTEND
3	EBLT	5	N-LCK	--	5	STOP BAR W/ EXTEND
3	EBTH	13	N-LCK	--	6	STANDARD (NORMAL)
3	EBTH	9	N-LCK	--	6	STOP BAR (CALLING)
3	WBTH	6	N-LCK	--	6	STANDARD (NORMAL)
3	WBTH	10	N-LCK	--	6	STOP BAR (CALLING)
3	NBLT	8	LOCK	--	8	STANDARD (NORMAL)
3	NBLT	7	N-LCK	--	8	STOP BAR W/ EXTEND

Table 5-3: Interchange Detector Configuration (Controller)

INT	DESCRIPTION (SEC)	1	2	3	4	5	6	7	8
2,3	MINIMUM GREEN	3	15	--	7	3	15	--	7
2,3	VEHICLE EXTENSION	2.5	5.0	--	3.0	2.5	5.0	--	3.0
2,3	MAXIMUM GREEN	35	80	--	45	35	80	--	45
2,3	YELLOW CLEARANCE	3.5	3.5	--	3.5	3.5	3.5	--	3.5
2,3	RED CLEARANCE	1.0	2.0	--	1.5	1.0	2.0	--	1.5
2,3	MINIMUM GAP TIME	2.5	3.0	--	3.0	2.5	3.0	--	3.0

NOTE: NODES 2 & 3 (DIAMOND INTERCHANGE) ARE CONTROLLED BY A SINGLE CONTROLLER.

NOTE: THE MAXIMUM GREEN TIMES SHOWN IN THIS TABLE ARE INHIBITED UNDER COORDINATION.

Table 5-4: General Phase Parameters (SR 26 – South)

INT	COS	CYC	OFF	1	2	3	4	5	6	7	8	LAG
2,3	311	120	N/A	30	50	--	40	35	45	--	40	1,5

NOTE: NODES 2 & 3 (DIAMOND INTERCHANGE) ARE CONTROLLED BY A SINGLE CONTROLLER.

Table 5-5: Diamond Interchange Coordination Plans and Splits

CHAPTER 6 – HARDWARE CONFIGURATION FOR THE EMERGENCY VEHICLE PREEMPTION NETWORK

Preemption Network

This chapter will use some of the procedures previously discussed for diamond interchanges, and explain how the hardware-in-the-loop concept can also be used for evaluating the impact of preemption on a typical arterial network. The system used for this analysis is shown in Figure 6-1, which ranges from Progress Drive to Meijer Parkway on SR 26 (South) in Lafayette, IN. Figure 6-1a shows the midday volumes, while Figure 6-1b shows the afternoon volumes that were used for the study. Nodes 2 and 3, shown in Figure 6-1, make up the diamond interchange that was previously discussed. The relative spacing between each of the intersections can be found in Figure 6-1a.

Controller Configuration and Phasing

The geometric lane and detector configurations for each of the intersections in the system is shown in Figure 6-2, while the precise locations of the pockets and detector locations are identified in Table 6-1. It can be seen from Figure 6-2 that all the minor movements have the detectors located at the stopbar. The phasing (numbering) used for each intersection in the system can be seen in Figure 6-3 while the relative ring structures can be found in Figure 6-4 or Figure 6-5. The only difference between Figure 6-4 and Figure 6-5 is in part (b), which dictates the overall operation of the interchange. Figure 6-4b assumes that separate controllers are used at the diamond, while Figure 6-5b assumes that only a single controller is used to operate the interchange. This study used

one controller for the analysis and hence Figure 6-3 and Figure 6-5 best apply for both the phasing diagrams and ring structures, respectively.

Notice from Figure 6-3 that all arterial movements in the system, with the exception of Meijer Parkway use a protected only (single entry) type operation. This is designated by the squares around the associated phase numbers. Hence, all of the left-turning movements are permitted only on the green arrow. Meijer Parkway is a different case since Phases 1 and 5 are not used. This implies that left-turning traffic may only turn after yielding to the opposing traffic on the green light (permissive only). The circles around Phases 2 and 6 in Figure 6-3c represent a dual-entry type operation. This implies that both (parent) phases should always be up together irrespective of demand. Conversely the squares around Phases 4 and 8 in Figure 6-3c represent that a single entry type operation exists. Thus only one side street approach can be active at any given period of time. This is more commonly referred to as “split phase” operation, which becomes apparent after examining the ring structure shown in Figure 6-5c.

The Letter “A”, seen in the lower left corner of Figure 6-3c, designates a right-turn overlap. It can be active with either Phase 2 or 8, however the arrow is typically omitted while the green indication is active. The ring structure shown in Figure 6-5c, clearly shows this overlap as a hollow arrow which designates it as an overlap. The overlap used here is the same type that is used for the diamond interchange (single controller) shown in Figure 6-5b. Hence, Overlap A at Node 2 is concurrent with both Phases 1 and 2, while Overlap B at Node 3 is active with both Phases 5 and 6. This can be verified by examining the ring structure shown in Figure 6-5b. The circles surrounding numbers 3, 4, and 8 in Figure 6-3a, designate a dual-entry type operation. This means that a two concurrent phases should always be active within the concurrent group (either Phases 3 & 8 or Phases 4 & 8). The circles also indicate that any left-turn movements (Phase 3) on the minor street are protected-permissive. See Figure 6-5a to verify this.

Hardware-in-the-Loop Configuration

Figure 6-6 shows the approach labels that are needed in order to properly configure the controller interface device (CID) file, which links the controller equipment to the CORSIM simulation. Notice that the labels go East, West, North, and South for each of the nodes. This has to do with the order that the network was configured when it was constructed. Record Type 43 in Figure 6-9 contains the approach labels for each of the nodes. Given this coding scheme, all Eastbound approaches are Number 1 while all Westbound approaches are Number 2. The Northbound side street approach would be Number 3 if it exists, followed by Number 4 for the Southbound approach given that an Approach 3 exists. Hence the arterial was configured first (East to West), followed by the minor street (North to South).

The CID file, shown in Figure 6-7, tells CORSIM where to map each of the phase indications received from the controllers. As seen in Figure 6-7, both the node and the approach number are required in order to properly define the appropriate location in the model for relative phase indication. The Left (L), Thru (T), and Right (R) then defines the specific movement (on the specified approach) that the phase is linked to. Looking at the CID file, shown in Figure 6-7, it can be seen that there are three controllers and four nodes. This is apparent when looking under the CID definition (CIDdef) section of the file. Under this section it can be seen that there are three CIDs assigned to ID address 1, 3, and 5 respectively. The next section of Figure 6-7 (NodeAssign), shows which CID each of the nodes are assigned to. Hence, Node 1 is linked to CID 1, Nodes 2 and 3 are linked to CID 2 (Single Controller Diamond), while Node 4 is linked to CID 3.

Following the example from the CID file previously discussed in the diamond chapter, it can be seen from Figure 6-7 (first line under phases) that the Eastbound left-turn movement for Node 1, Approach 1 is tied to Phase 5 which is

protected only. Recall that the phasing can be verified by examining both Figure 6-3a and Figure 6-5a. For a vehicle traveling Eastbound through the system it can be seen that Nodes 1, 2, 3, and 4 will be traversed. Notice again how the Eastbound direction for all nodes have an Approach 1 label assigned to them. Hence, the Eastbound through movement for Node 1, Approach 1 is tied to controller Phase 2, which is protected only. Similarly, the through movement for Node 2, Approach 1 is tied to controller Phase 2, which is also protected only.

Examining Figure 6-7, one can see that the Eastbound movement for Approach 1, of the remainder of the intersections, is linked to Phase 10 for Node 3 and Phase 2 for Node 4. Again, both of these phases are protected only, while Phase 10 is also Overlap B as seen in Figure 6-3a or Figure 6-5a. Had the vehicle decided to turn right at Node 4, then the vehicle would obey Phase 9 which is right-turn Overlap A. This is quite apparent when examining the appropriate lines of Figure 6-7. The "Preempt 32 31 26" after Node 4 shows that this CID file is configured for any preemption scenario that begins at Node 4.

External Detector Configurations and Examples

Now that the outputs from the controller have been linked to the simulation, we will now focus on linking the inputs to the actual control equipment. For this study, these inputs consist of the detector calls at each of the intersections along with any preemption calls that may arise from any of the simulated emergency vehicles. Note that Figure 6-8 shows the geometric configuration for all of the intersections within the system. Included in this figure are all local detectors and their associated numbers. It is important to note that not all detector numbers have the same number as their associated phase. Many times additional detectors must be used, which are then linked to their associated phase through the control equipment. For example, looking at Figure 6-8a it can be seen that Southbound Detectors 4 and 12 call Phase 4. This can

be verified by checking either the phasing diagram or ring structure shown in Figure 6-3a or Figure 6-5a. Table 6-3 confirms this assignment. In this case an additional detector (Number 12) was required since it was desirable to assign a delay value of 10 seconds to the right lane. This thereby prevents a vehicle, which can easily turn right-on-red, from tripping the signal and slowing arterial traffic.

Figure 6-9 shows how each of the local detectors in Figure 6-8 are assigned and configured within the simulation, so that they are able to communicate with the CID. The logic shown here is identical to the hardware configuration explained in the diamond chapter. Consulting the first line of Figure 6-9, note that link 101-1 (Eastbound Node 1, Approach 1) has a left-turn detector (located at the stop bar), that is 36 feet long with a Station ID of 105. This identification means that the detector communicates through the CID 1 / Detector 5 address. Since this CID is linked to Controller 1 (CIDdef - Figure 6-7) and is located on Approach 1 of Node 1 (as shown on Figure 6-6), this detector should theoretically call the Eastbound left-turn phase at the Progress Drive intersection. Looking at Figure 6-7 it can be seen that this movement (Node 1, Approach 1, Left, Phase 5, Protected) is linked to Phase 5 and so if the detector logic is correctly programmed, then Detector 5 should call Phase 5. The specific mapping of each detector is typically done thorough the control equipment and is documented in Table 6-3.

A similar example can be done using the second and third lines of Record Type 42, shown in Figure 6-9. Based on this coding it can be seen that link 101-1 has two through detectors (300 feet back from the stop bar), which are 6 feet long and are assigned to Stations 102 and 110, respectively. The Number 2 in the third column of line two (Figure 6-9) means that Station 102 is on the inside (left) lane, while the Number 1 in the third row means that Station 110 is on the outside (right) lane [CORSIM Manual]. This can be easily verified by referring to

Figure 6-8a, and examining the Eastbound through direction. The left-turn Detector 5 is also depicted on this very same figure. Looking at the station numbers, it can be seen that both detectors are assigned to CID 1 through the Detector 2 and 10 addresses respectively. Since these detectors are also on Approach 1 or Node 1, it can be seen that the relative through movement (Node 1, Approach 1, Through, Phase 2, Protected) belongs to Phase 2. Hence Detectors 2 and 10 should both be mapped to call Phase 2. Note that Table 6-3, which is similar to the diamond chapter, shows the local detector mappings used for this study.

Configuration of Preemption Detectors

Record Type 42 (Figure 6-9) is reserved for any detectors that require external control. This is typically associated with the local detectors discussed in the previous section, however such detectors can also be used to perform a variety of special functions. For this study additional detectors were added in order to enable and disable preemption. These detectors are programmed the same way as the local detectors, however they only respond to simulated emergency vehicles. Such vehicles are typically programmed in advance and are flagged in the simulation in order to help better identify the vehicle. Referring to Figure 6-9, it can be seen that there are two preemption detectors that are used to activate the preemption algorithm. They are designated by a [Path 7 - On] and a [Path 7 - Off]. As the comments state, this particular simulation file was configured for Path 7. Other configurations, shown in Figure 6-10, can be added to Figure 6-9 (Record Type 42), as needed.

It is possible to place all the preemption detectors shown in Figure 6-10 into Figure 6-9, however the user would need to make sure not to repeat any of the station numbers. Hence, many of the station numbers shown in Figure 6-10 would need to be changed. This includes both the preemption enable and

disable detectors. Such an approach can save time when experimenting with a variety of preemption paths, however during any given trial there could be many detectors that go unused for that particular run, thereby creating possible confusion. Hence it is recommended to configure each scenario independently using the procedures discussed herein. With any of the scenarios that are tried, it is important that the preempt enable and disable detectors are placed on the entry links of the emergency vehicle. Typically each scenario would consist of a given path, however more than one path can be programmed if desired.

From the case illustrated in Figure 6-8d and Figure 6-9, it can be seen that both preemption detectors are located on the entry link 110-4, which is the exit from Meijer Parkway (Path 7). Based on the coding shown in Figure 6-9 or Figure 6-10, it can be determined that Station 332 is the preempt enable detector while Station 331 is the preempt disable detector. This is apparent since Detector 32 is 2,000 feet from the stop-bar while Detector 31 is only 50 feet back. Hence the emergency vehicle would activate Detector 32 before Detector 31. Note that these detectors must be properly configured under the NodeAssign portion of the CID file shown in Figure 6-7. The preempt disable detector (Number 31) which spans all lanes (seen in Column 3 of Figure 6-8d), is placed 50 feet back from the stopbar so that there is no interference with the existing local detectors (8, 16, 17) shown in the figure. Based on the stationing, it can be determined that these preemption detectors are wired directly to the CID 3 / Detector 31 and 32 addresses.

The detector file shown in Figure 6-10 specifies that both preemption detectors are 6 feet long and run in pulse mode. The Number 1, in column seven (7), is what designates the pulse mode while the Number 8, in column three (3), is what permits both of the preemption detectors to span all lanes. This is necessary since it allows the emergency vehicle to enter and leave the approach from any lane. It would be undesirable for a detector call to be missed and

thereby stuck in the active (on) position, although this does happen occasionally in the field with an optical preempt since rescue personnel sometimes forget to turn off their emitter when they arrive at the scene. As a result many emitters are now tied in with the parking brake so that they are disabled once the vehicle is placed in park. A similar occurrence can occur with the simulation procedure, since the preempt calls (on or off) can be occasionally missed. It is therefore important that all preempt files be examined for quality control purposes.

Configuring the CID and Control Equipment for Preemption

Once the preempt detectors have been configured for the appropriate scenario, it is important that the CID file, shown in Figure 6-7 be configured to accurately reflect the detector information. This is done by simply adding an additional line of code after the appropriate node under the NodeAssign section of the file. Recall that the emergency vehicle entered at Node 4 for this particular scenario (Path 7). Hence, the line "Preempt 32 31 26" [Preempt On Off Output] was added after this node, as shown in the figure. Hence Detector 32 enables preemption while Detector 31 disables it. These detectors are then linked to an output on the CID (Detector 26), which can either be linked to the cabinet backpanel, if it exists, or the actual controller itself.

The preempt code, shown above, is always placed on the line of the intersection node, which matches the CID number that was identified in the stationing of the preempt detectors. For this example it was CID 3 since the station numbers were 332 and 331 respectively. This CID (Detector 26) would then be responsible for preempting all of the local controllers at the same time. Delay values and hold time were then used to ensure that the appropriate phases were preempted at the appropriate time once the emergency vehicle was detected. If a particular controller was not supposed to be preempted for a certain scenario, then Preempt 3 would be disabled in that controller for the

relative scenario. It is important that the preemption calls are locked so that the call does not prematurely go away after the emergency vehicle disabled the call. For each scenario, the preemption hold phases, and delay times, should be reconfigured in order to best match the associated scenario.

Under the TS II, Type 1, Mode 2 [NEMA, 1998] configuration, the Preempt 3 that was used for this research must be tied to Phase Hold 2. For this research the preemption output detector (Number 26 - Figure 6-7) would be tied to this input. This mode (Mode 2) was made active by grounding Status Bit B to logic ground. Such a procedure allows one to use up to twenty local detectors, rather than just the standard eight that come with the control equipment. In addition to this configuration, there are two additional files that must be added to the same directory as the preemption runs that are being examined. These include the Paths.dat and Vehicles.dat files, both of which are necessary in order for the preemption to run. They are essentially responsible for generating the specified emergency vehicle(s) at the appropriate time. The Paths.dat file contains all the preprogrammed paths while the Vehicles.dat file generally controls the times at which each of the specified emergency vehicles will release. These files and their relative parameters can be seen in Figure 6-11 and Figure 6-12, respectively. Such files can be created using a standard Notepad application.

Local Detector Configuration

Table 6-1 shows all the necessary pocket lengths along with the lengths of all the stopbar detectors by lane group (left, through, right). It also shows the length of the raceway detectors along with their relative setback distance. This information exactly matches that shown in Figure 6-8, which corresponds to the coding previously discussed in Figure 6-9. When comparing this information, it can be seen that the detector information matches up perfectly. The same is true for the raceway detectors, which are also shown in Table 6-1 as well. Recall that

every CORSIM detector requires a station number, which identifies the detector. This is necessary so that each detector can be assigned to the desired input on the actual control equipment. Table 6-2 lists all the local detectors on a per intersection basis. It contains all the detectors (shown in Figure 6-8), followed by the station number and operational mode. From this table it can be seen that all detectors run in presence mode.

Table 6-3 shows some of the additional parameters that are associated with each of the detectors shown in Figure 6-8. Recall that this table includes the detector number, operational mode (lock or non-lock), detector delay, and the relative phase that each of the detectors call. The detector type is also referenced in this table. Based on this information it can be seen that all raceway detectors are normal detectors that operate in lock mode. All other detectors, which are located at the stopbar, are normal detectors that are non-locked, unless the lane contains a right-turn movement. Notice that right-turn detectors have been assigned at Type 1 (Extend / Delay) so that a delay value can be programmed. This delay time, and its relative calling phase is found in the table. Realize that if the detector was in an exclusive right-turn lane, than a delay value of 20 seconds was used. Conversely, if the detector was in a shared lane with a right-turn movement, then a value of 10 seconds was used. This was done in order to prevent the controller from slowing the arterial movement under lighter conditions, when a vehicle could easily turn right-on-red.

Configuration of Preemption Detectors

Table 6-4 shows the configuration and programming for all the preemption detectors that were used for the study. This table contains all the preemption paths (scenarios) that were examined, in addition to the intersection and direction that the corresponding detectors are assigned to. Both the preemption enable (on) and disable (off) detectors shown here, along with their station number and

relative setback distance from the stopbar. The preempted phases for each of the scenarios is also depicted in Table 6-4, for each of the controllers in the study. Realize that all of this information, with the exception of the preempted phases, was obtained from the preemption detector file shown in Figure 6-10. Hence the setback distance of 2,000 feet for the enable (on) detector and 50 feet for the disable (off) detector is consistent with what was used in the figure. Also notice that the station numbering is also consistent with that found in Figure 6-10.

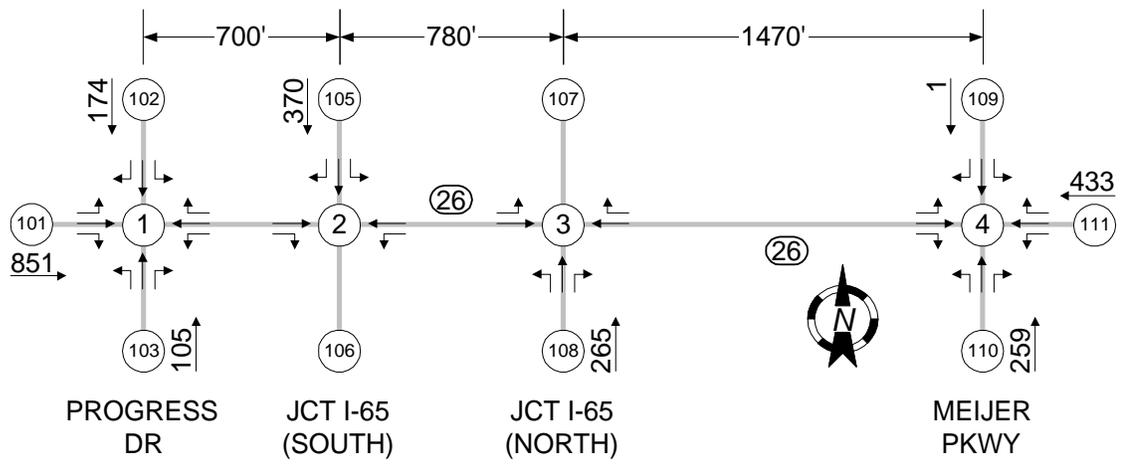
Based on this information (Table 6-4), it can be seen the first scenario (Path 1) has a preempt enable detector with a Station ID of 332, located 2,000 feet behind the stopbar, relative to Intersection 1. Similarly the preempt disable detector has a Station ID of 131, and is located 50 feet behind the intersection on the same approach. Looking at the table, it can be seen that both detectors are located on the Eastbound movement, which is the West approach to the intersection. As seen in the table, Phases 2 and 5 would be preempted at both Progress Drive and the Interchange, while Phases 2 and 6 would be preempted at Meijer Parkway. Since this scenario is an Eastbound preempt through the preempted phases are logical since Phases 2 and 5 are in the Eastbound direction as depicted in Figure 8-5. Delay times and preemption hold times were then used to ensure that the preempted phases were active at the appropriate time. The delay time was calculated by using the anticipated travel time along the path for each of the scenarios.

Summary of Timing Parameters

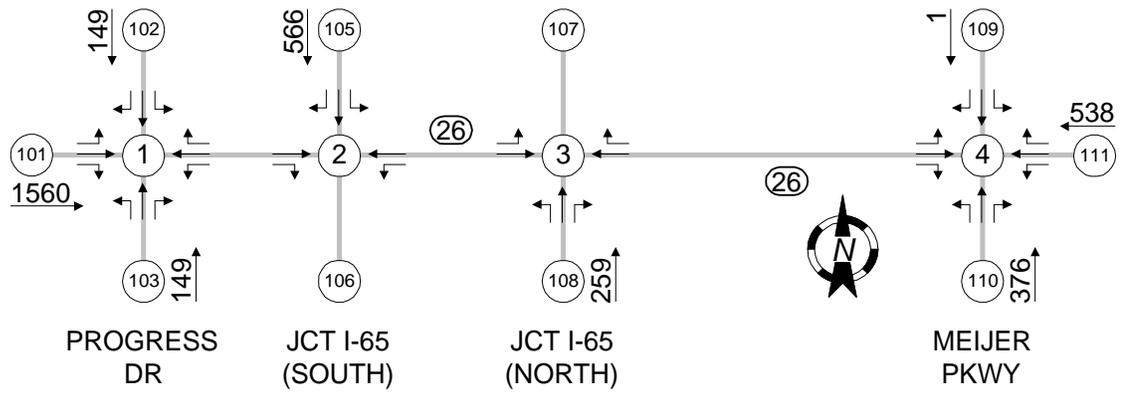
Table 6-5 shows the general timing parameters that were used to control each of the intersections within the system, while Table 6-6 shows the coordination splits that were used for each period, given the volume scenarios shown in Figure 6-1. The cycle lengths, offsets, and patterns for each of the intersections are also shown in this table, in addition to any left-turning

movements that are defined as lagging. When looking at Table 6-6, it can be seen that this system has two timing plans. Pattern 111 is the midday plan while Pattern 311 is the afternoon plan. As seen in the table, these plans run a 110 and a 120 second cycle, respectively. It can also be determined the all left-turn movements in the system are leading with the exception of the diamond interchange, where Phases 1 and 5 were denoted as lagging for both of the timing periods that were analyzed. The justification behind using lagging left-turns at the diamond is discussed in the previous chapters.

This concludes both the hardware and software configuration that was used for this study. Such procedures are necessary for this study since current simulation packages can not model preemption, or other vendor specific features that require cycle transitioning. The next chapter will build on the concepts discussed herein and use this same network to analyze some of the more advanced features available with modern day traffic signal controllers. It may be necessary to refer to this section for some of the more basic detector configurations, as future chapters will focus primarily on the system detectors that were used for the traffic responsive analysis.



(a) Midday Peak Period



(b) Afternoon Peak Period

Figure 6-1: SR 26 (South) – System Entry Volumes



a) Node 1: SR 26 & Red Cloud / Progress



b) Node 2: SR 26 & JCT I-65 (South)

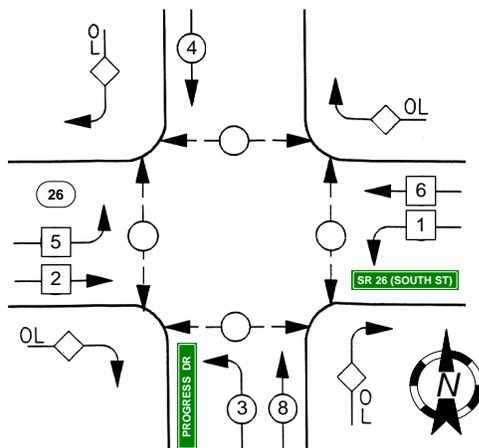


c) Node 3: SR 26 & JCT I-65 (North)

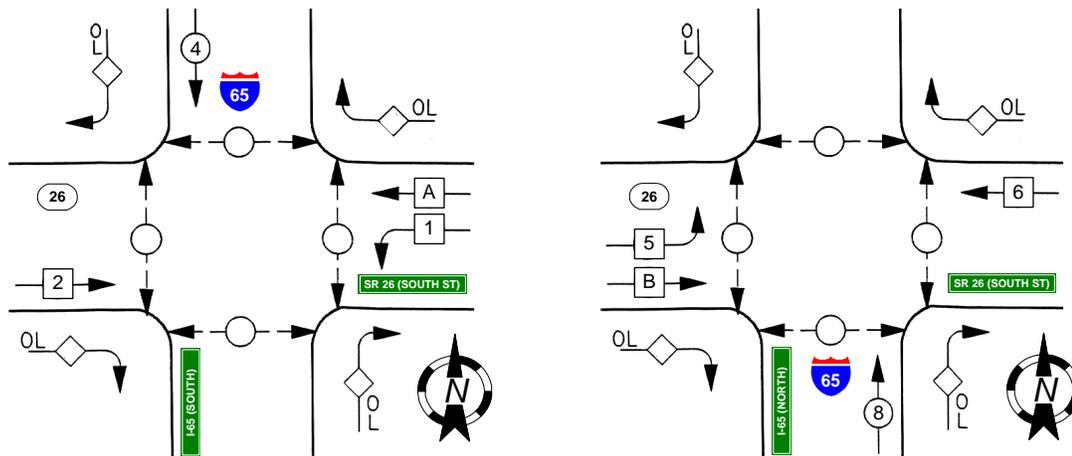


d) Node 4: SR 26 & Meijer Entrance

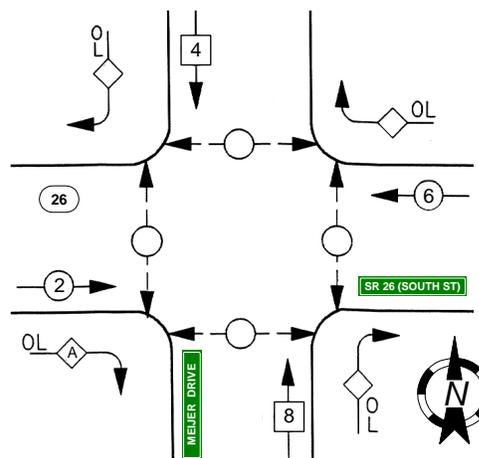
Figure 6-2: Intersection Lane Geometry and Configurations (SR 26 – South)



a) Node 1: SR 26 & Red Cloud / Progress

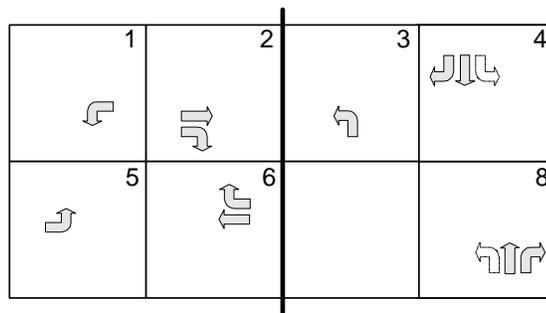


b) Nodes 2 & 3: SR 26 & JCT I-65 (South / North) – Single Controller

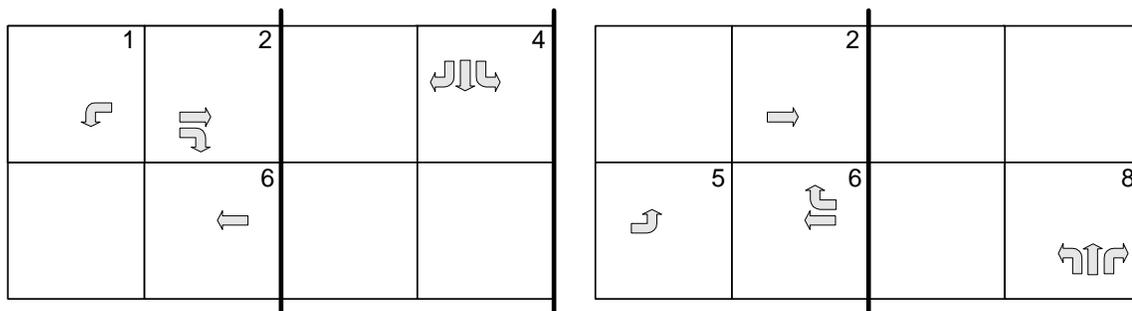


c) Node 4: SR 26 & Meijer Entrance

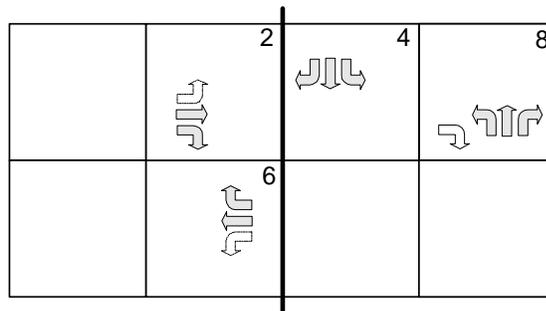
Figure 6-3: Intersection Phasing Diagrams (SR 26 – South)



a) Node 1: SR 26 & Red Cloud / Progress

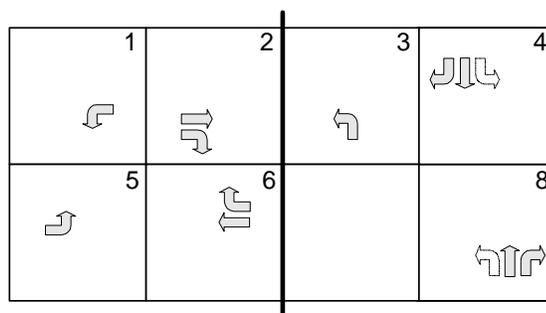


b) Nodes 2 & 3: SR 26 & JCT I-65 (South / North) – Seperate Controllers

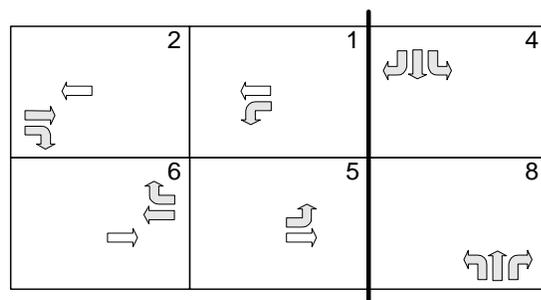


c) Node 4: SR 26 & Meijer Entrance

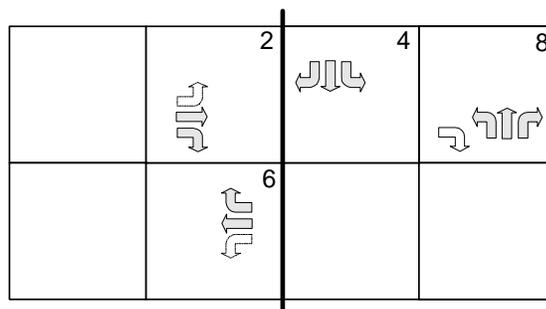
Figure 6-4: Intersection Ring Structures (Separate Controllers)



a) Node 1: SR 26 & Red Cloud / Progress



b) Nodes 2 & 3: SR 26 & JCT I-65 (South / North) – Single Controller



c) Node 4: SR 26 & Meijer Entrance

Figure 6-5: Intersection Ring Structures (Single Diamond Controller)

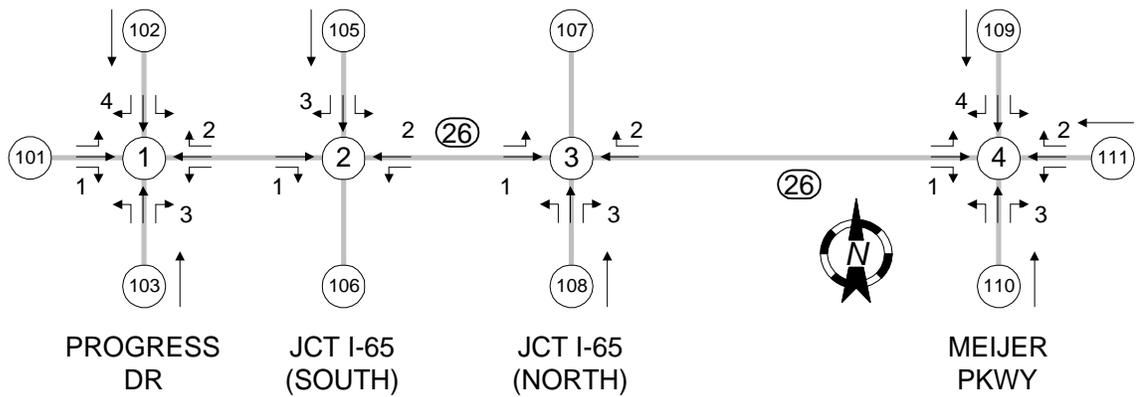
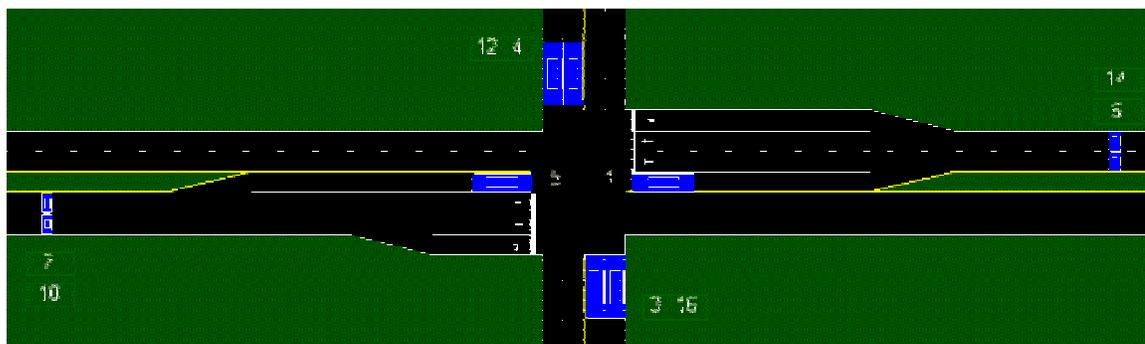


Figure 6-6: Intersection Approach Labels (Reference Figure 6-7)

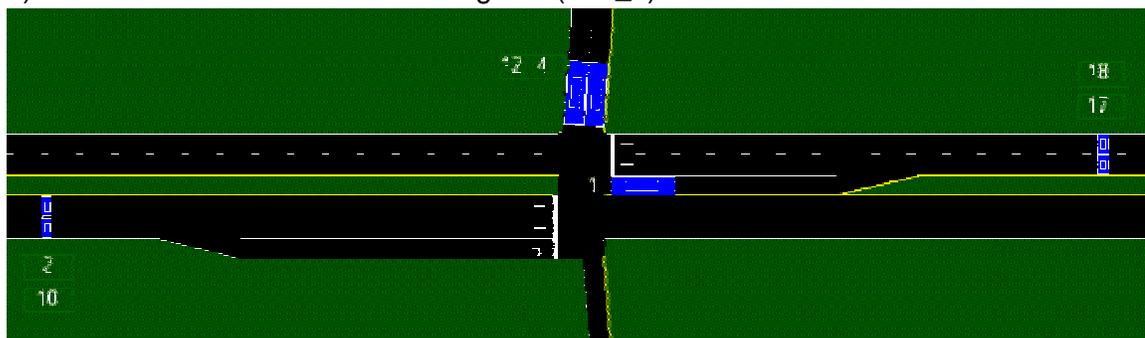
```

COM [PortID]
1 2, 1, R, 2, Prot
CIDdef [CID, Base ID]
1, 1 2, 2, L, 1, Prot
2, 3 2, 3, T, 9, Prot
3, 5 2, 3, L, 4, Prot
NodeAssign[Node, CID]
1, 1 2, 3, T, 4, Prot
2, 2 2, 3, R, 4, Prot
3, 2 3, 1, L, 5, Prot
4, 3 Preempt 32 31 26 3, 1, T, 10, Prot
Phases [Node, Approach, L/T/R, Phase#, Pro/Per/PP]
1, 1 3, 2, T, 6, Prot
1, 1 3, 2, R, 6, Prot
1, 2 3, 3, L, 8, Prot
1, 2 3, 3, T, 8, Prot
1, 3 3, 3, R, 8, Prot
1, 3 4, 1, L, 5, PP
1, 4 4, 1, T, 2, Prot
1, 4 4, 1, R, 9, Prot
1, 2 4, 2, L, 1, PP
1, 2 4, 2, T, 6, Prot
1, 2 4, 2, R, 6, Prot
1, 3 4, 3, L, 8, Prot
1, 3 4, 3, T, 8, Prot
1, 3 4, 3, R, 8, Prot
1, 4 4, 4, L, 4, Prot
1, 4 4, 4, T, 4, Prot
1, 4 4, 4, R, 4, Prot
2, 1 4, 4, R, 4, Prot
2, 1 2, 1, T, 2, Prot
    
```

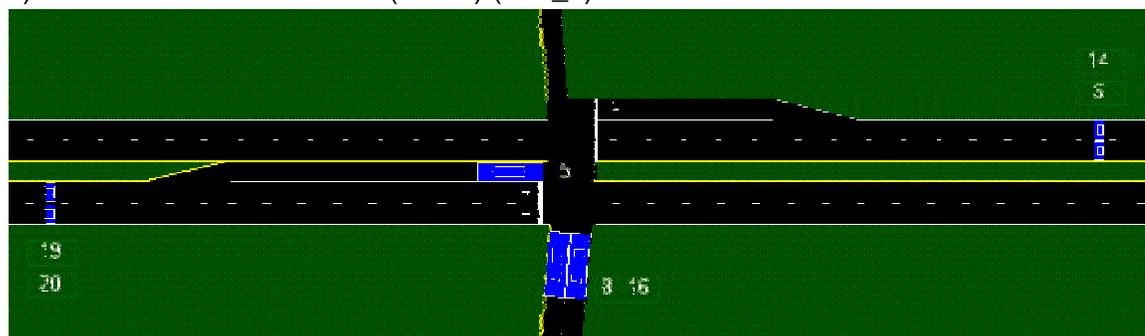
Figure 6-7: External Control File (CID) for Phasing (Reference Figure 6-6)



a) Node 1: SR 26 & Red Cloud / Progress (CID_1)



b) Node 2: SR 26 & JCT I-65 (South) (CID_2)



c) Node 3: SR 26 & JCT I-65 (North) (CID_2)



d) Node 4: SR 26 & Meijer Entrance (CID_3)

Figure 6-8: Intersection Detector Locations and Numbering (SR 26 – South)

```

101 1 7 105 360 42
101 1 2 3000 102 60 42
101 1 1 3000 110 60 42
  1 2 2 3000 202 60 42
  1 2 1 3000 210 60 42
  2 1 7 101 360 42
  2 1 2 3000 106 60 42
  2 1 1 3000 114 60 42
  2 3 7 205 360 42
  2 3 2 3000 219 60 42
  2 3 1 3000 220 60 42
  3 2 7 201 360 42
  3 2 2 3000 217 60 42
  3 2 1 3000 218 60 42
  3 4 8 3000 302 60 42
  4 3 2 3000 206 60 42
  4 3 1 3000 214 60 42
111 4 8 3000 306 60 42
102 1 2 104 360 42
102 1 1 112 360 42
105 2 1 204 360 42
105 2 7 212 360 42
108 3 1 208 360 42
108 3 7 216 360 42
110 4 3 308 360 42
110 4 2 316 360 42
110 4 1 317 360 42
110 4 8 20000 332 60 1 [PATH 7 - ON ] 42
110 4 8 500 331 60 1 [PATH 7 - OFF ] 42
109 4 1 304 200 42
103 1 2 103 360 42
103 1 1 116 360 42
  1 101 1 2 1 103 1 102 1 2 43
  2 1 2 3 2 105 2 2 43
  3 2 3 4 3 108 3 2 43
  4 3 4 111 4 110 4 109 4 2 43

```

Figure 6-9: Sample External Detector File (Reference Figure 6-8)

```

101 1 8 20000 132 60 1 [PATH 1,3 - ON ] 42
101 1 8 500 131 60 1 [PATH 1,3 - OFF ] 42
111 4 8 20000 332 60 1 [PATH 2,4 - ON ] 42
111 4 8 500 331 60 1 [PATH 2,4 - OFF ] 42
105 2 8 20000 232 60 1 [PATH 5 - ON ] 42
105 2 8 500 231 60 1 [PATH 5 - OFF ] 42
108 3 8 20000 232 60 1 [PATH 6 - ON ] 42
108 3 8 500 231 60 1 [PATH 6 - OFF ] 42
110 4 8 20000 332 60 1 [PATH 7 - ON ] 42
110 4 8 500 331 60 1 [PATH 7 - OFF ] 42

```

Figure 6-10: External Preemption Detectors (Apply to Figure 6-9)

```

1                               [NUMBER OF PATHS                ]
8                               [NUMBER OF NODES IN THE FIRST PATH  ]
8010 110 4 3 2 1 101 8001     [SEQUENCE OF NODES IN THE FIRST PATH ]

```

Figure 6-11: Sample Paths Data File for Path #7 [Paths.dat]

```

3                               [NUMBER OF VEHICLES TO EMIT INTO NETWORK ]
60 8010 1 10 1 16             [INFORMATION FOR FIRST VEHICLE, SEE NOTE ]
150 8010 1 10 1 16            [INFORMATION FOR SECOND VEHICLE, SEE NOTE ]
700 8010 1 10 1 16            [INFORMATION FOR THIRD VEHICLE, SEE NOTE ]

```

NOTE (LINES 2-4) -> TIME TO EMIT, ENTRY NODE, PATH ID, DRIVER TYPE, FLEET TYPE, VEHICLE TYPE

Figure 6-12: Sample Vehicles Data File for Path #7 [Vehicles.dat]

SR 26 (SOUTH ST)		POCKET LENGTHS (FT)		STOP BAR DETECTOR LENGTHS (FT)			RACEWAY DETECTORS (FT)	
INT	MOVE	LEFT	RIGHT	LEFT	THRU	RIGHT	THRU	DIST
1	EB	165	60	36	--	--	6	300
1	WB	140	140	36	--	--	6	300
1	NB	--	--	36	36	--	--	--
1	SB	--	--	--	36	--	--	--
2	EB	--	175	--	--	--	6	300
2	WB	130	--	36	--	--	6	300
2	SB	--	--	36	--	36	--	--
3	EB	180	--	36	--	--	6	300
3	WB	--	100	--	--	--	6	300
3	NB	--	--	36	--	36	--	--
4	EB	105	PREV	--	--	--	6	300
4	WB	--	--	--	--	--	6	300
4	NB	--	--	36	--	36	--	--
4	SB	--	--	--	36	--	--	--

NOTE: "PREV" DENOTES THAT THE TURNING BAY BEGINS AT THE PREVIOUS INTERSECTION.

Table 6-1: Intersection Pocket Lengths and Detector Locations

INT	MOVE -MENT	DET NUM	STAT ID	PUL PRS
1	EBLT	5	105	PRS
1	EBTH	2	102	PRS
1	EBTH	10	110	PRS
1	WBLT	1	101	PRS
1	WBTH	6	106	PRS
1	WBTH	14	114	PRS
1	NBLT	3	103	PRS
1	NBTH	16	116	PRS
1	SBTH	4	104	PRS
1	SBTH	12	112	PRS

INT	MOVE -MENT	DET NUM	STAT ID	PUL PRS
2	EBTH	2	202	PRS
2	EBTH	10	210	PRS
2	WBLT	1	201	PRS
2	WBTH	17	217	PRS
2	WBTH	18	218	PRS
2	SBLT	4	204	PRS
2	SBRT	12	212	PRS

INT	MOVE -MENT	DET NUM	STAT ID	PUL PRS
3	EBLT	5	205	PRS
3	EBTH	19	219	PRS
3	EBTH	20	220	PRS
3	WBTH	6	206	PRS
3	WBTH	14	214	PRS
3	NBLT	8	205	PRS
3	NBRT	16	216	PRS

INT	MOVE -MENT	DET NUM	STAT ID	PUL PRS
4	EBTH	2	302	PRS
4	EBTH	2	302	PRS
4	WBTH	6	306	PRS
4	WBTH	6	306	PRS
4	NBLT	8	308	PRS
4	NBLT	16	316	PRS
4	NBRT	17	317	PRS
4	SBTH	4	304	PRS

NOTE: INTERSECTION 2 & 3 DETECTORS ARE TIED TO THE SAME CONTROLLER (DIAMOND).

Table 6-2: Intersection Detector Configuration (CID Logic Only)

INT	MOVE -MENT	DET NUM	LOCK / N-LCK	DELAY (SEC)	CALL PHASE	DETECTOR TYPE
1	EBLT	5	N-LCK	--	5	STANDARD (NORMAL)
1	EBTH	2	LOCK	--	2	STANDARD (NORMAL)
1	EBTH	10	LOCK	--	2	STANDARD (NORMAL)
1	WBLT	1	N-LCK	--	1	STANDARD (NORMAL)
1	WBTH	6	LOCK	--	6	STANDARD (NORMAL)
1	WBTH	14	LOCK	--	6	STANDARD (NORMAL)
1	NBLT	3	N-LCK	--	3	STANDARD (NORMAL)
1	NBTH	16	N-LCK	10	8	EXTEND / DELAY (T-1)
1	SBLT	4	N-LCK	--	4	STANDARD (NORMAL)
1	SBTH	12	N-LCK	10	4	EXTEND / DELAY (T-1)
2	EBTH	2	LOCK	--	2	STANDARD (NORMAL)
2	EBTH	10	LOCK	--	2	STANDARD (NORMAL)
2	WBLT	1	N-LCK	--	1	STANDARD (NORMAL)
2	WBTH	17	LOCK	--	2	STANDARD (NORMAL)
2	WBTH	18	LOCK	--	2	STANDARD (NORMAL)
2	SBLT	4	N-LCK	--	4	STANDARD (NORMAL)
2	SBRT	12	N-LCK	20	4	EXTEND / DELAY (T-1)
3	EBLT	5	N-LCK	--	5	STANDARD (NORMAL)
3	EBTH	19	LOCK	--	6	STANDARD (NORMAL)
3	EBTH	20	LOCK	--	6	STANDARD (NORMAL)
3	WBTH	6	LOCK	--	6	STANDARD (NORMAL)
3	WBTH	14	LOCK	--	6	STANDARD (NORMAL)
3	NBLT	8	N-LCK	--	8	STANDARD (NORMAL)
3	NBRT	16	N-LCK	20	8	EXTEND / DELAY (T-1)
4	EBTH	2	LOCK	--	2	STANDARD (NORMAL)
4	EBTH	2	LOCK	--	2	STANDARD (NORMAL)
4	WBTH	6	LOCK	--	6	STANDARD (NORMAL)
4	WBTH	6	LOCK	--	6	STANDARD (NORMAL)
4	NBLT	8	N-LCK	--	8	STANDARD (NORMAL)
4	NBLT	16	N-LCK	--	8	STANDARD (NORMAL)
4	NBRT	17	N-LCK	20	8	EXTEND / DELAY (T-1)
4	SBTH	4	N-LCK	--	4	STANDARD (NORMAL)

NOTE: RACEWAY DETECTORS MUST BE IN LOCK MODE IF THEY ARE NOT IN VEHICLE RECALL.

Table 6-3: Intersection Detector Configuration (Controller)

PMT PTH	INT	MOVE -MENT	TURN ON		TURN OFF		PREEMPT PHASES		
			DIST	STAT	DIST	STAT	INT 1	DMD	INT 4
1	1	EB	2000	132	50	131	2, 5	2, 5	2, 6
2	4	WB	2000	332	50	331	1, 6	1, 6	2, 6
3	1	EB	2000	132	50	131	2, 5	2, 5	N/A
4	4	WB	2000	332	50	331	N/A	1, 6	2, 6
5	2	SB	2000	232	50	231	1, 6	4, 5	N/A
6	3	NB	2000	232	50	231	1, 6	1, 8	N/A
7	4	NB	2000	332	50	331	1, 6	1, 6	8

NOTE: ALL PREEMPTION DETECTORS LISTED IN THIS TABLE OPERATE IN PULSE MODE.

Table 6-4: Preemption Detector Configuration (CID & Controller)

INT	DESCRIPTION (SEC)	1	2	3	4	5	6	7	8
1	MINIMUM GREEN	3	15	3	7	3	15	--	7
1	VEHICLE EXTENSION	2.5	5.0	2.5	3.0	2.5	5.0	--	3.0
1	MAXIMUM GREEN	35	80	20	45	35	80	--	45
1	YELLOW CLEARANCE	3.5	3.5	3.5	3.5	3.5	3.5	--	3.5
1	RED CLEARANCE	1.0	2.0	1.0	1.5	1.0	2.0	--	1.5
1	MINIMUM GAP TIME	2.5	3.0	2.5	3.0	2.5	3.0	--	3.0
2,3	MINIMUM GREEN	3	15	--	7	3	15	--	7
2,3	VEHICLE EXTENSION	2.5	5.0	--	3.0	2.5	5.0	--	3.0
2,3	MAXIMUM GREEN	35	80	--	45	35	80	--	45
2,3	YELLOW CLEARANCE	3.5	3.5	--	3.5	3.5	3.5	--	3.5
2,3	RED CLEARANCE	1.0	2.0	--	1.5	1.0	2.0	--	1.5
2,3	MINIMUM GAP TIME	2.5	3.0	--	3.0	2.5	3.0	--	3.0
4	MINIMUM GREEN	--	15	--	3	--	15	--	7
4	VEHICLE EXTENSION	--	5.0	--	3.0	--	5.0	--	3.0
4	MAXIMUM GREEN	--	80	--	12	--	80	--	45
4	YELLOW CLEARANCE	--	3.5	--	3.5	--	3.5	--	3.5
4	RED CLEARANCE	--	2.0	--	1.5	--	2.0	--	1.5
4	MINIMUM GAP TIME	--	3.0	--	3.0	--	3.0	--	3.0

NOTE: NODES 2 & 3 (DIAMOND INTERCHANGE) ARE CONTROLLED BY A SINGLE CONTROLLER.

NOTE: THE MAXIMUM GREEN TIMES SHOWN IN THIS TABLE ARE INHIBITED UNDER COORDINATION.

Table 6-5: General Phase Parameters (SR 26 – South)

INT	COS	CYC	OFF	1	2	3	4	5	6	7	8	LAG
1	111	110	N/A	12	64	15	19	12	64	--	34	--
1	311	120	N/A	12	84	12	12	12	84	--	24	--
2,3	111	110	N/A	12	58	--	40	32	44	--	34	1,5
2,3	311	120	N/A	12	69	--	39	36	63	--	21	1,5
4	111	110	N/A	--	63	--	12	--	63	--	35	--
4	311	120	N/A	--	88	--	12	--	88	--	20	--

NOTE: NODES 2 & 3 (DIAMOND INTERCHANGE) ARE CONTROLLED BY A SINGLE CONTROLLER.

NOTE: OFFSETS ARE REFERENCED FROM THE BEGINNING OF THE FIRST COORDINATED PHASE.

Table 6-6: SR 26 (South) Coordination Plans and Splits

CHAPTER 7 – IMPACT EVALUATION OF EMERGENCY VEHICLE PREEMPTION ON SIGNALIZED CORRIDOR OPERATION

Overview of Emergency Vehicle Preemption

This chapter quantitatively describes the impact of emergency vehicle preemption on closely spaced arterial traffic signals. The quantitative data was obtained using hardware-in-the-loop simulation that was developed in this research. This study was conducted on SR 26 (South), which is a principal arterial and main thoroughfare connecting Interstate 65 with US 52 (Sagamore) on the Eastern part of Lafayette, Indiana. This research examines four coordinated intersections along SR 26 (South) using seven preemption paths and three different transition algorithms (smooth, add, and dwell). The number of preemption calls during the simulation period varied anywhere from one to three preempts for the specified time interval.

The findings generally show that a single preemption call had a minimal effect on both the overall travel time and delay for the network. The results also indicate that the smooth transitioning algorithm performed the best for most scenarios and paths, regardless if the call had originated on the arterial or the side street. When multiple emergency vehicles preempted at closely spaced time intervals; the impact of preemption was found to be slightly more severe. For the network studied, the most significant observed impact on arterial travel time was an increase on the order of 20-30 seconds. This study focused mainly on emergency vehicle preemption, however the general procedures used for this analysis could also be applied to both railroad and transit priority as well.

Introduction of Preemption Concepts

Emergency vehicle priority systems (EVPS) are used to detect vehicles approaching signalized intersections, that are “requesting” the traffic signal controller to provide preferential signal indications for authorized vehicles (e.g. fire or ambulance). Generally, the EVPS identifies a vehicle requesting priority treatment by using the optical, acoustic, special inductive loop, or global positioning system (GPS) technology. Once the priority request is recognized, and perhaps validated by the EVPS, an electrical relay is closed in the traffic signal cabinet allowing the controller to service the call. In a few specialized cases where the signals are adjacent to fire stations, a hardwire switch in the firehouse is typically used to place the priority request.

Traffic controllers are generally responsible for accepting requests from vehicles, pedestrians, highway-rail crossings, emergency vehicles, and transit vehicles. Based upon internally configured parameters, the controller sequences the indications in order to service the calls in a safe and efficient manner. Traditionally, preemption has applied to either rail or emergency vehicle requests that are received by the controller. More recently, the term “signal priority” has been used to reflect the fact that there is a need to assign relative priority to these different requests. For example, a highway-rail crossing is typically assigned the highest priority, which thereby provides for the most aggressive manipulation of the traffic controller.

Emergency vehicles, such as fire trucks, are generally assigned a slightly lower priority, in order to allow a signal from a highway-rail grade crossing to override the emergency vehicle request. The emergency vehicle priority request typically uses a slightly less aggressive procedure for manipulating the controller. Transit vehicles are typically assigned an even lower priority. Such requests received from transit vehicles typically do not cause major disruptions of the phase sequence, but may extend a green split by a prescribed amount allowing

the transit vehicle to clear the signal. The impact of these priority requests on overall system performance is also unknown.

Few debate the safety and time saving benefits that accrue to users of the system when the various preemption or priority schemes are used. However, there is significant debate regarding the extent of that benefit and if the current preemption and priority algorithms result in an overall net-positive societal benefit. Recently, evaluation procedures have evolved to the point where the impact of signal preemption can be studied and quantitatively evaluated [Bullock, 1998], [Bullock, 1999], [Bullock, 2000], [Engelbrecht, 2000], [Koonce, 2000]. Subsequent sections of this chapter build upon such work and examine the impact of emergency vehicle preemption (e.g. fire truck or ambulance) on the operation of the overall system.

Although the recent trend is to call all railroad, emergency vehicle, and transit requests priority requests, the remainder of this paper uses the term “preemption” for consistency with today’s traffic signal controllers and the definitions specified by National Electrical Manufacturer Association (NEMA) specification’s TS II and TS 3.5 [NEMA, 1992], [NEMA, 1996]. This paper does not address the impact of transit priority, where the controller is manipulated in a less aggressive manner. The same procedures that are used to evaluate emergency vehicle preemption may also be used to conduct such a study on either transit or railroad preemption.

Overview of Signal Preemption

The nature of railroad and emergency vehicle preemption is that they place the preempted intersection into “Free” operation. This typically is not of major concern for an isolated intersection, since they already operate in “Free” operation. However, under coordinated operation, the situation is different since

the intersection is configured to operate as part of a system. Preemption disrupts this process by temporarily removing coordination constraints to service the preemption call. Once the call is dropped, the signal then returns back to normal operation after a period of offset seeking. This is generally a process that takes anywhere from 0 to 5 cycles depending on the selected transition algorithm and the cycle length of the system. Consequently, there is a concern that preemption adversely impacts the system operation in a substantial and lasting manner, even after the emergency vehicle has cleared the intersection.

Prior Studies on Preemption

Few studies have been conducted for determining the quantitative effects that emergency vehicle preemption has on coordinated signal networks. Many practitioners believe that emergency vehicle preemption is a bad idea, since it is believed to cause significant disruptions in traffic. This, in turn is expected to increase the overall travel time and delay through the system. Based upon this perceived negative impact, governmental agencies, and those directly responsible for maintaining traffic signals, are generally reluctant to deploy the preemption technology.

In 1998, a preemption study was performed on Route 7, in Northern Virginia. This study consisted of three coordinated intersections that spanned over 1.5 miles [Bullock, 1999]. The findings generally indicated that there were statistically significant differences in the mean travel times along the network for many of the preemption cases, when compared to the base case (without preemption). However, the largest increase in average travel time was on the order of only 1 to 2% during the morning peak.

The Route 7 study only looked at the morning peak volumes and did not evaluate alternative transition procedures used to resynchronize preempted

signals. Also, this arterial had a background cycle of over 200 seconds. Based upon this, and the relatively long spacing between intersections, it was not clear whether preemption would have a similar (relatively minor) impact on an arterial with closely spaced signals running a shorter cycle length. Hence, this study on a busy section of SR 26 (South) in Lafayette was performed.

Impact of Preemption on Signal System

The impact of signal preemption is caused by two different, but related, phenomena. First, preemption reallocates some of the green time by stealing it from other movements. If one of the shortened movements is already saturated, then significant delay can result on that approach (and upstream approaches) due to spillback. Secondly, once the preemption terminates, the controller must resynchronize itself with the arterial background cycle. This is done using a transition algorithm. Note that while the intersection is transitioning, the system is theoretically not running as efficiently as possible.

Many of the controllers today have a variety of transition algorithms that are used for switching between various coordination patterns. Generally, these same algorithms are also used to recover from preemption. Although the default values for transition algorithms vary slightly from vendor to vendor, most controllers provide the basic algorithms discussed below, all of which were examined in this study.

- Smooth - Allows the controller to lengthen or shorten the local cycle by adding up to a maximum of 20% or subtracting a maximum of 17% of the cycle length per cycle. Typically, the controller would automatically determine which option is quicker and then run that option. Appropriate checks are made so that even if subtraction was faster, it would not be permitted if the controller determined that one or more of the phases were

reduced to less than their minimum split time. In such situations, the addition algorithm would instead be used.

- Add Only - Allows the controller to lengthen the local cycle up to 20% per cycle. This transitioning guarantees that no phase is cut short, however such transitioning often takes longer to get back in coordination depending where in the cycle the local controller is when it releases from preemption.
- Dwell - This transition will cause the controller to rest in the coordinated phases until the period of offset seeking has been completed. Generally, this is the quickest way to get coordination back, however it can cause significant delay on the side streets due to the relatively long periods associated with some of the longer cycle lengths. The maximum dwell time used for this study was set at half the cycle length. Hence a 120-second cycle would be configured for 60 seconds of dwell time. This would allow the controller to service the side street if the dwell time had expired. Once served it would then revert back to the coordinated phases and dwell again until either coordination is obtained or the maximum dwell time is again reached.

The dwell transition concept is modeled after legacy transition procedures used on old interconnected electro-mechanical controllers. This is rarely used in practice today. The smooth and add-only transitions are among the most commonly used and, as a result, there is often debate among practitioners about which transition procedure is better for the overall operation of the system. The parameters for 20% addition and 17% subtraction were fixed parameters on the control equipment used to conduct this evaluation. Other vendors use similar transition procedures, however they may have slightly different addition and subtraction percentages or allow the user to change such parameters.

Evaluation Procedure and Equipment

SR 26 is classified as a principal arterial and is the main thoroughfare connecting Interstate 65 with US 52. This study examined four coordinated intersections in Lafayette, Indiana along SR 26 (Figure 6-1). There were seven different preemption paths that were studied (Figure 7-1), along with three different transition algorithms (smooth, add, and dwell). The number of preemption calls in the simulation were also varied from one to three preempts per period, all of which had an equal length of twenty-two minutes for both volume scenarios. Both the midday and afternoon peak-hour volumes (Figure 7-1), and the relative turning movements (Table 7-1) were examined. These periods were then compared against each other in order to determine the effect of volume variation on the results.

For this study, the TSIS/CORSIM analysis package was used to obtain the quantitative data for the SR 26 arterial. The standard TSIS/CORSIM simulation does not simulate preemption, and so the simulation model was linked to the actual equipment using hardware-in-the-loop simulation. This approach used CORSIM to model the network but relied upon the actual equipment to provide the control and preemption logic. Node 1 was controlled by one controller, Nodes 2 and 3 were part of a diamond intersection controlled by one controller, while Node 4 was controlled by one controller. The diamond interchange controller ran a variation of 3-Phase (TTI) diamond control logic.

For the purposes of this study, emergency vehicles were emitted into the network at the specified times as shown in Table 7-2, traveling the paths shown in Figure 7-1. Special emergency vehicle detectors activated preemption calls, and were wired directly to the controllers. The paths of the emergency vehicles were programmed in advance and the controllers were configured so that all intersections in the path of the vehicle would preempt the appropriate phases at the appropriate time.

Preemption at both Nodes 1 and 4 were held for 30 seconds while the diamond interchange (Nodes 2 and 3) was held for 42 seconds due to the additional travel time that was needed to clear the interchange. Due to minimum green times and pedestrian clearances, the start of the preemption sequence would occasionally be delayed. As a result, all controllers were programmed to terminate at the end of the hold interval, thereby allowing the total hold time to be cut short in such cases. This best models the situation in the field had an optical preempt been used, since preemption terminates once the vehicle clears the intersection. No exit phases or exit calls were programmed for any of the preemption runs.

There were seven preemption paths that were analyzed as shown in Figure 7-1. All paths were analyzed for both the midday and afternoon peak periods. The simulation time for both periods was 22 minutes, which was equally divisible by both the 110 second midday and 120 second afternoon cycles, thereby eliminating bias in the results. For each path, there were three transition algorithms and three different preemption sequences evaluated. In order to estimate an average impact, each scenario was replicated 10 times with different random number seeds. In total, there were 3 transition algorithms, 3 preemption scenarios, 7 preemption paths, and 10 replications. Hence, there were 630 twenty-two minute simulations performed for each of the volume scenarios. This is nearly equivalent to 462 hours of straight simulation.

As one can imagine, an enormous amount of data was produced by CORSIM. In order to simplify the analysis, the link data produced from CORSIM was aggregated into approach and path based statistics [Shoup, 1999]. The paths were then compared between the different time periods in order to find similarities between the midday and afternoon peak periods, and determine the effect of volume variation on the results. Summaries of general findings are discussed in the following sections.

Preemption Case Study – Lafayette, IN

The volumes used for this study were the actual volumes obtained from the field, however the base timing plans created for the system were developed in the laboratory in order to ensure an efficient base timing plan for each of the periods. Both a midday and an afternoon timing period were selected in order to determine whether a variation in volume had an impact on both travel time and delay when the network is preempted. Two-way progression was obtained where possible, however priority was given to the heavier eastbound direction when necessary.

Table 7-3 summarizes the through movement travel time on the arterial while Table 7-4 summarizes the minor movement delay values during midday peak. Table 7-5 and Table 7-6 show the results for the afternoon peak arterial travel time and afternoon minor movement delay, respectively. It can be seen from these tables that the effects of preemption on coordinated operation are relatively minor for a single preemption call. In general, the more preempt calls, the greater the impact on the travel time and delay for the opposing movements. This was the case with the afternoon peak as well, however the impact was slightly more pronounced.

Table 7-3 to Table 7-6 show mostly the smooth transition since this algorithm appeared to perform the best, for the majority of cases, and is most commonly used in practice today. The add and dwell transitions are shown for Paths 1 and 2 since they are considered to be the more common preemption paths in the system and would be useful for comparing alternative transition algorithms. The bottom of Table 7-3 to Table 7-6 tabulate additional selected add and dwell transitions for various paths and scenarios. Examples of the relative impact on average travel time are shown in Figure 7-2 and Figure 7-3, which show some of the most significant cumulative travel time plots for each direction. These plots allow one to compare the effects of the three transition

algorithms. Notice that the smooth transition performed slightly better in both directions.

Somewhat surprisingly, the smooth transition generally appeared to help the side street travel time and delay for both peak periods. (Table 7-6, Scenario 3). This was regardless of whether or not the preemption call was on the arterial or side street. Generally, this was not the case for other transitions, and is likely due to the fact that the smooth transition algorithm frequently shortens the cycle. Since shorter cycle lengths reduce delay, the smooth transition algorithm has a beneficial impact on side streets, as long as they are not at or near saturation. This improvement (in side street delay) was not any greater than 4% for any of the periods, relative to the base case.

It was also found that for lighter conditions (midday peak only), the smooth transition appeared to slightly help the cumulative arterial travel time and delay, generally in the direction of the preempt if the emergency vehicle had originated on the arterial. Paths 1, 2, & 4 show slight evidence of this, although none of these cases had greater than 3% improvement over the base case. Also, as would be expected, the minor movements experienced reductions in delay when an emergency vehicle path included them. The data in Table 7-6, for the westbound left-turn at Intersection 2 (Path 4) helps illustrate this point. In that particular case, the delay was reduced by nearly 25% when subject to three preemption calls in 22 minutes.

Figure 7-4 graphically illustrates the side street delay at each of the intersections within the system for three preemption calls in the westbound direction (Path 2 in Figure 7-1). This figure shows that the dwell transition procedure performed worst, and the smooth transition procedure performed best, particularly for the Southbound Ramp at JCT I-65. When examining the mainline number of stops for each of the directions, the smooth transition also performed

better than the other algorithms. Figure 7-5 illustrates another way of looking at the evaluation by tabulating the number of stops. As would be expected, stops generally increase as the number of preemption calls increase. Since intersections 2 and 3 are controlled by a single controller (running diamond control logic), the number of stops at the second ramp (Intersection 2) are dramatically lower than the first ramp (Intersection 3).

Statistical Analysis of Results

A one-sided t-test on the mean arterial travel time was performed using a 95% confidence interval. The test statistics indicated that all of the scenarios for the afternoon peak, and many of the scenarios in the midday peak, had different mean values when there were three preemption calls during the simulation period. Table 7-7 summarizes the test statistics for a variety of margins. Notice that preemption did not have a statistically significant impact for most midday scenarios experiencing a single preemption call. However, notice that as the volumes increase, the effects of preemption became more apparent, as evident in Table 7-7.

When a second check was made to determine whether or not the results were statistically different with a margin of 10 sec/veh, nearly all of the midday and half of the afternoon scenarios were not significant. In fact, none of the single preemption scenarios were significant for either period, but the majority of the second and third preempts in the afternoon period were significant. This analysis was also checked in order to determine whether or not the results were statistically significant within 15 and 20 sec/veh. Generally, as the number of preemption calls in the 22-minute simulation period were increased, the results became more significant. A summary of this analysis is shown in Table 7-7.

Referring to Table 7-7 for the afternoon peak, it can be seen that there were many preemption paths that had statistically significant results of greater than 15 sec/veh. Although all of the cases had more than a single preempt call during the simulation period, this finding indicates, not surprisingly, that a significant number of preemption calls in a short period of time can be harmful to the overall operation of the network. For this study, there appears to be some explanations for the occurrence.

Looking at Table 7-7, it can be seen that preemption Paths 2, 4, 5, 6, and 7 were the paths that were statistically significant over 15 sec/veh. Generally the problem was in the Eastbound direction at the JCT I-65 (North Ramp). It was determined that the Eastbound left-turn at this intersection was very near saturation during the afternoon rush hour. Under normal operation, this movement has just enough time to clear. Looking at the vehicle paths, it can be seen that Numbers 2, 4, 6, and 7 are preemption paths that conflict with the Eastbound left-turn. Since the left-turn at this ramp is lagging (and protected only), there was not enough time to accommodate the peak arrivals following preemption. Therefore, this left-turn lane would backup and briefly hinder the through movement. An illustration of this impact is shown in Figure 7-6.

Multiple preemption calls, in close proximity to each other appeared to cause the most serious queuing and delay problems. Path 5, even though it did not directly conflict with the movement, would impact the I-65 Northbound Ramp (Figure 6-1, Node 3) since both ramps were preempted together. Path 5 would preempt the JCT I-65 Southbound Ramp and the Eastbound through and left-turn at Node 3. This was done due to close intersection spacing and limited time for an optical preempt at the northbound ramp, had the priority vehicle turned left.

If this interchange had been operated using separate controllers, it is likely that this same procedure would have been considered due to the close

intersection spacing. Such an operation is typically a problem since it backs up all of the left-turning traffic at Node 2. Once preemption releases, both intersections revert back to the coordinated phases at the same time. This causes the left-turn to quickly back up, and creates the same problems as the other paths that were previously mentioned.

It should be noted that none of the preemption paths had statistically significant impacts greater than 30 sec/veh. Had exit phases been programmed, many of the above problems could have been reduced by immediately reverting to the Eastbound left-turn movement after the preemption had terminated. However, for the purposes of this study, it was decided that no additional variables should be considered. Another alternative would have been to either provide more slack time for the left-turn movement or switch the movement to a leading left-turn so that slack time from the non-coordinated phases could be applied when necessary. Had such adjustments been made, it is believed that the results may have been closer to the midday peak period. This is now an area for future research.

Summary of Results

Based on the above findings, the impact of preemption on a coordinated arterial has a lot to do with the amount of slack time in the preempted intersection's cycle, how well the system is programmed, and how preemption is configured to run in the network. Slack time allotted to heavy mainline left-turns, especially protected only movements, appear to be a crucial factor in quicker preemption recovery. The findings generally show that a single preemption call has minimal effect on the overall travel time and delay through the network.

The results also show that the smooth transitioning procedure performed the best with most of the scenarios and paths, for both the arterial and side

streets. When multiple emergency vehicles preempt at closely spaced time intervals the impact of preemption is generally more severe. For this network, the most severe impact observed for the average arterial travel time, was an increase on the order of 20-30 seconds. The most severe impact observed on the side street delay and minor movement delay occurred with the “dwell” transition and was also on the order of 20-30 sec/veh.

These results should not be interpreted as general guidelines for estimating the impact of preemption, since the impact is not deterministically predictable. The impact depends on a variety of factors including the intersection spacing, transitioning algorithm, saturation of the intersection, duration of the preemption, and the amount of slack time available in the cycle. Furthermore, human factor issues such as driver reaction to aggressive emergency vehicle drivers were not considered. However, the results of this research should be useful to practitioners by providing them with an “order-of-magnitude” feel for the impact of preemption on a coordinated network. Finally, as noted in the discussion section of this paper, there are research opportunities to further reduce the impact of preemption or priority devices by intelligently allocating green time after the preemption event has terminated.

Node	Direction	Midday Peak (%)			Afternoon Peak (%)		
		LT	TH	RT	LT	TH	RT
1	NB	39	7	54	34	5	61
1	SB	69	4	27	73	1	26
1	EB	8	83	7	4	89	7
1	WB	4	83	13	7	79	14
2	SB	29	0	71	40	0	60
2	EB	0	82	18	0	81	19
2	WB	3	97	0	4	96	0
3	NB	80	0	20	77	0	23
3	EB	23	77	0	22	78	0
3	WB	0	83	17	0	75	25
4	NB	97	0	3	97	0	3
4	SB	75	15	10	75	15	10
4	EB	0	55	45	0	67	33
4	WB	6	94	0	6	94	0

Table 7-1: Turning Movement Percentages for the Studied Network

Preemption Scenario	Entry Time of Emergency Vehicle Into Network (s)		
	First Vehicle	Second Vehicle	Third Vehicle
0 – Base case			
1	$t_0 + 60$		
2	$t_0 + 60$	$t_0 + 150$	
3	$t_0 + 60$	$t_0 + 150$	$t_0 + 700$

Table 7-2: Times that Emergency Vehicles are Introduced into Network

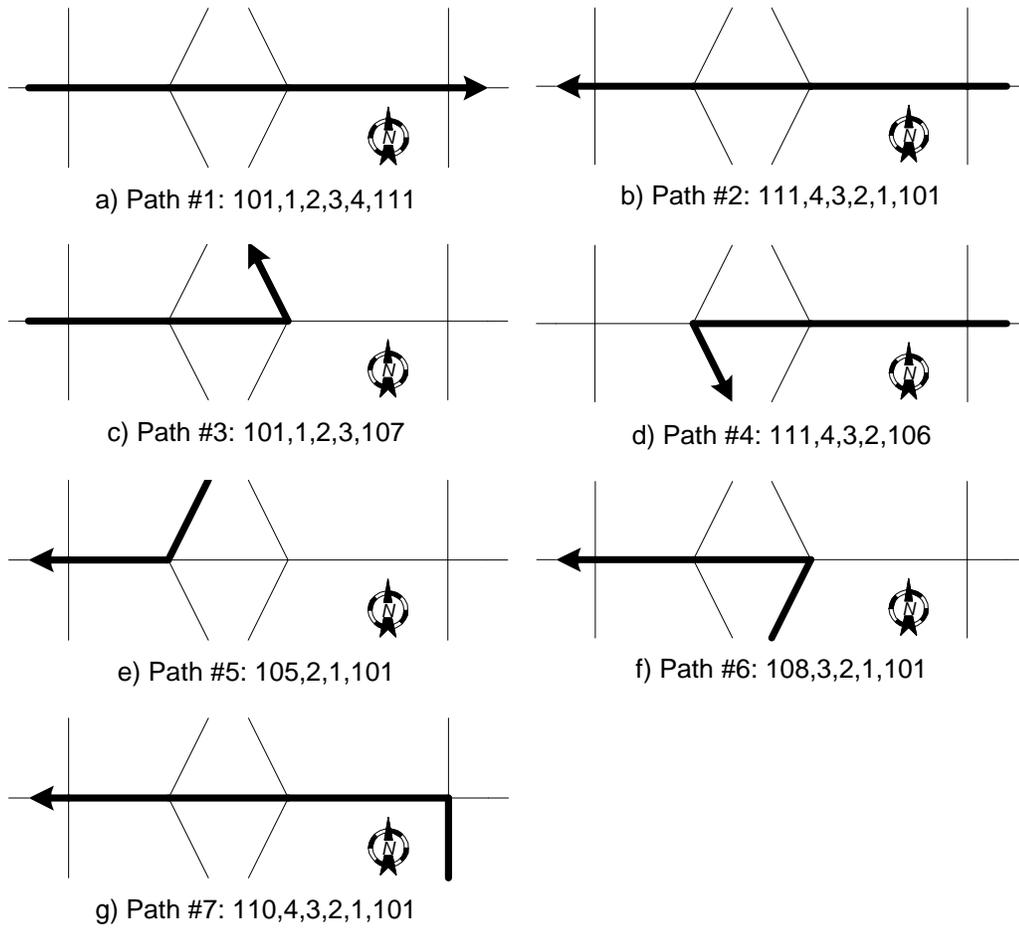


Figure 7-1: Studied Paths of Emergency Vehicles

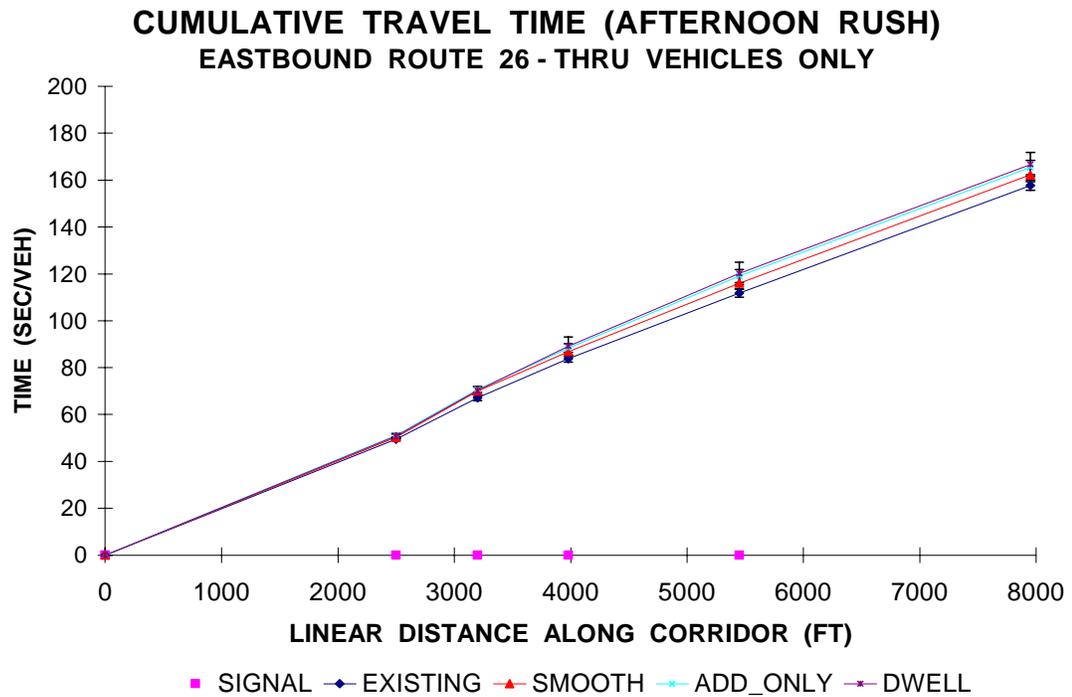


Figure 7-2: Cumulative EB Travel Time Subject to Path #5, Scenario 1

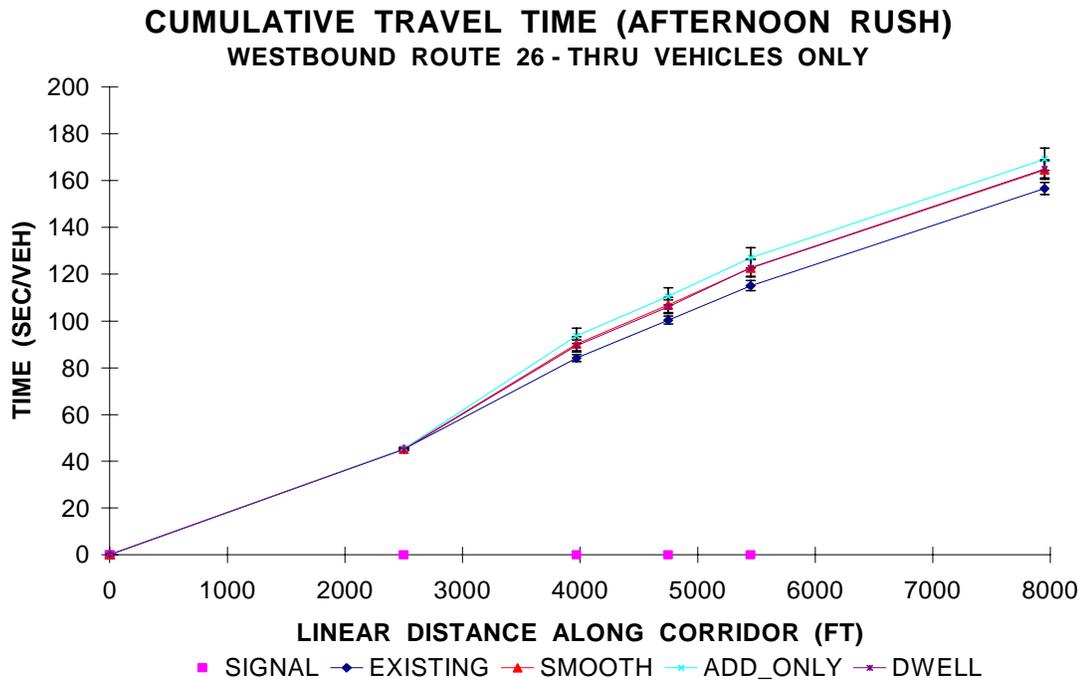


Figure 7-3: Cumulative WB Travel Time Subject to Path #3, Scenario 2

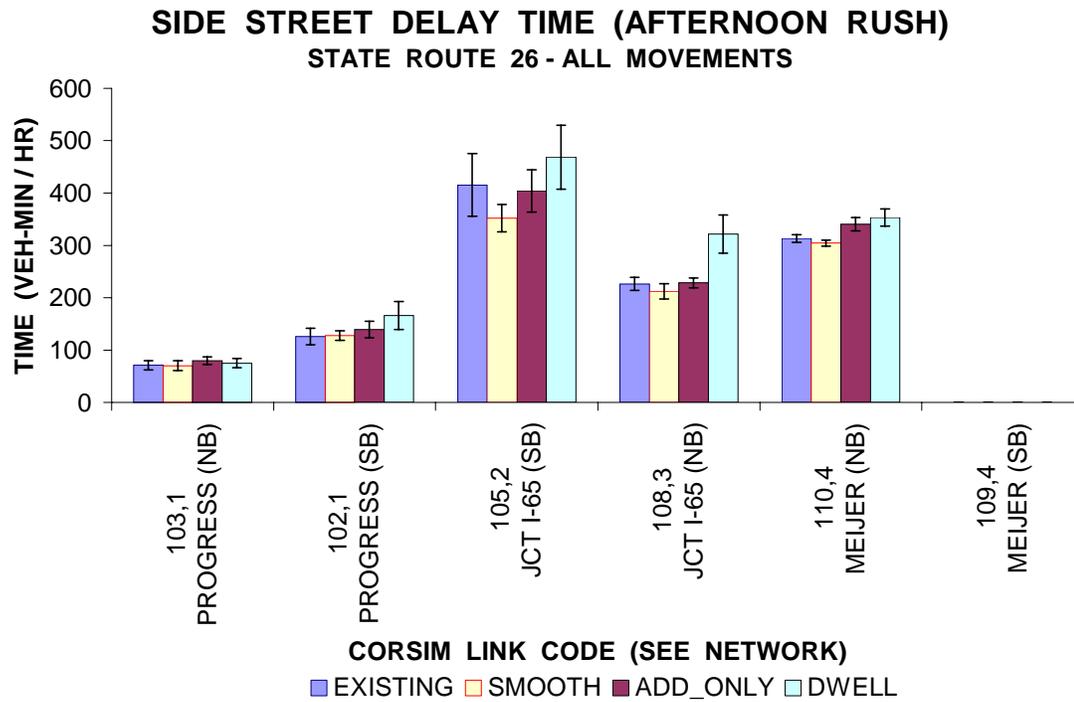


Figure 7-4: Minor Movement Delay Subject to Path #2, Scenario 3

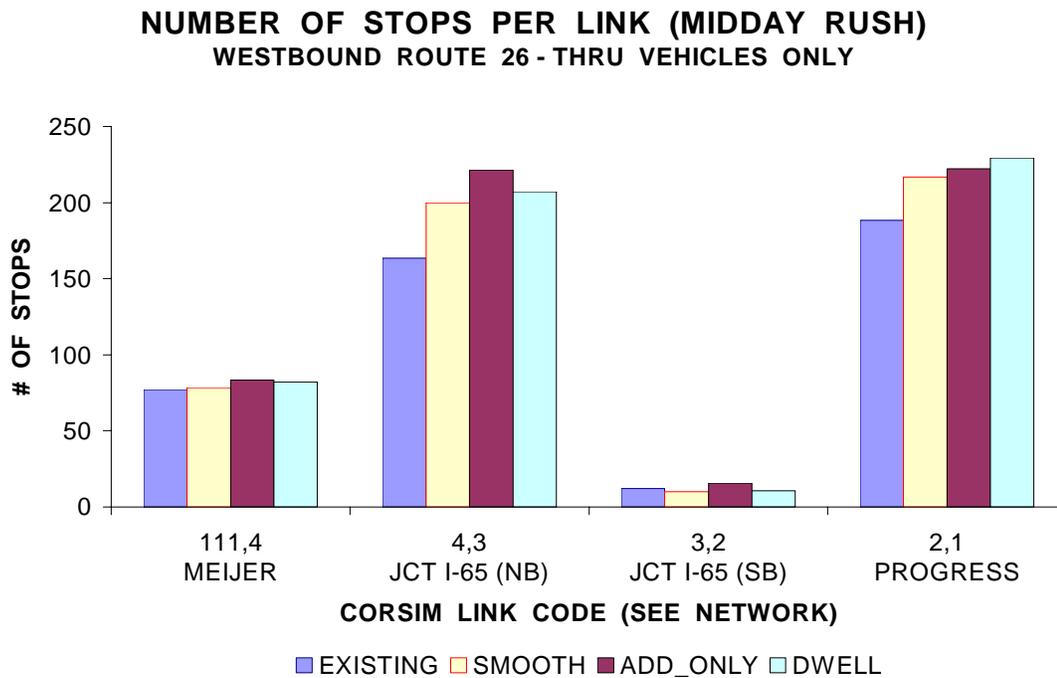


Figure 7-5: WB Number of Stops per Link Subject to Path 1, Scenario 2

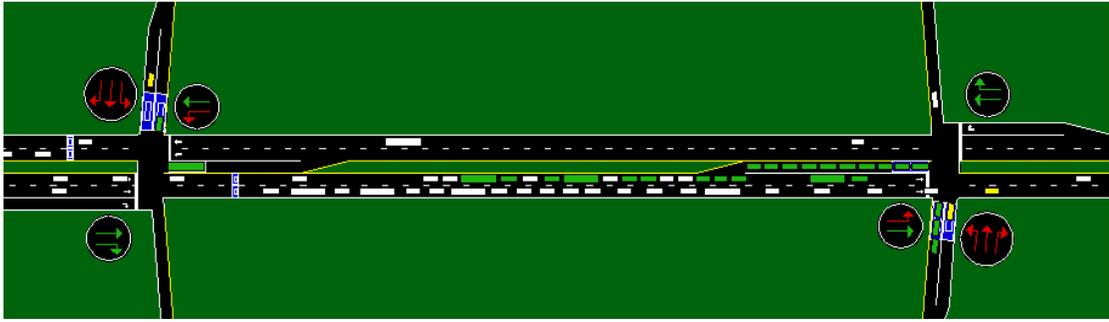


Figure 7-6: Typical Impact of Inadequate Slack Time for the EBLT

Scenario (Table) (7-2)	Path (Fig) (7-1)	Trans	Cum. WB Travel Time (s/v)	STDEV Of EB Travel Time (s/v)	Cum. WB Travel Time (s/v)	STDEV Of WB Travel Time (s/v)
0			152.1	4.7	156.8	4.9
1	1	SMT	152.2	4.2	160.5	5.7
1	1	ADD	152.0	3.2	161.4	6.3
1	1	DWL	151.3	3.9	159.8	5.9
1	2	SMT	155.2	6.4	156.7	11.2
1	2	ADD	155.9	6.3	160.6	12.0
1	2	DWL	155.1	6.0	156.1	10.4
1	3	SMT	152.6	3.8	161.0	7.2
1	4	SMT	153.5	7.8	156.4	9.1
1	5	SMT	155.6	4.6	164.5	5.9
1	6	SMT	155.7	5.5	159.9	5.0
1	7	SMT	155.6	4.5	159.8	5.0
2	1	SMT	150.2	7.0	167.9	10.1
2	1	ADD	152.2	4.5	167.4	6.7
2	1	DWL	152.3	4.0	167.1	8.3
2	2	SMT	161.9	6.0	160.9	5.7
2	2	ADD	162.8	6.9	165.0	6.2
2	2	DWL	163.5	7.2	159.0	5.3
2	3	SMT	152.8	4.6	164.2	7.9
2	4	SMT	160.5	6.0	159.7	5.4
2	5	SMT	159.2	7.0	172.5	10.2
2	6	SMT	164.9	9.6	163.2	6.1
2	7	SMT	161.0	6.8	161.1	6.4
3	1	SMT	151.5	3.6	171.9	9.0
3	1	ADD	152.2	5.2	170.7	7.8
3	1	DWL	152.4	5.2	171.2	9.6
3	2	SMT	163.6	5.4	163.8	6.8
3	2	ADD	167.2	6.8	170.1	9.4
3	2	DWL	163.3	5.4	162.4	5.8
3	3	SMT	152.6	4.4	167.7	8.3
3	4	SMT	164.9	9.7	160.5	5.4
3	5	SMT	161.1	7.4	179.2	13.1
3	6	SMT	165.4	7.7	166.7	6.0
3	7	SMT	164.4	7.3	163.6	5.6
1	4	ADD	156.3	8.0	159.5	10.4
2	5	ADD	159.2	6.2	174.7	11.2
3	6	ADD	170.0	11.4	171.2	9.6
1	6	DWL	156.2	5.2	159.5	7.7
2	5	DWL	158.4	5.0	173.1	9.8
3	4	DWL	163.2	6.3	162.1	5.4

Table 7-3: Summary of Midday Arterial Travel Times

Scenario (Table) (7-2)	Path (Fig) (7-1)	Trans	Int 1 NB (s/v)	Int 1 SB (s/v)	Int 2 SB (s/v)	Int 2 WB LT (s/v)	Int 3 NB (s/v)	Int 3 EB LT (s/v)	Int 4 NB (s/v)
0			81.3	97.1	81.4	72.6	97.5	53.1	103.5
1	1	SMT	79.6	99.3	80.7	77.2	97.5	51.9	103.2
1	1	ADD	80.3	97.3	81.7	83.2	100.6	54.9	106.5
1	1	DWL	81.5	99.8	81.7	83.2	99.9	55.7	106.8
1	2	SMT	82.3	94.3	82.3	69.0	97.9	53.2	93.7
1	2	ADD	82.8	98.0	80.5	71.3	99.5	53.3	105.3
1	2	DWL	78.6	94.6	80.5	66.8	97.9	60.7	106.6
1	3	SMT	79.4	97.9	79.5	71.9	98.4	50.0	103.6
1	4	SMT	79.6	93.6	81.7	57.3	98.2	54.7	91.4
1	5	SMT	81.0	97.5	79.5	75.3	102.1	52.0	102.9
1	6	SMT	79.8	94.2	79.9	72.0	96.1	54.3	103.8
1	7	SMT	80.6	94.9	80.6	76.4	97.3	55.0	102.1
2	1	SMT	78.8	93.5	79.8	77.1	97.8	46.6	100.9
2	1	ADD	80.1	96.7	80.4	86.7	101.4	50.6	106.1
2	1	DWL	82.8	99.2	81.9	81.8	101.8	54.3	106.0
2	2	SMT	80.9	96.7	79.9	69.7	99.3	59.7	103.1
2	2	ADD	80.7	97.8	81.9	76.0	100.2	60.3	105.5
2	2	DWL	79.9	99.6	81.5	74.2	98.9	67.3	107.1
2	3	SMT	80.0	94.9	80.0	74.5	97.0	47.9	103.0
2	4	SMT	80.5	96.2	80.6	57.1	96.7	56.2	104.1
2	5	SMT	79.6	97.3	79.7	77.0	97.4	51.2	102.8
2	6	SMT	79.6	96.8	80.7	71.7	94.1	57.1	104.0
2	7	SMT	79.4	96.6	81.5	70.1	98.9	55.3	101.1
3	1	SMT	79.0	98.0	80.8	74.2	99.1	49.1	102.1
3	1	ADD	81.1	100.7	82.3	82.7	103.7	49.6	109.8
3	1	DWL	80.6	102.5	84.9	92.3	105.1	53.9	110.5
3	2	SMT	81.1	97.8	81.0	68.5	98.5	58.7	103.2
3	2	ADD	79.6	99.1	82.9	69.9	101.3	59.8	108.5
3	2	DWL	80.9	101.3	84.9	73.8	105.5	76.9	107.3
3	3	SMT	78.8	97.9	80.0	78.0	98.9	46.7	103.3
3	4	SMT	79.5	97.0	80.8	49.6	98.0	64.6	104.5
3	5	SMT	80.1	98.3	78.7	74.8	101.8	50.2	103.9
3	6	SMT	78.1	96.9	81.5	64.3	90.6	68.0	103.0
3	7	SMT	80.2	96.9	79.5	66.9	99.7	61.9	98.4
1	4	ADD	80.2	94.8	79.0	62.5	99.9	54.5	96.2
2	5	ADD	79.9	98.7	79.7	75.6	101.2	50.5	103.8
3	6	ADD	80.4	99.7	80.7	67.2	94.5	67.2	104.9
1	6	DWL	81.7	95.4	81.9	71.5	97.0	60.5	104.1
2	5	DWL	79.0	100.5	80.0	75.9	101.7	54.7	103.9
3	4	DWL	80.1	95.2	83.7	60.3	106.4	70.5	108.5

Table 7-4: Summary of Midday Minor Movement Delay

Scenario (Table) (7-2)	Path (Fig) (7-1)	Trans	Cum. EB Travel Time (s/v)	STDEV Of EB Travel Time (s/v)	Cum. WB Travel Time (s/v)	STDEV Of WB Travel Time (s/v)
0			157.7	3.7	156.6	4.4
1	1	SMT	158.9	4.7	161.2	5.0
1	1	ADD	160.8	6.4	161.4	5.8
1	1	DWL	163.7	14.3	159.8	5.1
1	2	SMT	166.9	7.0	159.3	5.5
1	2	ADD	170.2	8.9	164.8	6.6
1	2	DWL	165.7	6.7	159.8	5.8
1	3	SMT	162.3	8.3	162.4	6.5
1	4	SMT	167.4	6.3	158.5	5.9
1	5	SMT	162.3	5.2	162.0	6.2
1	6	SMT	166.1	6.4	160.0	5.7
1	7	SMT	175.0	20.6	161.7	10.2
2	1	SMT	159.6	4.1	165.7	5.3
2	1	ADD	163.7	6.2	171.9	8.1
2	1	DWL	161.3	4.8	167.5	6.7
2	2	SMT	184.6	18.2	159.5	4.8
2	2	ADD	183.6	11.0	165.2	8.6
2	2	DWL	185.7	23.4	161.0	5.2
2	3	SMT	159.9	3.7	164.6	6.8
2	4	SMT	182.2	14.0	158.7	4.6
2	5	SMT	170.4	8.3	170.9	7.2
2	6	SMT	183.2	18.0	162.5	5.6
2	7	SMT	177.0	10.6	162.3	5.3
3	1	SMT	160.9	4.2	171.0	7.9
3	1	ADD	162.7	5.4	174.5	10.8
3	1	DWL	162.2	11.5	169.2	7.7
3	2	SMT	195.1	19.3	164.8	8.2
3	2	ADD	194.7	14.1	176.5	9.6
3	2	DWL	190.3	17.0	161.3	5.3
3	3	SMT	161.0	4.8	171.0	8.2
3	4	SMT	189.5	10.0	161.9	5.4
3	5	SMT	178.0	9.7	178.9	12.4
3	6	SMT	197.7	19.0	167.4	6.2
3	7	SMT	189.5	14.0	163.0	5.1
1	6	ADD	171.4	7.8	168.3	6.3
2	4	ADD	187.6	13.4	167.5	6.6
3	5	ADD	179.9	9.7	189.9	14.3
1	5	DWL	166.7	8.7	163.4	5.9
2	6	DWL	200.3	26.3	162.5	4.8
3	7	DWL	191.4	13.6	164.9	6.1

Table 7-5: Summary of Afternoon Peak Arterial Travel Times

Scenario (Table) (7-2)	Path (Fig) (7-1)	Trans	Int 1 NB (s/v)	Int 1 SB (s/v)	Int 2 SB (s/v)	Int 2 WB LT (s/v)	Int 3 NB (s/v)	Int 3 EB LT (s/v)	Int 4 NB (s/v)
0			85.1	108.3	101.0	84.7	109.6	52.7	107.4
1	1	SMT	85.2	114.1	99.1	81.3	112.4	50.3	107.6
1	1	ADD	85.7	111.8	98.5	97.1	111.8	53.1	108.5
1	1	DWL	86.3	113.2	108.4	94.0	126.1	62.8	110.4
1	2	SMT	85.4	106.4	98.6	80.6	110.2	61.7	105.9
1	2	ADD	85.8	104.8	103.1	91.2	110.3	58.4	108.3
1	2	DWL	85.2	118.2	122.0	84.0	134.7	73.8	110.7
1	3	SMT	86.8	108.7	104.1	84.8	109.6	53.4	106.6
1	4	SMT	85.4	105.0	94.2	75.4	110.0	61.2	107.6
1	5	SMT	87.6	106.8	92.5	84.0	109.6	50.7	107.4
1	6	SMT	85.5	107.9	98.3	80.3	106.9	58.7	106.7
1	7	SMT	84.9	106.6	94.9	84.7	109.2	60.7	104.6
2	1	SMT	84.3	103.1	96.7	84.4	108.0	48.5	106.4
2	1	ADD	82.6	106.6	101.2	94.6	115.5	49.8	108.2
2	1	DWL	88.2	118.4	103.6	93.3	129.4	53.3	110.1
2	2	SMT	85.7	106.4	95.6	82.5	109.8	65.4	106.9
2	2	ADD	85.6	109.0	99.6	83.5	111.4	64.8	108.6
2	2	DWL	85.9	108.8	102.4	87.2	127.8	91.7	108.3
2	3	SMT	85.7	106.8	99.0	82.5	112.4	46.8	106.6
2	4	SMT	83.9	108.0	95.2	68.5	107.5	66.8	106.7
2	5	SMT	85.9	104.6	94.6	84.9	111.7	51.6	105.6
2	6	SMT	85.6	108.9	102.0	80.5	105.2	88.4	107.0
2	7	SMT	83.2	105.8	94.7	83.9	112.5	62.0	103.9
3	1	SMT	86.4	106.7	96.2	83.3	110.3	48.5	108.1
3	1	ADD	86.6	110.0	99.8	87.9	114.9	51.0	110.6
3	1	DWL	89.4	132.4	111.6	101.2	139.6	67.2	111.2
3	2	SMT	85.0	109.3	94.4	76.5	106.9	69.1	106.3
3	2	ADD	89.4	114.6	110.5	83.8	110.9	77.5	111.7
3	2	DWL	87.5	124.3	106.9	87.0	132.5	96.0	113.8
3	3	SMT	84.7	105.0	95.5	82.1	109.4	48.1	105.0
3	4	SMT	87.8	106.8	98.9	64.1	112.8	75.6	106.9
3	5	SMT	84.8	107.0	93.9	89.8	114.4	54.0	107.7
3	6	SMT	84.3	104.9	101.4	70.0	98.9	86.1	106.8
3	7	SMT	84.7	105.0	99.2	76.8	111.3	78.7	103.2
1	6	ADD	86.3	108.7	100.6	85.4	109.1	63.1	107.1
2	4	ADD	85.6	109.7	100.0	77.0	112.6	60.7	107.7
3	5	ADD	84.8	108.6	99.7	88.4	114.7	54.4	106.7
1	5	DWL	85.7	113.0	103.1	83.2	130.9	59.8	106.4
2	6	DWL	86.7	116.2	109.2	90.1	122.7	125.0	106.1
3	7	DWL	88.6	123.4	110.5	87.6	135.6	104.0	110.8

Table 7-6: Summary of Afternoon Peak Minor Movement Delay

Scenario / Path	MIDDAY PEAK PERIOD				AFTERNOON PEAK PERIOD			
	Arterial direction that has a significant statistical difference in travel time for various scenarios				Arterial direction that has a significant statistical difference in travel time for various scenarios			
	>0 (s/v)	>10 (s/v)	>15 (s/v)	>20 (s/v)	>0 (s/v)	>10 (s/v)	>15 (s/v)	>20 (s/v)
1 / 1					WB			
1 / 2					EB			
1 / 3					WB			
1 / 4					EB			
1 / 5	WB				EB WB			
1 / 6					EB			
1 / 7					EB			
2 / 1	WB				WB			
2 / 2	EB				EB	EB	EB	
2 / 3	WB				WB			
2 / 4	EB				EB	EB	EB	
2 / 5	EB WB				EB WB			
2 / 6	EB WB				EB WB	EB		
2 / 7	EB				EB WB	EB		
3 / 1	WB				WB			
3 / 2	EB WB				EB WB	EB	EB	EB
3 / 3	WB				WB			
3 / 4	EB				EB WB	EB	EB	EB
3 / 5	EB WB	WB			EB WB	EB WB		
3 / 6	EB WB				EB WB	EB	EB	EB
3 / 7	EB WB				EB WB	EB	EB	EB

Table 7-7: Statistical Significance Tests on Arterial Travel Time

CHAPTER 8 – TRAFFIC RESPONSIVE ANALYSIS OF THE SR 26 (SOUTH) NETWORK – LAFAYETTE, IN

Chapter Overview

This chapter will use the simulation and evaluation concepts previously discussed and examine some of the more advanced features available on modern traffic signal controllers. For simplicity and comparison purposes, the network used for the preemption analysis will also be used in this chapter. Rather than focusing on issues at the local (intersection) level, like in previous chapters, the remainder of this document will look at evaluating system performance for an entire group of signals. With the modern technology, this is typically accomplished with the use of a master controller or central control center that would change the operation of the system (group of signals) as desired. Hardware-in-the-loop simulation would then be used to quantitatively evaluate the performance of the system as a whole.

There are essentially two methodologies for changing the operation of the system. These include both the traditional Time-of-Day (TOD) pattern changes, where the system operation is updated based on a pre-programmed schedule, or a Traffic Responsive (TRP) procedure where the signal operation is updated based on the current traffic demands within the network. Provided that all of the local parameters have been configured appropriately, the traditional Time-of-Day configuration is the quickest and easiest way to control the system since the appropriate plan can always be specified for the relative time period. It works well when traffic patterns are known and consistent on both an hourly and weekly

basis. However, when volumes are inconsistent, because of weather, incidents, or events, the Time-of-Day procedure may not always be the most efficient.

In cases of stochastic traffic variations which differ on a weekly basis, it may be beneficial to use a traffic responsive procedure, so that the system could respond to the current traffic conditions by automatically selecting a preprogrammed system algorithm. This is typically accomplished by using system detectors that are strategically placed within the system. Such detectors are capable of taking both volume and occupancy counts, which the master controller, or central control center, would process and automatically select the appropriate plan, based on the current information. Both the details and configuration for evaluating each of these procedures will be discussed in the subsequent section.

The procedures discussed above are not the only way to coordinate a system. Recently, the trend has been aimed toward real-time traffic adaptive systems. Some of the more common systems include SCOOT, SCAT, OPAC, and RHODES [Bretherton, 1990], [Dobinson, 1980], [Gartner, 1983], [Head, 1992], [Head, 1998]. These are each different and unique, in their own way, but are different from a traffic responsive system in that they generate their own timing plans. RHODES is even more unique in that there is no defined cycle length for any of the intersections within the system, and the operation is constantly changing based upon a delay equation. Conversely, with traffic responsive operation, all of the plans are programmed in advance, at which time the master controller, or central control center, would automatically attempt to match the current traffic conditions with the best existing system plan.

Considering that traffic adaptive systems are rather new, and that there is a lot of work to be done in the area, only the traffic responsive procedures will be compared with the traditional time-based coordination procedures as part of this

research. Although the concept behind traffic responsive operation has been around for nearly 30 years, and is available with many of the newer systems, it has typically gone unused in most regions because of lack of familiarity with the parameters and design procedures. In addition, each of the controller vendors typically have their own parameters and methodologies that are used for configuring the operation, which complicates the process even more. This makes such procedures difficult to learn and comprehend, without some type of evaluation methodology that can be used to help understand the overall effect that each of the parameters will have on the overall operation of the system.

Realizing that traffic responsive features are available with the modern technology, the remainder of this research will look at quantitatively evaluating these systems, by building on the basic evaluation concepts discussed in previous chapters. In order to help better determine the advantages and disadvantages of the traffic responsive methodologies, all results will be compared with the traditional timed-based approach, which is most prevalent today. Based on remaining discussions, the reader should have a better understanding of traffic responsive methodologies and how to effectively evaluate them. This is useful because the procedures discussed herein can be applied to other systems as well, even those developed outside the United States, such as SCOOT and SCAT.

Overview of the System

The network used for this study is the same as that used for the preemption analysis. Figure 8-1 shows the network, and intersection spacing, which extends from Progress Drive to Meijer Parkway on SR 26 (South) in Lafayette, IN. Since the entry volumes for the network are constantly changing, they are summarized in Table 8-1, along with the relative turning percentages in Table 8-2, on a per period basis. Again, Nodes 2 and 3, shown in Figure 8-1,

make up the diamond interchange, which is operated by a single controller. The local geometric lane and detector configurations for each of the intersections in the system can be found in Figure 8-2, while the precise location of both the detector and pocket lengths are shown in Table 8-3.

The phasing diagrams are shown in Figure 8-3, while the relative ring structures are found in Figure 8-4 or Figure 8-5, which depend on the operation of the diamond. Considering that the interchange will be acting as one (single controller), the ring structure in Figure 8-5 applies. Notice how this is consistent with the phasing diagram shown in Figure 8-3. The details behind these diagrams were thoroughly discussed in the preemption chapter. Figure 8-6 and Figure 8-7 use the same approach labels and CID file, as in the preemption network with the only difference being that the CID file (Figure 8-7) does not have the “Preempt 32 31 26” after Node 4 in the initialization section. This is because preemption is not being analyzed for this portion of the research.

Configuration of System Detectors

Now that all the controller outputs have been integrated to work with the simulation, via the CID file, we will now focus on configuring the internal detectors (inputs) to do the same. There is no significant deviation here from the preemption network, other than the preemption detectors have been removed, and new system detectors have been added. Figure 8-8 shows all detectors for each of the intersections in the system. The system detectors, which have been added as part of the study, are represented by the brackets “[]” that are shown in the figure. In some cases, the system detectors are located beyond the extents of the image, and hence, such detectors are noted in the caption. For this study, notice that there are ten system detectors that were used.

It is important to note that not all of the detectors shown in Figure 8-8 have the same number as their associated phase. Many times there were additional detectors required, which were then linked to their associated phase through the actual control equipment. For example, looking at Intersection 1, shown in Figure 8-8a, it can be seen that the Northbound Detectors 3 and 16 call Phases 3 and 8, respectively. This becomes apparent after checking the relative phasing diagram and ring structure shown in Figure 8-3a and Figure 8-5a. Such information can also be verified by viewing the actual assignments shown in Table 8-5. In this case, Phase 3 calls the Northbound left-turn, as expected, however Detector 16 calls Phase 8. For this case, Detector 16 could have very easily been Detector 8, since it is not being used anywhere else at the intersection. However since there is a delay value assigned to that lane (Table 8-5), it was decided to use a different detector that would help remind the field engineer of that.

The previous case reminds the reader that detectors greater than eight must be assigned to their respective phases (Table 8-5). Such programming is also required for Detectors 1 to 8, however since a standard intersection consists of eight phases, they are typically already defaulted to call their respective phases (e.g. Detector 1 calls Phase 1, etc). This is sometimes overlooked, and hence, the auxiliary detectors (Detector 9+) would not be assigned to their respective phase(s). Such an occurrence would result in either missed calls, or false calls at the intersection. To help emphasize this, look at the Southbound Detectors for Intersection 2, shown in Figure 8-8b. Following the logic previously discussed, and referring to Table 8-5, it can be seen that Detectors 4 and 12 both call Phase 4. Also realize that Detector 12 (exclusive right-turn lane) has a 20 second delay assigned (right-on-red), which is the primary reason why detectors were required in each lane.

Had there been no delay for these detectors, then both could have been wired into the Detector 4 input and thus, no special programming would be required. However, since there is a delay for Detector 12 at Intersection 2, it is important that it be mapped to Phase 4. At this particular intersection, Detector 12 is critical since it calls ramp phase for right-turning vehicles. In the morning, the majority of the traffic is turning right, towards Purdue University. Had this detector not been programmed, the ramp phase would never be called, thereby backing up traffic onto the Interstate. Left-turners could eventually activate the signal, however, they most likely would not be able to trip Detector 4 because of spillback, which would prevent them from accessing the left-turn lane. During this peak, the right-turn demand can not be accommodated during the red interval, and hence, Detector 12 must be programmed to operate as desired.

These concepts were introduced because system detectors operate almost the same way as the auxiliary detectors. In fact, all system detectors are essentially auxiliary detectors, because they each must be assigned to the appropriate input and traffic function. Failure to do so may result in the wrong plan being selected under traffic responsive operation, which can greatly impact the overall performance of the arterial. Hence, strong emphasis will be placed on the correct configuration of these detectors. Looking at Figure 8-9, it can be seen that the local detector configuration exactly matches that used in the preemption chapter. The only difference is that the ten system detectors, used as part of this study, have been added to the file. Recall that the system detectors are represented by the brackets “[]” as shown in Figure 8-8.

Referring to Figure 8-9, it can be seen that each of the ten system detectors have been commented and noted. Looking at the first system detector, and following the procedures used for the local detectors, it can be seen that the first system detector is found in Line 4, and is located on Link 101,1 (Figure 8-9). It can also be noted that this detector is in the left through lane (Denoted by a “2”

in Column 3) and is setback 2,200 feet from the stopbar. It has a Station ID number of 109 and is 6 feet in length. When examining the caption in Figure 8-8a, it can be determined that Detector 9 is located west of the image shown in Figure 8-8a. Looking at Line 5 of Figure 8-9 it can be seen that the information exactly matches Line 4 with the exception of Columns 3 and 5. The "1" in Column 3 implies that the detector is in the right lane and the Station ID of 111 indicates that this detector (Number 11) is also tied to CID 1. As seen from the figure, all other information regarding these detectors are identical.

Continuing to look at Figure 8-9, it can be seen that both system detectors, and all other detectors for that matter, operate in presence mode. This can be verified by the fact that Column 7 is empty for all detectors. Looking at Lines 11 and 12, in Figure 8-9, the next two system detectors can be located. Referring to Line 11, and following the same concept above, it can be determined that Detector 13 is assigned to CID 2 (Station ID = 213), which is located on the left lane (Column 3) of Link 2,1. This detector is setback 600 feet from the stopbar of the first intersection and has a length of 6 feet. The information in Line 12 is identical to Line 11, other than this detector (Number 15) is located in the right lane of the same link. Figure 8-8b can be used to verify the locations of these system detectors, which are clearly shown on the image.

Following this same procedure, one can configure the remainder of the system detectors, shown in Figure 8-9. Looking at this figure, system detectors are easy to find because of the comments. However, even if the comments were removed, they could still be readily identified, using the setback distance shown in Column 4. Recall that all local detectors are generally located at the stopbar or are setback a distance on the order of 250 to 300 feet (dilemma zone detection). Hence, using the ITRAF coding and multiplying by 10, any blank (stopbar) or setback distance (Column 4) on the order of 2,500 to 3,000 is most likely a local detector. All other detectors are usually system detectors, since

they are typically located anywhere from 100 to 300 feet after the intersection. This would result in setback distances that are only slightly less than the intersection spacing.

Looking at Figure 8-9, it can be seen that these detectors generally have setback distances greater than 600 feet. The only exception in this system, are detectors on the interstate ramps, which are setback 380 from the stopbar. This is far enough, that it would be unlikely for traffic to queue over them. If such an event were to occur, it would be apparent that a different pattern should be selected in order to help alleviate the congestion on the ramps. Ideally, it is not desirable for traffic to queue over system detectors, which is why they are typically located after major intersection. Such a location allows for the counting of arterial through traffic, in addition to turning traffic (often heavy) from the side streets. However, when one desires to include traffic on side streets, as part of the system count, a large setback distance is not always possible. Figure 8-8 shows the remainder of the system detectors that correspond with the detector file in Figure 8-9. The programming and mapping of these detectors will be discussed in the subsequent section.

System Detector Mapping

Table 8-3 shows all of the pocket geometry along with the lengths and setback distances of all the local detectors. This information matches that shown in Figure 8-8, which corresponds to the detector coding just discussed in Figure 8-9. Recall that each of these detectors require a station identification number, so that they can correspond with the appropriate address on the actual control equipment. These assignments are summarized in Table 8-4 on a per intersection basis. From this table it can be verified that all the detectors are operating in presence mode. Table 8-5 shows some of the additional parameters that are associated with each of the local detectors. The most important piece of

information in this table is the actual phase that each of the detectors are assigned to. The importance of this assignment was discussed in the previous section. Other information found in Table 8-5, includes the detector number, operational mode, detector delay, and the detector type, all of which were discussed in previous chapters.

Now that the local intersection detectors have been properly assigned and configured, Table 8-6 will summarize the configuration of the ten system detectors, used for selecting the desired traffic responsive plan. This table is similar to Table 8-4, however it also includes additional information that is only pertinent to system detectors, such as the local and system telemetry address, and also the system detector number. The detector length and setback distance from the upstream intersection is also shown here. Since system detectors are almost never located at the stopbar, there is typically only one detector that is required per lane. This detector is usually a standard 6 by 6 loop, which has its own amplifier associated with it. It is generally not recommended to tie parallel system loops in series (e.g. [13] [15] in Figure 8-8b). Such reasoning will be discussed in the subsequent sections.

Looking at Table 8-6, it can be seen that all the system detectors have a length of 6 feet, which is typical. Also notice how both the Station ID and detector numbers are shown here as well. The Station ID numbers found in Table 8-6 directly match those found in the detector file (Figure 8-9) for system detectors. Recall that the last two digits of the Station ID are the detector number while the first number specifies which CID the detector is assigned to. For example, looking at the first line of Table 8-6, it can be seen that the Station ID of 109 is really local Detector 9, which corresponds to Line 4 of Figure 8-9. Looking down the list in Table 8-6, the actual detector numbers can be easily determined, based upon the Station ID.

When viewing the detector number column of Table 8-6, it can be seen that there are two detectors that have the Number 9 assigned to them. However, when looking at the Station ID's, it can be seen that they have a identification of 109 and 209, thereby meaning that they are assigned to CID 1 and CID 2, respectively. Had these detectors had the same Station ID, an error would have resulted. Realize that Station ID's can only be used once, regardless of whether it is a local or system detector that is being configured. This is why Station ID's 109 and 111 are not found for Intersection 1, in Table 8-4. The same is true for the remainder of the Station ID's shown in Table 8-6. Likewise the detector numbers 11, 13 and 15 are used twice, however after careful examination it can be seen that each of the duplicates have been assigned to a different CID, which are thereby connected to a different controller.

The data from the system detectors eventually ends up at the master controller or central control center. It would be very costly to wire each system loop directly to the master, as such a procedure would require a lot of trenching, depending how far away the detector is from the master controller. Hence, these detectors are typically wired directly to the controller cabinet of the nearest intersection, at which time the telemetry would send the information to the master. Recall that system loops are typically placed anywhere from 100 to 300 feet after an intersection. Given such criteria, there is usually a controller cabinet nearby, which to link the detectors. Often times the existing raceway junction boxes can be used to feed the inputs of the system detectors.

The above concept is important, because there is a slight difference from how CORSIM references the location of these detectors, compared with how they are actually identified in the field. CORSIM references all detectors from the upstream signal, while in the field, the detector is typically referenced from the nearest intersection. This is generally not a problem with local detectors since they are traditionally located on the approach to the nearest intersection,

however with system detectors, they are typically located after the intersection, which is also the approach to the upstream intersection. This is why some of the setback distances shown in Figure 8-9 are so large. These very same distances, or setbacks, can also be seen in Table 8-6. A “-“ in front of the setback distance means that the system detector is referenced the traditional way, and is actually on the approach to the relative intersection, and not the upstream junction.

Lines 7 and 8 of Table 8-6 help illustrate this case, which was discussed in the previous section. For example, the “-“ in front of the 380 at Intersections 2 and 3 (Interchange) mean that the system detector is actually located on the approach to the intersection. Looking at the movement column, it can be seen that these detectors are located on both the Southbound and Northbound approaches of the interchange, which are really the ramp movements. Considering that there are no downstream intersections on the ramps, the only location for the system detectors is on the actual approach. Hence, the configuration of this detector would be much like a standard raceway detector. As previously discussed, such detectors should be located far enough back such that traffic will not queue over the detectors on a regular basis. If volumes are light, it may be possible to use the traditional raceway detectors (if they exist), as both system and dilemma zone detectors.

Looking at Table 8-6, it can be seen that the only other detectors that are located on the actual approach to the intersection (“-“) are Lines 1 and 2, which have a setback distance of -2,200 feet. Looking at these detectors it can be seen that both detectors are located on the Eastbound approach to Intersection 1. The “*” after the local telemetry Number 1 represent that an alternate address was used, other than what would typically be assigned in the field. For this case, these system detectors would have been linked to the Farrington Drive intersection, which is just one street West of Progress Drive. However since Farrington Drive was not modeled in the simulation, Progress Drive was used

instead, which is what the asterisk (“*”) indicates. For modeling purposes, this does not change the outcome of the results, however in the field it would be much less expensive to link the detectors to Farrington, since it is closer to this particular group of system detectors.

From Table 8-6, it can be seen that there is also a telemetry number, telemetry address, and system number that must be assigned for each of the system detectors. Telemetry addresses are important since they separate all the controllers from one another. This way the master controller or central control center would always be able to determine exactly which controller the information is coming from. The telemetry address is assigned to each controller and can be any number, within given constraints, realizing that no two controllers in the system could have the same telemetry address. In order to prevent this from occurring, it is always good to begin with the Number 1 and increment the address sequentially through the system, realizing that one telemetry address is required for each controller. Hence, the diamond interchange, which is operated with a single controller, will require one address. Had two controllers been used at the diamond, separate addresses would be necessary.

Since only one CID is required for each controller and the numbering of the CID's are consistent with the telemetry addresses, these numbers should directly match one another. This can be verified by examining Table 8-6, and making sure that the first number of the Station ID directly matches the local telemetry address. When doing so, it can be seen that they match up perfectly. The next column shows the system telemetry address. With this particular vendor, there are eight local system detector addresses, which are expandable to sixteen, with the use of auxiliary addresses. Since none of the local intersections require more than eight system detectors, only the basic system addresses will be discussed. These addresses include SDA1, SDA2, SDB1, SDB2, SDC1, SDC2, SDD1, and SDD2, which is the convention used by this

particular master controller. Each of the addresses shown in Table 8-10 corresponds with the eight local system detector addresses.

The equipment used for this research allows up to a maximum of 32 system detectors, with no more than 8 at the local level (16 with auxiliary). The eight “SD” addresses, understood by the master, can be found in Table 8-10. This vendor allows up to 24 controllers, however only 3 controllers were used as part of this study. Looking at Table 8-6, it can be seen that the telemetry addresses start over at SDA1 each time the local telemetry number in the previous column changes. For simplicity, the detectors in Table 8-6 have been sorted by the system detector number. Hence, the local detectors were listed by intersection from West to East with the left-arterial lane first. Given this methodology (regardless of direction), the system detector in the left lane will always have a lower detector number than a parallel detector in the right lane. The same applies for the local system detector numbering which also follows this convention, as seen in Figure 8-8. Such logic makes the configuration easier to remember, when it comes time to assign traffic functions to each of the detectors.

Understanding how to relate Table 8-6 and Table 8-10 is one of the most important parts of the system detector mapping. Notice that Table 8-6 shows the overall detector configuration at the local level, while Table 8-10 is primarily concerned with detector configuration at the master level. The detector number seen in Table 8-6 is used at the local intersection, while the system detector number is used at the master level. Looking at Table 8-6, it can be seen that there are 2, 6, and 2 system detectors assigned to Intersections 1, 2, and 3, respectively. Referring to Table 8-10, the same can be found. The only difference is that the local detector numbers have been converted over to system detector numbers. Hence, Detectors 9 and 11, shown in Lines 1 and 2, of Table 8-6 are now System Detectors 1 and 2. Realize that the telemetry addresses in Table 8-10 directly match those shown in Table 8-6 for each of the detectors.

The numbers that are entered in Table 8-10, directly control what the actual system number will be. Hence, if the Number 12 were placed in the SDA1 address for Controller 1, then the local Detector 9 (first line of Table 8-6) would now be System Detector 12. Looking down the list for the SDA1 assignments in Table 8-10, it can be seen that System Detectors 1, 3, and 9 are assigned to this address, which belongs to the local telemetry addresses of 1, 2, and 3, respectively. This directly matches the information shown in Table 8-6 for the SDA1 address. It is important to realize that none of the numbers shown in Table 8-10 (SDA1 to SDD2) can be repeated. Hence, if the Number 10 was entered for the SDA1 address at Controller 1, an error would result. Such a configuration is necessary since the local system detector numbers (9, 11, 13, and 15, in Table 8-6) repeat themselves and must be distinguished apart.

Overview of System Timing Plans

Table 8-7 shows some of the general timing parameters that were used to control each of the intersections within the system, while Table 8-8 shows the coordination splits that were used for each period, given the volume scenarios and turning percentages shown in Table 8-1 and Table 8-2, respectively. The cycle lengths, offsets, and pattern numbers for each of the intersections are also shown in Table 8-8, in addition to any left-turning movements that are defined as lagging. Based on this, it can be seen that only the left-turns at the diamond interchange are specified as lagging. This is consistent with the phasing used in the preemption study, as are the general timing parameters shown in Table 8-7. The main difference is in Table 8-8, where additional timing plans have been configured as part of this study.

Referring to Table 8-8, it can be seen that there are five different timing plans that are possible. Pattern 111 is the midday plan, which has a cycle length of 80 seconds. The relative offsets and splits for each of the intersections are

shown in the columns that follow, for each of the plans. Patterns 211, 311, 411, and 511 are the morning, afternoon, event-inbound, and event-outbound plans for this particular network. Generally these plans are arranged in the order of demand, with the midday being the lightest and event traffic being the heaviest. They are arranged this way because lighter traffic typically requires shorter cycle lengths, while heavier traffic usually requires longer cycle lengths. Longer cycles are used in order to help reduce the lost time and increase the bandwidth as the system becomes saturated. The three numbers that make up the pattern number, such as 111, are the cycle length, offset, and split. Notice how it is the cycle length that distinguishes between the different plans. The subsequent sections will use these pattern numbers to distinguish between the active plans.

Time-of-Day Configuration

Configuring the system to run Time-of-Day is relatively simple, given that one knows the time periods to run each of the plans. This is why the governmental agencies, and the majority of the country, run their systems this way. Time is valuable, and hence, many agencies do not have the time, or do not understand how to configure some of the more advanced parameters typically associated with more advanced operations like traffic responsive. Table 8-9 shows a typical time-based programming chart that would be used to select the different plans. Realize that system detectors are not necessary for this type of operation. Looking at Table 8-9, it can be seen that the morning pattern (111) runs from 6:30am to 9:00am. Similarly, the midday plan (211) runs from 9:00am to 2:30pm, at which time the afternoon plan (311) would run until 7:00pm. After 7:00pm the midday plan (111) would again run until 11:00pm, at which time the system would run independently (Free).

The scenario above is a typical weekday plan that runs Monday through Friday. Looking at Table 8-9, it can be seen that there is a different schedule for

weekends. In this example the midday plan (111) runs on both days, ranging from 7:30am to 10:00pm on Saturday, and 9:00am to 8:00pm on Sunday. This can be changed as desired, in order to help better match the expected traffic conditions. The different program numbers, shown in Table 8-9, are what permit alternate schedules to be used on weekends. Notice how the event plans (411 and 511 shown in Table 8-8) are not used here, as they are not recurring plans. This is one of the pitfalls of time-based operation, as such events would have to be activated manually. Table 8-9 is only an example, considering that the simulations used for this research spanned only an hour. The subsequent section will focus on the configuration of traffic responsive parameters.

Traffic Responsive Configuration

Now that the system detectors have been mapped to the actual control equipment, and the methodology behind time-based operation is understood, this section will focus on assigning traffic responsive parameters to each of the system detectors. Looking at Table 8-11, it can be seen that there are four traffic parameters. These include the Level, Directionality (1 or 2), Split Demand (A or B), and Arterial / Non-Arterial Demand. Level is typically used to help determine the length of the cycle that should be running. Generally the higher the Level, the higher the cycle length, however this does not always have to be the case, as will be seen from the programming in Table 8-14. Next, there is the directionality parameter, which helps determine the heavier direction and in the selection of the most appropriate offsets. With this parameter, Direction 1 or 2 can be heavier, or they can both be considered equally as heavy, depending on the thresholds that are programmed in Table 8-13.

The next parameter, or traffic function, is Split Demand A or B. Typically “A” would be assigned to the arterial, while “B” would be assigned to the side street. This traffic function attempts to find the most appropriate split for the

system. Looking at the thresholds in Table 8-13, it can be determined that there are up to four split-levels that are possible. Lastly there is Arterial / Non-Arterial demand which determines whether the arterial or the side streets have more demand, at which time it would adjust the plan accordingly depending on the program shown in Table 8-14. The main drawback with these last two parameters is that they are all or nothing. For example, if all the side streets were assigned to Split Demand B, then heavy traffic on just one of the side streets could be enough to alter the operation of the entire system, even if the other side street movements were not heavy to begin with. This same problem can occur with the Arterial / Non-Arterial Demand parameter. Hence, these parameters are typically applied at the busiest or most critical intersections, if they are even used at all.

Recall that there are up to 32 system detectors that can be assigned with this equipment. Looking at Table 8-11, it can be seen that there are eight groups, each of which can contain up to four system detectors (Lane 1 to 4). Together this matrix creates the maximum of 32 detectors that are permitted. Looking at the table, it can be seen that Detectors 1, 2, 3, and 4 have been assigned to Group 1. Referring to Figure 8-8, it can be determined that all these detectors are located on the arterial. Notice that two (1 & 2) of them are for the Eastbound direction while the remaining two (3 & 4) are for the Westbound direction. Given this information, it was determined that at least three of these detectors should be working properly, in order to ensure valid information, as seen in Table 8-11. This is because two bad detectors can result in no data for one of the directions, which is considered unacceptable.

Looking at the first group in Table 8-11, it can be seen that the second highest scaled volume or occupancy will be assigned to the Level parameter. Also, the averages of all functional detectors in the group will be assigned to Split Demand "A", while the second highest scaled volume or occupancy will be

assigned to the Arterial Demand parameter. Since all of the detectors in the group are located on the arterial, these assignments make sense. Notice that none of the directionality parameters were assigned for this group, since the detectors which make up the group come from both arterial directions. To make directionality assignments here would have been illogical and likely yielded undesirable results. Notice that Group 2 uses the exact same traffic functions, with the only difference being that Detectors 5, 6, 9, and 10 now make up the group. This group is much like the first in that the detectors come from both of the arterial directions. See Figure 8-8 for verification.

Group 3 is slightly different from the groups just discussed, since the detectors that comprise this group are located on the ramps to the interchange. Given that these are not arterial detectors, different traffic parameters should be assigned to this group. Referring to Figure 8-8, one will realize that Detector 7 is on the Southbound ramp while Detector 8 is on the Northbound ramp. Based on previous discussions, these are local Detectors 3 and 7, respectively. Referring to Table 8-11, it can be seen that both of these detectors are required for valid operation. Also, the average of the volume or occupancy (whichever is higher) will be used to determine Split Demand B. Lastly the higher volume or occupancy will be assigned to the Non-Arterial Demand function.

Groups 4 and 5 are assigned for directionally purposes. The traffic parameters for these groups are the same as Groups 1 and 2, with the exception that Group 4 is assigned to Direction 1, while Group 5 is assigned to Direction 2. In order for this to be correct, it is important that the system detectors in these groups be in the same arterial direction. From Table 8-11, it is readily apparent that Detectors 1, 2, 5, and 6 are assigned to Group 4, while Detectors 3, 4, 9, and 10 are assigned to Group 5. When examining Figure 8-8, it can be seen that all the Group 4 detectors are in the Eastbound direction while all the Group 5 detectors are in the Westbound direction. Since all detectors in Groups 4 and 5

are also in Groups 1 and 2 and the same traffic functions are assigned, other than the directionality, it is possible to move the information from Groups 4 and 5 to Groups 1 and 2, thereby removing two of the groups. This system was configured in such a way to help better illustrate that the same system numbers can be used in multiple groups.

Traffic Responsive Function Computations

Once the groups and traffic parameters have been assigned, as in Table 8-11, it is then necessary to aggregate the data from all the groups so that each of the traffic parameters can be summarized. This is done with the careful configuration of Table 8-12. Looking at this table, it can be seen that the four traffic parameters are listed, which the Level (LEV), Directionality (DR1 / DR2), Split Demand (SPA / SPB), and Arterial / Non-Arterial Demand (ART / NRT). Below each of the parameters are the type of computation (volume / occupancy), the value of the group, the Smoothing Factor (SMF), and the Update Predictor Threshold (UPT). Notice that these computations are summarized on a per parameter basis, once all the groups have been summarized according to the configuration shown in Table 8-12. Hence, it is important to realize that this information applies to the actual traffic parameters and not the individual groups shown in Table 8-11.

The value of the group computation, shown in Table 8-12, controls how the groups in Table 8-11 are summarized. This is necessary since many of the groups use the same traffic parameter. For example, looking at Table 8-11, it can be seen that both Groups 1 and 2 are assigned to the Level parameter. Recall that the 2 means that the second highest value from each of the groups will be used. Once these values are determined, the controller will then refer to Table 8-12 to establish which of the values to use. The parameter coding (1, 2, AV) used in this table is the same as that used in Table 8-11. Hence, the 1 under

the Level (LEV) parameter in Table 8-12, means that the highest value amongst the groups will be used. This value can consist of volume, occupancy, or both volume and occupancy counts. The traffic parameter coding in Table 8-12 determines what will be used. VOL implies that only volume counts will be used while OCC means that only occupancy counts will be used. CON stands for concentration and implies that both volume and occupancy counts will be used to compute that particular traffic function.

Since all the thresholds in Table 8-13, are represented as a percentage (0-100%), it is important that all the volume and occupancy counts be converted over to a percentage so that they can be compared with the thresholds. Looking at Table 8-12, it can be determined that all the traffic functions are computed using both volume and occupancy counts, as denoted by the CON under each of the parameters. Since volume and occupancy counts can not be compared directly, each of them must be converted over to a scaled percentage, ranging from 0-100%, so that they can be compared with one another. When concentration (CON) is used, the higher of the scaled volume or occupancy is applied for the relative parameter. In order to scale these counts, both a scaled volume factor and a scaled occupancy factor are required. Figure 8-10 helps illustrate the relationship between volume and occupancy. Notice that volume is always higher except during saturated conditions, when occupancy then takes precedence. This makes sense, since traffic is typically slowed during saturated conditions, at which time occupancy information can be very valuable.

The scaled volume factor is used to compute the scaled volume, which is a percentage value representing the actual volume. This factor is typically chosen to yield a value of approximately 100% for saturated conditions. Looking at Figure 8-11, it can be seen that a scale factor of 15 produces 100% when the actual volume is 1,500 vehicles per hour. For this research a scale factor of 12 was used, implying that the lane is considered saturated when three are greater

than 1,200 vehicles per hour that are counted. The scaled occupancy factor works much the same way. Recall that occupancy is a measure of the amount of time that a vehicle presence is detected over a detector. Again, this factor should be scaled to yield a scaled occupancy value of approximately 100% for saturated conditions. Looking at the example in Figure 8-12, it can be determined that a scale factor of 20 produces 100% when the actual occupancy is 20%. With this equipment, these scale factors can be set on a global basis, or on a per detector basis.

Referring to Table 8-12, it can be seen that there is a Smoothing Factor (SMF) and an Update Predictor Threshold Factor (UPT) that must be configured for each of the parameters. The Smoothing Factor is responsible for controlling how quickly the parameter data gets updated. Looking at Table 8-12, it can be determined that this factor has been set to 30% for all the parameters. Hence only 30%, of the difference between the new sample and existing periods, will be applied to the current period, for the relative parameter. For example, if the current Level (LEV) number is 42% and the new sample period comes back with 50% for that parameter, then the new number will be 30% of the difference between these numbers, which is then added to the existing data. Hence the new period data would now be 44.40%, which is rounded up to 45%, since the remainder (0.40) is greater than the SMF factor (0.30). Hence the larger the SMF value, the faster the new sample period data will be implemented into the system. These calculations are applied to the other traffic parameters as well.

For the majority of the time, it is desirable that the Smoothing Factor (SMF) to be used since traffic usually increases or decreases on a gradual basis. Given this trend, it would be undesirable to respond to each surge in traffic, since this may result in rapid pattern changing, which could thereby make coordination difficult to maintain, particularly if the plans are changing on a frequent basis. However there are instances, such as events or accidents, which can result in

rapid queuing, where it may be desirable to bypass the smoothing process altogether, and immediately respond to the demand. This is because the smoothing procedure is gradual and takes time to respond to traffic, particularly if the SMF factor is low. In such cases, the Update Predictor Threshold Factor (UPT) can be very beneficial by responding immediately to such an event, thereby minimizing the overall congestion likely from a delayed response.

Looking at Table 8-12, it can be seen that the UPT has been set to 20% for all the parameters. This value works the opposite of the SMF in that the lower the value used for the UPT, the faster the new sample period data will be implemented into the system. Again if this criteria is met, then smoothing will be bypassed altogether for the sample period, otherwise it will be applied. Using the example in the previous case for the Level (LEV) computation, it can be determined that the UPT factor will not be used since the new value of 50% is not 20% (UPT) greater than the current value of 42%. In order for changes to immediately take effect, it is necessary that the new sample data is greater than or equal to 62%, which is 20% greater than the existing value of 42%. Had the UPT value been 10%, then the new sample would only need to be 52% instead of 62%. This reinforces the concept that a smaller UPT factor would result in a more immediate pattern change. Again, both the SMF and UPT factors can be changed on a per parameter basis as seen in Table 8-12.

The UPT factor of 20% ensures that a rather significant event would need to occur for an immediate pattern change to take effect. The likelihood of such an event occurring depends greatly on the length of the sample period, which can range anywhere from 1 to 30 minutes or cycles. For all the studies contained herein, a new sample period was generated every cycle. Hence, the likelihood of a sudden surge in traffic during this period is minimal. Conversely, if a new sample period was generated every 10 cycles, it is more likely that the traffic patterns may have changed and the UPT factor would be applied.

However, if a typical cycle length of 120 seconds was running for the period, then it would be 20 minutes before the next update is made. Hence, if a major traffic surge occurs right after a pattern update, it would then be 20 minutes before the master controller would recognize this surge. Hence it would be desirable to take frequent sample periods and use the SMF to tune out the minor surges in traffic.

Given that the sample periods were taken every cycle, the UPT value of 20% would typically come into play when traffic queues over a critical system detector. Queuing is an indicator of a potential problem where it may be desirable to immediately respond to such demand. This is particularly the case at interchanges where it is essential to respond to ramp congestion, in order to avoid queuing onto the Interstate. In such instances the UPT of 20% provides enough cushion to respond to this, provided that the occupancy information is being applied from the relevant detectors. It is unlikely that the volume counts would change enough over the cycle to warrant use of the UPT. Had this factor been reduced, or if the sample period is increased, then it would be more likely that the UPT is used on a more frequent basis. However, it is suggested that this factor (UPT) be reserved for extreme cases in order to prevent the rapid switching between plans for minor changes in traffic conditions.

Traffic Responsive Plan Selection

Once all of the traffic parameters have been computed according to the configurations shown in Table 8-12, it is then necessary for the master to determine the most appropriate plan to be running given the current information. Table 8-13 shows the thresholds that were used for each of the four traffic functions. All of these thresholds are in a percentage, as are the scaled volume and occupancy counts. As seen from Table 8-12, the higher of the volume or occupancy data (CON) for each of the parameters will be applied to Table 8-13, in order to determine the most appropriate plan. Each of the four columns

represents a different traffic function. Column 1 represents the Level (LEV), followed by the Directionality (Offset), Split, and Arterial / Non-Arterial Demand. Looking at the Level thresholds, it becomes apparent that there are up to 5 Levels, which can be used if needed. Level 1 normally corresponds to the lowest level of demand while Level 5 is typically associated with the highest level of demand. Thresholds initiate changes between the levels and are expressed as a percentage, where 100% is equivalent to saturated conditions. Levels are omitted by placing a value of 101% for those levels that are not used. Looking at Table 8-13, it becomes apparent that all levels are active for this particular study.

Starting with Row 2 of the first column in Table 8-13 and looking at every other row, it can be seen that the levels are constantly increasing. For example, the 1>2 in Row 2, shows that a threshold value of 20% is required for the system to change from Level 1 to Level 2. Similarly, the values of 40%, 60% and 80% correspond to Levels 2>3, 3>4, and 4>5, respectively. These are the thresholds required in order to move to the next level. Notice that the odd numbered rows show the thresholds required in order to move to the previous level. The value of 12% for Row 1 (2>1) means that the parameter data must be at or below 12% in order to drop from Level 2 to Level 1. It is important that this value be less than Row 2 (parent), which is the threshold required to move from Level 1 to Level 2. In this case, 12% is less than 20% and hence, the configuration is relevant. The thresholds of 30%, 45%, and 65% correspond to the remaining Levels of 3>2, 4>3, and 5>4, respectively. Notice how these values are increasing and are less than their parent values of 40%, 60%, and 80%. Also realize how none of the consecutive levels overlap with one another.

Column 2 in Table 8-13 is used to determine the heavier direction. Both directions can be considered to be equally as heavy, or one of the directions can be heavier than the other. This all depends on the configuration of the thresholds. Directionality is typically used to help determine the most appropriate

offsets for the system. Looking at Column 2, it can be seen that Direction 1 (DR1) must be greater than the difference of both the direction thresholds by more than 20% ($AV > 1$), in order for Direction 1 to be considered dominant. Looking at Table 8-13, it can be seen that the same applies for Direction 2 (DR2) as well ($AV > 2$). In order for both directions to be considered equal (Average), it is important that these differences are less than 20%. However, if one of the directions have already be determined as dominant, then differences between the two thresholds must be less than 15% ($1 > AV$ or $2 > AV$), as seen from Column 2 of Table 8-13.

Using the directionality configuration shown above, and a Direction 1 threshold of 32% and a Direction 2 threshold of 50%, it can be determined that the directionality will come up as Average since the difference between the directions are 18%, which is less than the threshold of 20%. Had Direction 2 retained a threshold of 52%, this direction would be considered the dominant one. If this were to occur, the Direction 2 threshold must be reduced to 47% in order for both directions to again be considered equal ($47\% - 32\% = 15\%$). This is provided that the Direction 1 threshold of 32% remains unchanged. Given everything else the same, it is important to realize that a threshold of 52% is required to switch from Average to Direction 2 ($AV > 2$), while a value of only 47% is need to change from Direction 2 to Average ($2 > AV$). This difference prevents the parameter from bouncing around at the threshold value of 20%. Realize that this same configuration applies for Direction 1 as well.

Column 3 of Table 8-13 is used to determine the most appropriate split for the given traffic condition. This parameter works only after Column 3 has been properly configured, and a zero has been entered for the split in the traffic responsive plan. For example, a COS of 310 would need to be entered instead of 311. This study did not use the computed split function, but will briefly go through the procedure. Like the level computation, a value of 101% is used to

omit the splits that are not in use. With this parameter there are up to four splits that are applicable. The selection is made by comparing the scaled values of Split Demand A (SPA), and Split Demand B (SPB). The results of the comparison are then weighed against the threshold values in order to determine which of the split functions should be running.

As was done for the Level computation, it can be seen from Column 3 of Table 8-13, that the necessary thresholds for the next split are 20%, 30% and 40% for $1>2$, $2>3$, and $3>4$, respectively. Similarly the thresholds for the the previous split are also listed. They are 10%, 20%, and 30% for $2>1$, $3>2$, and $4>3$, respectively. Again, notice how both these ranges are gradually increasing and that the odd rows of Column 3 are less than or equal to the even rows. Hence, in order to advance from Split 2 to Split 3 ($2>3$), a threshold value of 30% would be required, while a value of 20% would be necessary in order to move from Split 3 to Split 2 ($3>2$). There are essentially two methods for deriving the comparison value for selection of the split, which depends primarily on whether or not the Smoothing Factor (SMF) has been set to zero. If so, the computation is a function of SPB only, otherwise $SPB - SPA$ is the comparison value unless SPA is greater, at which time Split 1 is automatically selected. This parameter is helpful when the side street demand at a particular intersection is greater than the arterial traffic as the splits can be adjusted accordingly.

The last parameter shown in Table 8-13, is the Arterial / Non-Arterial preference. This allows up to five additional plans to be selected. A Non-Arterial preference is determined by comparing the Arterial Demand (ART) to the Non-Arterial Demand (NRT). The results of this comparison are then weighed against the threshold values in order to select the appropriate preference. As can be seen from Column 4, the Non-Arterial Demand must be greater than the Arterial Demand ($ART>NRT$) by 30%. Conversely, the Non-Arterial Demand must be greater than the Arterial Demand ($NRT>ART$) by only 20% in order to return back

to Arterial Demand. Realize that the same two methods used for the split comparison also apply here as well. Hence, if the Smoothing Factor (SMF) has been set to zero, then the computation is a function of NRT only, otherwise NRT – ART is the comparison value unless ART is greater than NRT, at which time arterial plans are instead selected.

Using the configuration above, if the Non-Arterial Demand equals 53% and the Arterial Demand is equal to 25%, the Arterial preference would stay selected since 28% is less than 30%. Had the Non-Arterial Demand been equal to 55%, Non-Arterial preference would have been selected, had the Arterial Demand remained constant. This concludes the configuration of the four traffic responsive parameters. Based on a selection of these parameters, a traffic responsive plan can then be determined using the plan assignments shown in Table 8-14. Hence, if Level 3, Direction 2 (DR2) were to be determined, it can be seen that Pattern 211 would be selected. Had it been Level 3, Direction 2 (DR2) and Non-Arterial Demand, then Pattern 411 would have been selected since Non-Arterial preference overrides all of Arterial directionality parameters. Notice how all the parameters in Level 1 have been reserved for independent (Free) operation. The subsequent section will use this information to analyze six different traffic responsive scenarios.

Overview of the Study

This study analyzed six different traffic scenarios that all had a length of 60 minutes (1 Hour). It was primarily focused on examining the intervals where there was an opportunity for traffic responsive pattern changes to provide significant benefits. In all cases it was assumed that these pattern changes would occur at times not usually expected on a typical day. All six of the scenarios had two different volume scenarios. The first volume scenario was active for the first 20 minutes of the simulation while the remainder of the time

(40 minutes) had a different volume scenario that could potentially be addressed by the auto program. The second period was longer in order to give the Traffic Responsive procedure more time to respond to the newer scenario. The six cases are as follows; 111 to 211, 111 to 311, 111 to 411, 111 to 511, 411 to 111, and 511 to 111. Recall that Plans 111, 211, 311, 411, and 511 are the midday, morning, afternoon, event-inbound and event-outbound patterns, respectively.

For all cases, the Traffic Responsive (TRP) procedure was compared to the traditional Time-of-Day (TOD) procedure, which remained unchanged for all the cases. This is because it was assumed that the pattern changes were not occurring during the typical periods. For example, Pattern 111 to 211 is the midday to morning plan change. Typically, under Traffic Responsive operation, the midday plan is brought up before the morning plan since the morning rush starts out on the lighter side before becoming busy. With the traditional Time-of-Day (TOD) configuration, this step is usually omitted and the morning peak starts out directly in Pattern 211. Hence, for this case it will be assumed that there is a second morning rush hour that occurs after the midday plan has already started. The time-based procedure would not recognize this and stay in Pattern 111, while it is expected that the Traffic Responsive procedure would adapt. The comparison of these procedures will be compared in the subsequent sections. These same concepts should be applied to the other five cases as well. Each of the Time-of-Day and Traffic Responsive procedures consisted of 5 runs.

Scenario Results and Cycle Analysis

Based on the concepts discussed in the previous section, and Traffic Responsive programming found in Table 8-14, the results of the pattern changes for the first three scenarios can be analyzed according to Table 8-15 (Node 1). Notice that each of the cases consist of the Time-of-Day (TOD), Traffic Responsive (TRP), and Desired (DES) pattern changes. Recall that the traffic

volumes for each of the cases change 20 minutes into the simulation, which is why it is desirable (DES) for the plans to change at 8:20am (simulation time). It can also be seen that the Time-of-Day (TOD) plans remained unchanged, for reasons previously discussed. Notice that the middle column for each of the cases is the Traffic Responsive (TRP) procedure. As expected these pattern changes fell somewhere in-between the TOD and DES columns. For all cases shown in Table 8-15, it can be seen that the first Traffic Responsive (TRP) program change did not occur until after 20 minutes (8:20am) into the simulation. This makes sense, considering that it takes time to respond to changes in traffic.

Looking at Case 1 in Table 8-15, it can be determined that the TRP procedure did not begin responding to the volume change until 8:32am, which is 12 minutes after the initial volume change that always occurs at 8:20am. Looking at this column, notice that the TRP procedures change from 111 to 211 as desired, however at 8:54am it began to change over to Pattern 411, which was not expected. Recall that Pattern 411 is the event-inbound pattern, while Pattern 211 is the morning plan, which is heavier in the inbound direction (DR2). This is better illustrated in Figure 8-13a, which shows the cycle graphs for Node 1. This closely resembles the information shown for Case 1 (111_211) in Table 8-15. Notice that the transitions shown for the other controllers in Figure 8-13b and Figure 8-13c also closely resemble that shown in Figure 8-13a. This makes sense since each of the controllers belong to the same system, which transitions at the same time. The cycle lengths for each of the patterns can be verified by examining the coordination plans in Table 8-8.

Looking at Figure 8-13, it is determined that the system (TRP) transitions from 111 to 211 as desired. However, as mentioned it also transitioned from 211 to 411 at approximately 50 minutes into the simulation. This can be verified by looking at Table 8-15, or by noticing the horizontal line in Figure 8-13c at approximately 8:55am. This horizontal line means that a constant cycle has

been reached. It occurs at a cycle length of 140 seconds, which matches Pattern 411, as seen in Table 8-8. This horizontal line is not as apparent in Figure 8-13a and Figure 8-13b, which indicates that these intersections reached coordination for only a short period of time, if at all. Figure 8-13 is good for illustrating how each of the controllers respond differently to the new cycle command, depending on where they were in the previous cycle when they received the command. The smooth transition algorithm was used for all controllers in the system.

From Table 8-15, it can be seen that Node 1 (TRP), shown in Figure 8-13a, was only in coordination 84% of the time. Had the system not tried to transition to Pattern 411, this value would have been much higher for the TRP operation. The system is in coordination 100% of the time for the TOD operation, since it never transitioned. It will be seen later how this lack of transitioning hurt the overall system performance in terms of both travel time and delay. Looking at Figure 8-13c, it can be seen that Pattern 411 was only active for a brief period of time, where it then appeared to transition back to Pattern 211 towards the end of the simulation. Looking at Table 8-14, it is likely that the system was in Level 3, Direction 2 (DR2) when it was in Pattern 211. It is assumed that one of the interchange ramps (JCT I-65 North) became heavy and traffic briefly queued over System Detector 8, at which time NRT Demand took precedence, overriding the typical Arterial operation. The queuing on this ramp was quickly alleviated, at which time the system began transitioning back to Pattern 211.

This concludes the analysis of Case 1 (111 to 211). The remainder of the cases operate much the same way and will be analyzed in less detail. The results from Case 2 (111 to 311) can be found in the middle of Table 8-15. Notice from this table that the Traffic Responsive procedure transitioned as expected. It began to transition at 8:24am, which is only 4 minutes after the traffic volumes had changed (8:20am). As could be seen from the table, it transitioned to Pattern 311 and stayed there, just like the desired operation. This

becomes even more apparent after examining the cycle graphs shown in Figure 8-14. Notice again that in all cases, the TRP lines closely resembles that of the desired (DES) transition. By comparing the three sections of Figure 8-14, it can be seen that each of the controllers began transitioning at the same time, however some of the controllers reached coordination quicker than the others. Looking at Table 8-14, it is likely that the master controller went from Level 2, Average or Direction 1 (DR1) to Level 3, Direction 1 (DR1). From Table 8-15, it can be determined that Node 1 (TRP) was in coordination 93% of the time.

Let us now look at the last case shown in Table 8-15. It is desired that Case 3 changes from Pattern 111 to 411. Looking at the table, it can be determined that TRP eventually transitions to Pattern 411 after first transitioning to Pattern 211. The transitioning begins at 8:26am, which is only 6 minutes after the traffic volumes were changed in the simulation, however it does not reach Pattern 411 until 8:38am. This is 18 minutes after the traffic volumes had changed. Not only that, but the system begins to transition back to Pattern 211 at approximately 8:54am. Looking at Parts b and c of Figure 8-15, it becomes apparent that coordination is not obtained by the end of the simulation. However, in Figure 8-15a, this was not the case as coordination (211) was again obtained before the simulation ended. The information for Case 3 in Table 8-15 verifies this for Node 1, which was in coordination only 80% of the time. Again realize how each of the controllers transitioned differently, as seen from Figure 8-15.

Based on the information in Table 8-14, it is likely that the master controller went from Level 2, Average or Direction 1 (DR1) to either Level 2 or 3, Direction (DR2), at which time it most likely went to Level 3, NRT Demand (411). This is likely attributed to the heavy traffic on the JCT I-65 North Ramp, from the Event (411) traffic that was headed inbound towards Purdue University. Once the heavy ramp demand on System Detector 8 was serviced, it is anticipated that the master reverted back to Pattern 211 via the Level 3, Direction 2 (DR2)

pattern select. Conversely, Case 4 shown in Table 8-16 examines the Event Outbound traffic scenario. Notice that this one operated much as expected since it bounced directly from Pattern 111 to 511, as desired. As seen from Table 8-16, there was only a 4 minute delay in the response, which closely follows the desired operations shown in Figure 8-16. Also, coordination was obtained 81% of the time at Node 1. Referring to Table 8-14, it is likely that the master controller went from Level 2, Average or Direction 1 (DR1) to Level 5, Direction 1 (DR1). The transition took slightly longer since the master had to advance three levels at once (Level 2 to Level 5), which takes time, particularly if the Update Predictor Threshold (UPT) feature was not applied.

Cases 5 and 6 are slightly different from the first four in that they do not begin with the midday traffic scenario (111). They instead start with either the event-inbound or outbound patterns, eventually ending up with the midday volume scenario. The purpose of these last two scenarios is to examine how the system transitions from a higher plan to a lower plan. Looking at the middle of Table 8-16, it can be seen that Case 5 examines Pattern 411 to 111. Looking at the table it can be seen that the system transitions as expected. It begins its transition down to Pattern 111 at 8:28am, which is only 8 minutes after lighter volumes were introduced into the network. However, like the previous case this transitioning procedure took greater than 8 minutes to accomplish, likely because the multiple levels were spanned. Looking at Table 8-14, it is anticipated that the master has to go from Level 4, Direction 2 (DR2) to Level 2, Average (AVG). This is a drop of two levels, which added to the amount of transitioning time, that was required.

It is obvious from both Figure 8-17 and Case 5 of Table 8-16 that the system had difficulty obtaining Pattern 411. Notice that Pattern 211 was first activated before the Event Inbound pattern (411) could be obtained. It is likely that Pattern 211 was eventually activated by either the Level 2 or 3, Direction 2

(DR2) parameter, at which time it eventually transitioned to Level 4, Direction 2 (DR2), as indicated above. Looking at Table 8-16, it can be determined that this system was only in coordination approximately 76% of the time. After investigating all of the transitioning in Figure 8-17, this becomes quite apparent. Looking at Case 6 (511 to 111), it can be determined that the same problems are evident, since this particular scenario was only in coordination 74% of the time, which is even less than the 76% in Case 5. This indicates that transitioning can be inefficient, particularly when multiple levels must be spanned.

Looking at Case 6 in even greater detail, it can be seen that according to Table 8-16, the pattern change begins and eventually ends up as desired patterns. It is likely that the Update Predictor Threshold (UPT) immediately jumped the system from Free operation to Level 5, Direction 1 (DR1), where Pattern 511 was immediately obtained. When examining the cycle graphs in Figure 8-18, this becomes apparent, in that all controllers were initially in coordination and running a 160 second cycle, which corresponds to Pattern 511 in Table 8-8. Looking at Table 8-16, it can be seen that the pattern change to 111 begins at 8:26am, which is only 6 minutes after the Event volumes had ended. Also notice that the plan bounces in and out of Pattern 311 at least two times before finally resting in Pattern 111. Given this information and referring to Table 8-14, it is likely that the system went from Level 5, Direction 1 (DR1 – 511), to Level 4, Direction 1 (DR1 – 311), to Level 3, Average (211), to Level 3, Direction 1 (DR1 – 311) to Level 2, Average (111).

This transitioning for Case 6, which ranges from 8:26am to 8:44am, is quite apparent when examining the cycle graphs in Figure 8-18. By looking at Figure 8-18b, there are two points around 8:28am and 8:36am where a brief 90 second cycle becomes apparent. This is not as evident in Parts a and c. Table 8-8 verifies that the 90 second cycle is associated with the Pattern 311 that appears twice for Case 6 of Table 8-16.

This concludes the scenario results and cycle analysis for each of the cases. Based on these results, it should be apparent that the amount of transitioning required can often be reduced by simply minimizing the number of active Levels. Table 8-17 summarizes the percentage of time that each of the controllers were in coordination. Notice that the synchronization percentages are close for the majority of the scenarios, however there are some cases (3) where they deviate by as much as 17% between controllers. It should also be noted that the transitioning is typically done on a gradual basis. For the last two scenarios it is unlikely that traffic would go immediately from heavy to light, as was done in the model. Hence, Patterns 211 or 311 may be applicable for larger periods of time than actually occurred for these particular scenarios. The subsequent section will focus on examining the quantitative data associated with these pattern changes.

Analysis of Quantitative Results

The quantitative data obtained from this study can be found in Table 8-18 to Table 8-20. All of these tables show the same scenarios, however they all contain different data. Table 8-18 shows the cumulative Eastbound and Westbound travel times, along with the relative standard deviations, while Table 8-19 shows the minor movement delay in seconds per vehicle. This includes both the side streets and the arterial left-turns for each of the scenarios, which consist of the various traffic conditions, operations, and controller transition algorithms. Lastly, Table 8-20 summarizes the total system delay in vehicle minutes, which includes both arterial directions, mainline left turns, and all relative side street delay. All of these values are then totaled in order to come up with a total system delay that is then compared with the base conditions for each of the Traffic Responsive (TRP) procedures.

In order to help better understand this data, it is important that one understands the difference between the demand volumes and operations, which are consistent throughout each of the tables. Looking at Table 8-18, it can be seen that there are three different operations that were examined. These include the Time-of-Day (TOD), Traffic Responsive (TRP), and Manual (MAN) procedures. All of these, with the exception of the Manual procedure which will be discussed later, should be understood by now. Lastly, it can be seen that Table 8-18 to Table 8-20 are broken into six distinct groups, as represented by the double horizontal lines. Notice that Group 1 analyzes each of the five patterns on an individual basis, by running the relative plans for the entire period. Recall that all of these scenarios consist of 5 runs each. Looking at Table 8-18, it is apparent that all of the travel times and standard deviations for Group 1 are reasonable. This is because the corresponding plan was matched with the appropriate pattern number by using the Time-of-Day (TOD) procedure as indicated in the tables.

Next, Group 2 looks at what would happen if the midday volume scenario were run with each of the remaining pattern scenarios. Again, this was done using a time-based procedure that was effective throughout each of the simulations. Since the midday scenario was already run with Pattern 111, as seen in Group 1, this scenario was omitted from Group 2. When viewing Group 2, it becomes quite apparent that there was a problem in the Eastbound direction when the midday volumes were run with Pattern 411. This is obvious because of the standard deviation value of 207.6 and travel time of 501.9 seconds per vehicle. Both values are much greater than the majority of the values in the table. When examining Table 8-19, it becomes apparent the problem initiated at the Eastbound Left-Turn where there was a delay of 565.3 seconds per vehicle. This indicates that there was inadequate time for this movement, which ended up spilling-back and hindering some of the through movements.

Recall that Pattern 411 is for Event Inbound and hence, it did not make much sense to allocate much time to an outbound left-turn movement. Hence, this can be an indication of what could occur if the wrong Traffic Responsive (TRP) plan was selected for a particular volume scenario. Notice that all of the values for the midday scenario in Group 1, for both Table 8-18 and Table 8-20, are less than all of the scenarios shown in the Group 2 cases. This indicates that Pattern 111 is indeed the optimum timing plan for the midday volume scenario, which was expected. Looking at the minor movements in Table 8-19, it can be determined that the majority of the values are lower for Pattern 111. The remaining four groups, shown in Table 8-18 to Table 8-20, represent the six cases that were examined in the previous section. Groups 3 and 4 are associated with Cases 1 and 2, respectively, while Groups 5 and 6 combine Cases 3 and 5 and Cases 4 and 6, respectively.

Looking at Group 3 in Table 8-18, it can be seen that three different scenarios were examined for Case 1 (111 to 211). These include the two Time-of-Day (TOD) procedures and one Traffic Responsive (TRP) procedure. It is important to note that all three of the cases used the same volume scenarios, which began with the midday volumes and then changed over to morning volumes 20 minutes into the simulation. The only difference is the patterns that actually ran during these periods. Each of the TOD procedures are different because the first one runs Pattern 111 for the entire scenario while the second one runs Pattern 211 for the entire simulation period. The TRP procedures respond to this situation using the configuration discussed in the previous sections. Recall that Figure 8-13 shows the cycle graphs associated with this particular TRP scenario.

Looking at Group 3 in Table 8-18, it can be determined that the TOD Pattern 111 does best in terms of arterial travel time for each of the directions. Figure 8-19 and Figure 8-20 help illustrate this concept for both the Eastbound

and Westbound direction, respectively, since the Traffic Responsive (TRP) travel times are greater than the traditional Time-of-Day (TOD) procedures for each of the directions. This is apparent because the TRP line is higher than the TOD line, which indicates that additional travel time is required. The arterial delay graphs shown in Figure 8-21 and Figure 8-22 also yield similar results for each of the arterial directions, however the results are more substantial as indicated by the greater spacing between the lines. The number of stops for both the Eastbound and Westbound directions are shown in Figure 8-23 and Figure 8-24, respectively. Notice that overall, Traffic Responsive (TRP) operation increases the total number of stops, particularly in the Eastbound direction. This is likely associated with the transitioning that is involved with the TRP procedure, where the system is not running as optimally as possible.

When examining the total system delay in Table 8-20, it can be seen that it does 38% worse than the other two cases. This contradicts the information shown in Figure 8-21 and Figure 8-22, since they only incorporate the arterial delay. Once the side street and mainline left-turn delay have been added to the arterial delay, it then becomes apparent that Pattern 111 does much worse (38%) than the other two cases. This is obvious when probing Table 8-19 and realizing that one of the side streets must not have adequate split time, considering that the side street delay is 1,600 vehicle-minutes greater than the other cases in the Group. From Figure 8-25, it becomes evident that the problem is at the JCT I-65 North Ramp (Intersection 3). Hence, Traffic Responsive (TRP) was advantageous, by preventing traffic from backing up onto the Interstate, as occurred with the time-based (TOD) Pattern 111. Notice from Table 8-20 that resting in Pattern 211 for the entire simulation would have yielded similar results as the TRP procedure, in terms of total vehicular delay.

Group 4 in Table 8-18 to Table 8-20 shows the results for Case 3 (111 to 311) which follows the same format used in Group 3. The only exception is that

a Manual (MAN) procedure was added in order to determine what would happen if the Traffic Responsive (TRP) operation responded immediately to the volume change. Hence, two time-based procedures (TOD), one Traffic Responsive (TRP) procedure and one Manual (MAN) procedure, will be examined as part of the group. Again, all of these cases will use the same volume scenarios, which begin with the midday volumes and then change over to the afternoon volumes 20 minutes into the simulation. Each of the TOD procedures are different since the first one runs Pattern 111 for the entire scenario while the second one runs Pattern 311 for the entire simulation period. Recall that Figure 8-14 shows the cycle graphs that are associated with this particular TRP procedure.

Looking at Group 4 in Table 8-18, it can be determined TRP does better in the Eastbound direction and slightly worse in the Westbound direction when compared with TOD Pattern 111. Figure 8-26 and Figure 8-27 help illustrate these findings for each of the directions, respectively. The relative delay graphs shown in Figure 8-28 and Figure 8-29 also yield consistent results for both the Eastbound and Westbound directions. Again these results are slightly more substantial as indicated by the greater spacing between the lines. The number of stops for both of the directions are shown in Figure 8-30 and Figure 8-31, respectively. Notice how Traffic Responsive (TRP) operation reduced the number of stops in some locations, but increased the number of stops for others for both of the arterial directions. Again, this is likely attributed to the transitioning that is involved with the TRP procedure. Lastly, Figure 8-32 shows the side street delay time for each of the side streets. Notice how this data is generally consistent amongst both operations, with the exception of Meijer Parkway where the difference is slightly more substantial. This is likely attributed to the increase in the cycle length.

When examining the total system delay in Table 8-20, it can be seen that the TRP operation does 14% better than the time-based (TOD) Pattern 111.

Conversely, when Manual (MAN) pattern switch is done at exactly 20 minutes into the simulation, it can be seen that the delay is improved by 21%, relative to the TOD Pattern 111. When the TOD Pattern 311 is permitted to run for the entire simulation, the total delay is improved by nearly 20%. While probing Table 8-19, it becomes apparent that Pattern 111 in Group 4 has difficulty with the Eastbound left-turn being oversaturated. This is apparent because the value of 110.7 is nearly twice that of the other scenarios in Group 4. This is also apparent in Table 8-20, where the total left-turn delay value of 743.1 is higher than the other values in the group. This, and a higher Eastbound delay, is likely attributed to spillback from the Eastbound left-turn, which is responsible for the increased total delay for Pattern 111. Hence, Traffic Responsive (TRP) was again advantageous for this case by responding properly to the traffic and limiting the amount of spillback for the Eastbound left-turn. Notice from Table 8-20 that resting in Pattern 311 for the entire simulation, or doing a Manual (MAN) plan shift, would have yielded better results than the TRP procedure in terms of total vehicular delay.

Group 5 in Table 8-18 to Table 8-20 examines both Case 3 (111 to 411) and Case 5 (411 to 111). The original three scenarios are examined for Case 3 while only the TOD and TRP procedures are analyzed for Case 5. Looking at Case 3 in Group 5 of Table 8-18, it can be determined that the TOD procedures do better than TRP in terms of arterial travel time. Conversely, according to Table 8-20, TRP does better in terms of overall vehicular delay, where this value was reduced by 25%. The benefits were gained from the reduction in side street delay time from 3,289.6 to 1,422.9 vehicle minutes. According to Table 8-19, it is apparent that the majority of the side street delay for Pattern 111 was at the JCT I-65 Northbound Ramp, with a value of 527.9 vehicle-minutes. When comparing this to the TRP value of 132.5 vehicle minutes, it becomes apparent that the TRP operation prevents traffic from queuing onto the Interstate. Notice that Figure

8-15 and Figure 8-17 show the cycle graphs associated with the TRP procedures for Case 3 and Case 5, respectively.

As seen from Table 8-20, running Pattern 411 for the entire period actually did 7% worse than running Pattern 111 for the simulation period. Although Pattern 411 did fine at the JCT I-65 Northbound Ramp, it did substantially worse for the Eastbound left-turn at JCT I-65, which thereby increased the mainline left-turn delay. This turn delay then caused spillback, which considerably increased the Eastbound through delay, as seen in Table 8-20. When examining the total delay for the reverse situation (Case 5 – 411 to 111), it was determined that the TRP procedure did 18% better than the timed-based (TOD) procedure. The mainline travel time was also reduced in both directions, as seen in Table 8-18. This is most likely attributed to the reduction in cycle length, once the event traffic had cleared the system. Looking at Table 8-19, it is apparent that all delay times were reduced, with the exception of the Northbound movement at the JCT I-65 (East Ramp). This slight increase in side street delay becomes evident in Table 8-20 as well. Realize that all other delay values are less than the time-based (TOD) procedure, where Pattern 411 runs for the entire simulation period.

Group 6 in Table 8-18 to Table 8-20 examines both Case 4 (111 to 511) and Case 6 (511 to 111). The original three scenarios are examined for Case 4, while only the TOD and TRP procedures were analyzed for Case 6. Looking at Case 4 in Group 5 of Table 8-18, it can be determined that the TRP procedure does much better, in terms of the Eastbound travel time, than running the time-based (TOD) Pattern 111 for the entire simulation period. This is quite apparent when examining Figure 8-33 because of the huge deviation between the lines. Conversely, notice that the Westbound travel time shown in Figure 8-34 is approximately the same as the time-based procedure. The arterial delay graphs shown in Figure 8-35 and Figure 8-36 also yield similar results for each of the arterial directions, however they are more substantial as indicated by the greater

spacing between the lines, particularly for the Westbound direction. Recall that Figure 8-16 and Figure 8-18 show the cycle graphs associated with the TRP procedures for Case 3 and Case 5, respectively.

The number of stops for both the Eastbound and Westbound directions are shown in Figure 8-37 and Figure 8-38, respectively. Notice how the overall number of stops greatly decreases under Traffic Responsive (TRP) operation, particularly in the Eastbound direction. This is likely associated with the proper transitioning, which enables the appropriate event pattern, thereby preventing spillback and decreasing the overall number of stops. The deviations for each of the directions are similar to the relative travel time graphs that were previously discussed. When examining the total system delay in Table 8-20, it can be seen that the overall system delay is reduced by nearly 64% with the Traffic Responsive (TRP) procedure. Looking at Table 8-19, it is apparent that the delay reductions came from significant reductions in the Eastbound left-turn at the interchange, which prevented spillback and greatly reduced the arterial delay time.

Looking at Figure 8-39, it can be determined that the side street delay is greatly reduced for the JCT I-65 Southbound Ramp, since the Eastbound left-turn no longer impedes the through movement at this junction (Intersection 2). Hence, Traffic Responsive (TRP) was advantageous, by preventing traffic from backing up onto the Interstate. When examining the reverse situation (Case 6 – 511 to 111), and referring to Table 8-20, it can be seen that resting in Pattern 511 for the entire simulation would have yielded similar results to the TRP procedure, in terms of total vehicular delay. In fact, the TRP procedure only did 4% better than the timed-based (TOD - 511) procedure. Although Pattern 511 did fine for all approaches, including the JCT I-65 Northbound Ramp (Intersection 3), it did slightly worse for all the minor movements, with the exception of the Eastbound left-turn at Intersection 3, as shown in Table 8-19. Resting in Pattern 511 (TOD)

appeared to do slightly better than the Traffic Responsive (TRP) procedure, by means of arterial travel time for both directions; however such improvements were minimal, as seen from Table 8-18, and likely attributed to the lack of transitioning required with the time-based (TOD) procedure.

Summary of Results

This concludes the analysis of the traffic responsive procedures for the six cases analyzed in this chapter. Based on these examples and illustrations, it should be very apparent that Traffic Responsive (TRP) operation can be very unpredictable, particularly when traffic conditions are rapidly changing or do not closely resemble any of the existing case scenarios. When looking at the total system vehicular delay in Table 8-20, it is evident that the Traffic Responsive (TRP) procedures did better for all of the cases examined as part of this study. This indicates that constantly responding to the traffic conditions can be beneficial, even with all the transitioning that took place with some of the scenarios examined as part of this study. Had the transitioning procedures or configuration logic been improved, it is expected that the arterial travel time and the number of stops could have been reduced as well. The following chapter will build on such concepts and analyze a more realistic network (TRP) where the demand volumes change on a more gradual basis.

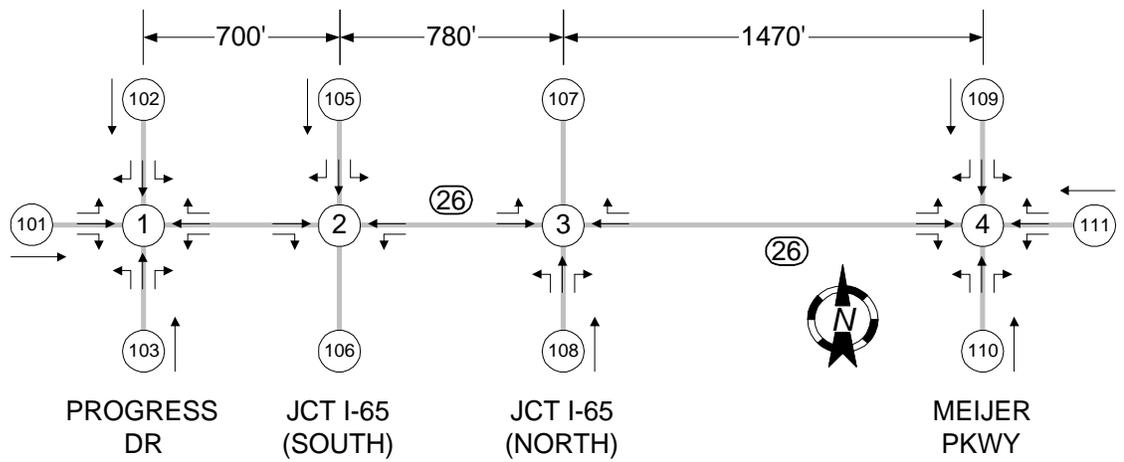


Figure 8-1: SR 26 (South) Network – Progress to Meijer Parkway

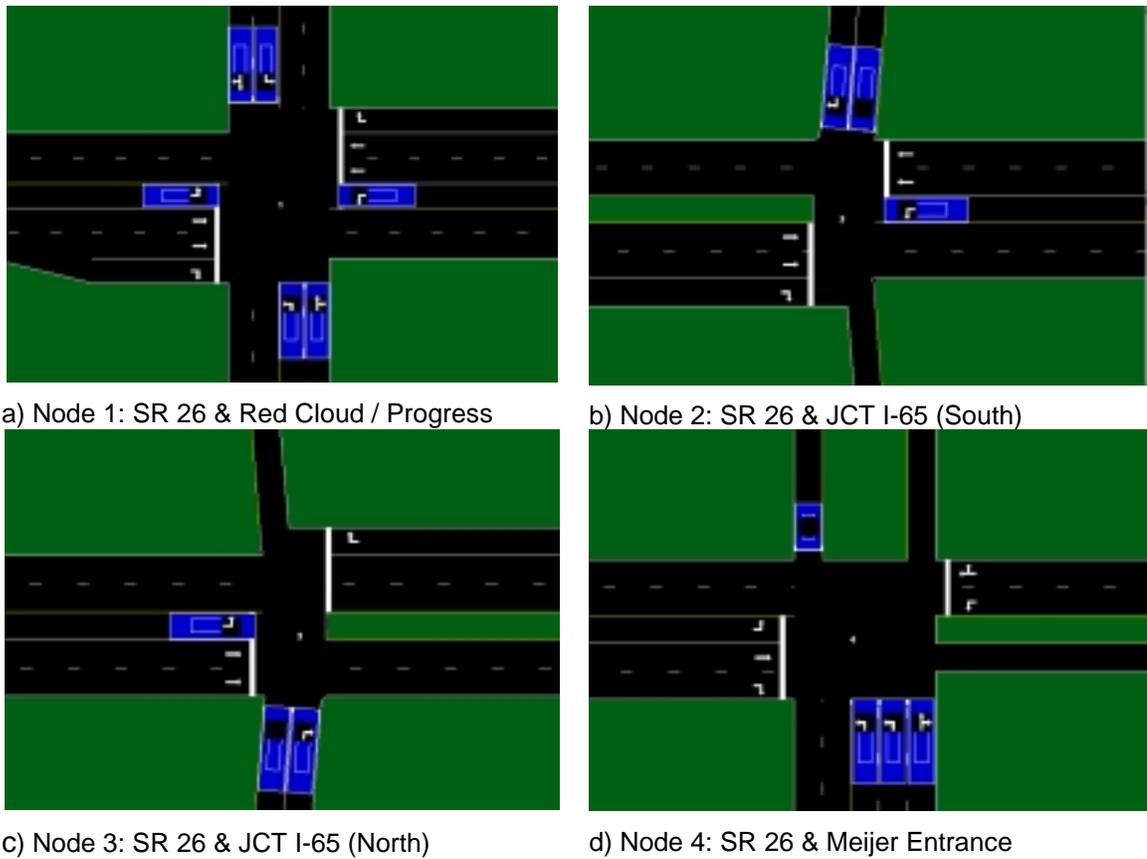
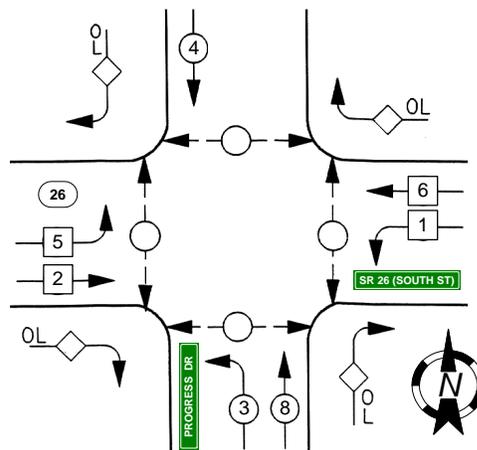
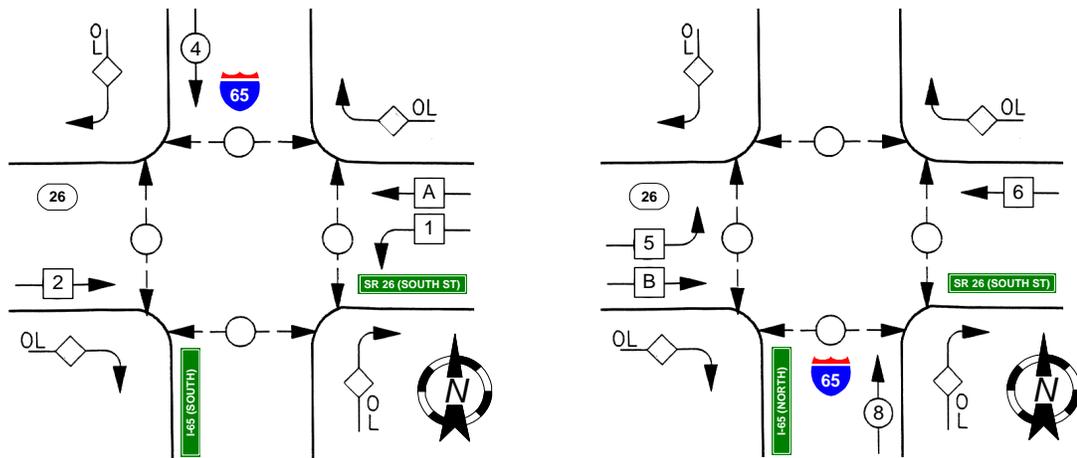


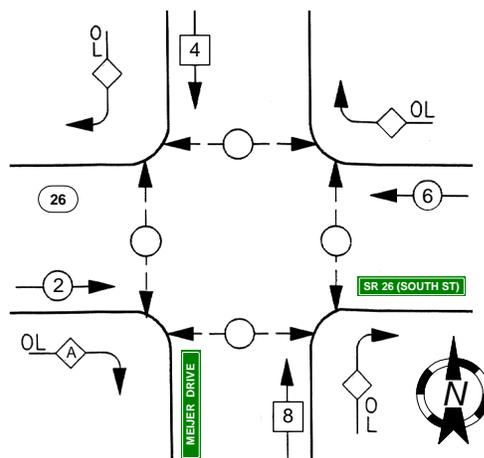
Figure 8-2: Intersection Lane Geometry and Configurations (SR 26 – South)



a) Node 1: SR 26 & Red Cloud / Progress

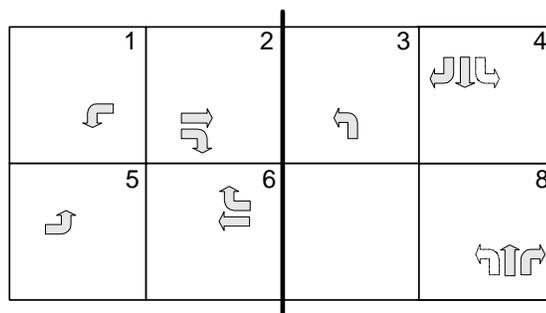


b) Nodes 2 & 3: SR 26 & JCT I-65 (South / North) – Single Controller

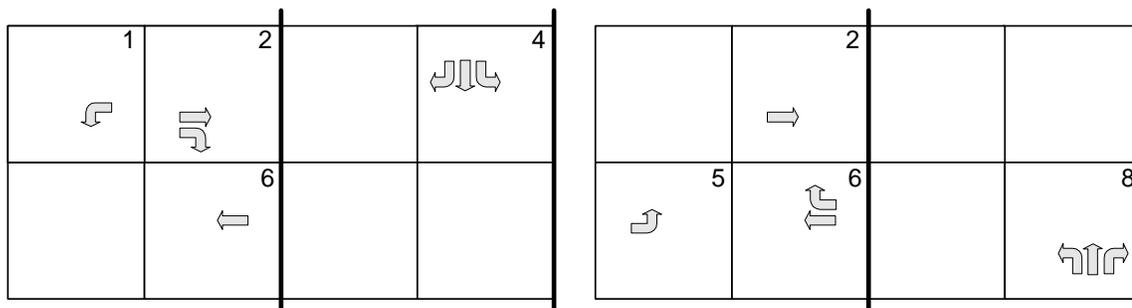


c) Node 4: SR 26 & Meijer Entrance

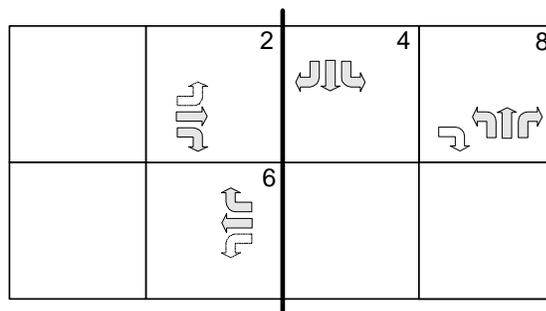
Figure 8-3: Intersection Phasing Diagrams (SR 26 – South)



a) Node 1: SR 26 & Red Cloud / Progress

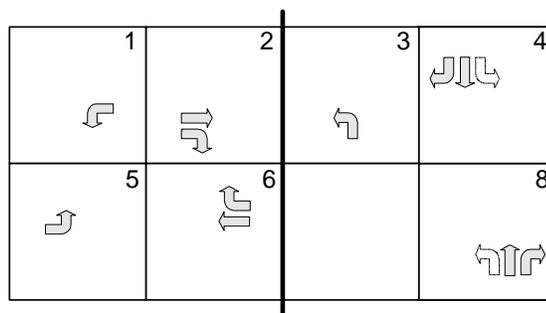


b) Nodes 2 & 3: SR 26 & JCT I-65 (South / North) – Seperate Controllers

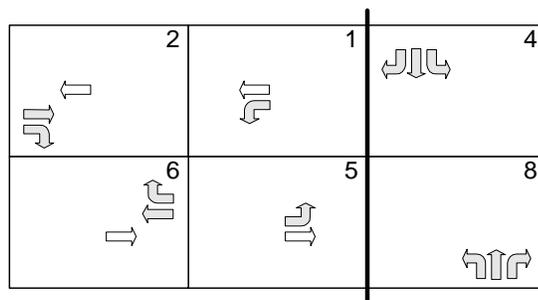


c) Node 4: SR 26 & Meijer Entrance

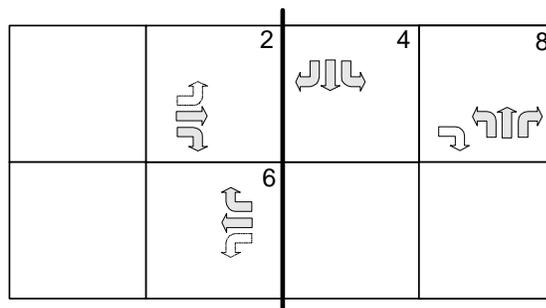
Figure 8-4: Intersection Ring Structures (Separate Controllers)



a) Node 1: SR 26 & Red Cloud / Progress



b) Nodes 2 & 3: SR 26 & JCT I-65 (South / North) – Single Controller



c) Node 4: SR 26 & Meijer Entrance

Figure 8-5: Intersection Ring Structures (Single Diamond Controller)

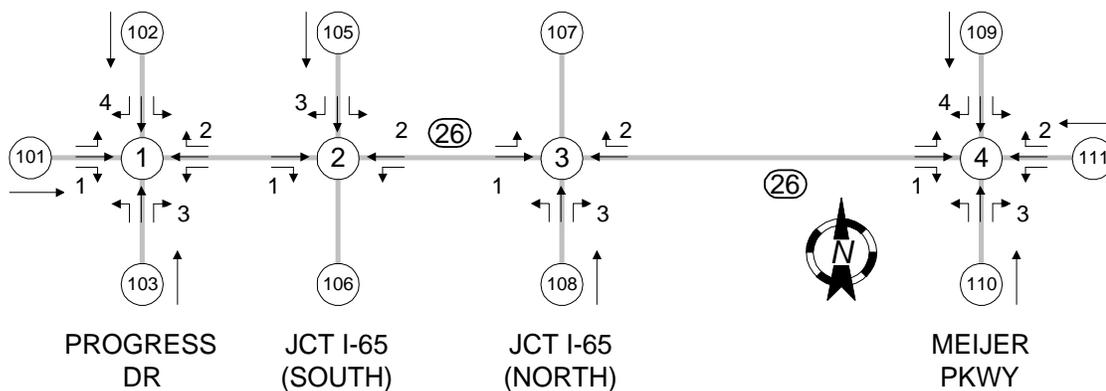


Figure 8-6: Intersection Approach Labels (Reference Figure 8-7)

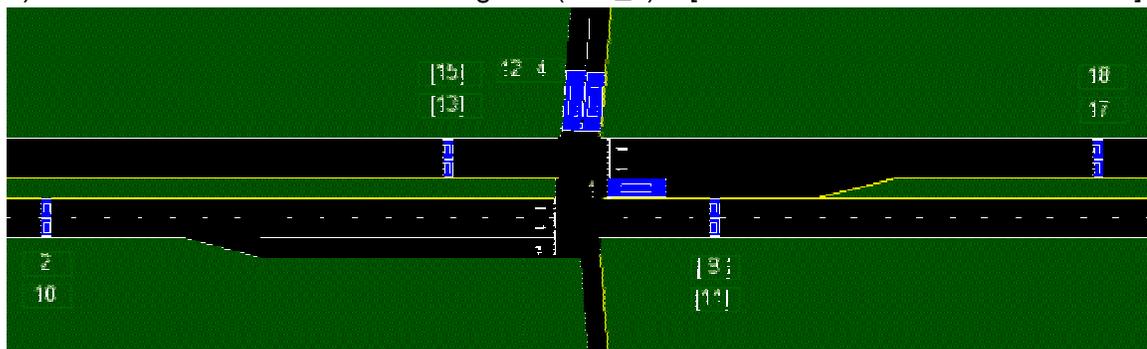
```

COM [PortID]                2, 1, R, 2, Prot
1                            2, 2, L, 1, Prot
CIDdef [CID, Base ID]      2, 2, T, 9, Prot
1, 1                        2, 3, L, 4, Prot
2, 3                        2, 3, T, 4, Prot
3, 5                        2, 3, R, 4, Prot
NodeAssign[Node, CID]     3, 1, L, 5, Prot
1, 1                        3, 1, T, 10, Prot
2, 2                        3, 2, T, 6, Prot
3, 2                        3, 2, R, 6, Prot
4, 3                        3, 3, L, 8, Prot
Phases [Node, Approach, L/T/R, 3, 3, T, 8, Prot
Phase#, Pro/Per/PP]       3, 3, R, 8, Prot
1, 1, L, 5, Prot          4, 1, L, 5, PP
1, 1, T, 2, Prot          4, 1, T, 2, Prot
1, 1, R, 2, Prot          4, 1, R, 9, Prot
1, 2, L, 1, Prot          4, 2, L, 1, PP
1, 2, T, 6, Prot          4, 2, T, 6, Prot
1, 2, R, 6, Prot          4, 2, R, 6, Prot
1, 3, L, 3, PP            4, 3, L, 8, Prot
1, 3, T, 8, Prot          4, 3, T, 8, Prot
1, 3, R, 8, Prot          4, 3, R, 8, Prot
1, 4, L, 7, PP            4, 4, L, 4, Prot
1, 4, T, 4, Prot          4, 4, T, 4, Prot
1, 4, R, 4, Prot          4, 4, R, 4, Prot
2, 1, T, 2, Prot
    
```

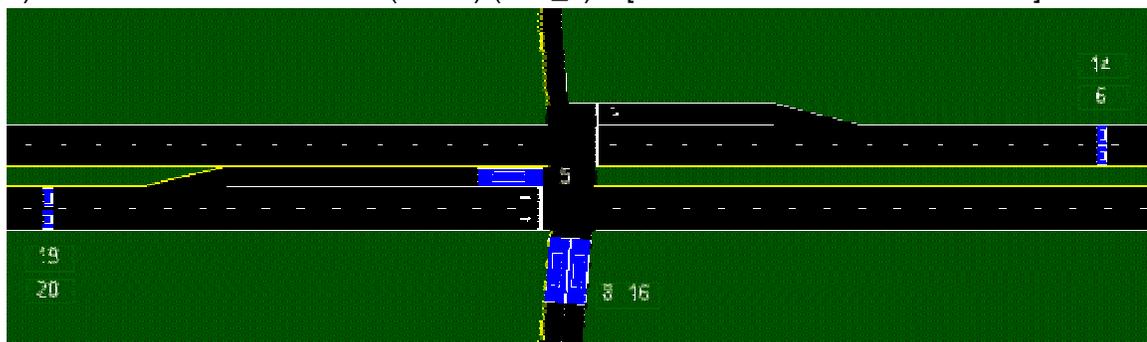
Figure 8-7: External Control File (CID) for Phasing (Reference Figure 8-6)



a) Node 1: SR 26 & Red Cloud / Progress (CID_1) – [SYS 9 / 11 – WEST APPROACH]



b) Node 2: SR 26 & JCT I-65 (South) (CID_2) – [SYS 3 – NORTH APPROACH]



c) Node 3: SR 26 & JCT I-65 (North) (CID_2) – [SYS 7 – SOUTH APPROACH]



d) Node 4: SR 26 & Meijer Entrance (CID_3)

Figure 8-8: Intersection Detector Locations and Numbering

101	1	7		105	360			42		
101	1	2	3000	102	60			42		
101	1	1	3000	110	60			42		
101	1	2	22000	109	60	[SYSTEM DETECTOR]		42		
101	1	1	22000	111	60	[SYSTEM DETECTOR]		42		
1	2	2	3000	202	60			42		
1	2	1	3000	210	60			42		
2	1	7		101	360			42		
2	1	2	3000	106	60			42		
2	1	1	3000	114	60			42		
2	1	2	6000	213	60	[SYSTEM DETECTOR]		42		
2	1	1	6000	215	60	[SYSTEM DETECTOR]		42		
2	3	7		205	360			42		
2	3	2	3000	219	60			42		
2	3	1	3000	220	60			42		
2	3	2	6800	209	60	[SYSTEM DETECTOR]		42		
2	3	1	6800	211	60	[SYSTEM DETECTOR]		42		
3	2	7		201	360			42		
3	2	2	3000	217	60			42		
3	2	1	3000	218	60			42		
3	4	8	3000	302	60			42		
4	3	2	3000	206	60			42		
4	3	1	3000	214	60			42		
4	3	2	13700	313	60	[SYSTEM DETECTOR]		42		
4	3	1	13700	315	60	[SYSTEM DETECTOR]		42		
111	4	8	3000	306	60			42		
102	1	2		104	360			42		
102	1	1		112	360			42		
105	2	1		204	360			42		
105	2	7		212	360			42		
105	2	1	3800	203	60	[SYSTEM DETECTOR]		42		
108	3	1		208	360			42		
108	3	7		216	360			42		
108	3	1	3800	207	60	[SYSTEM DETECTOR]		42		
110	4	3		308	360			42		
110	4	2		316	360			42		
110	4	1		317	360			42		
109	4	1		304	200			42		
103	1	2		103	360			42		
103	1	1		116	360			42		
1	101	1	2	1	103	1	102	1	2	43
2	1	2	3	2	105	2			2	43
3	2	3	4	3	108	3			2	43
4	3	4	111	4	110	4	109	4	2	43

Figure 8-9: Sample External Detector File (Reference Figure 8-8)

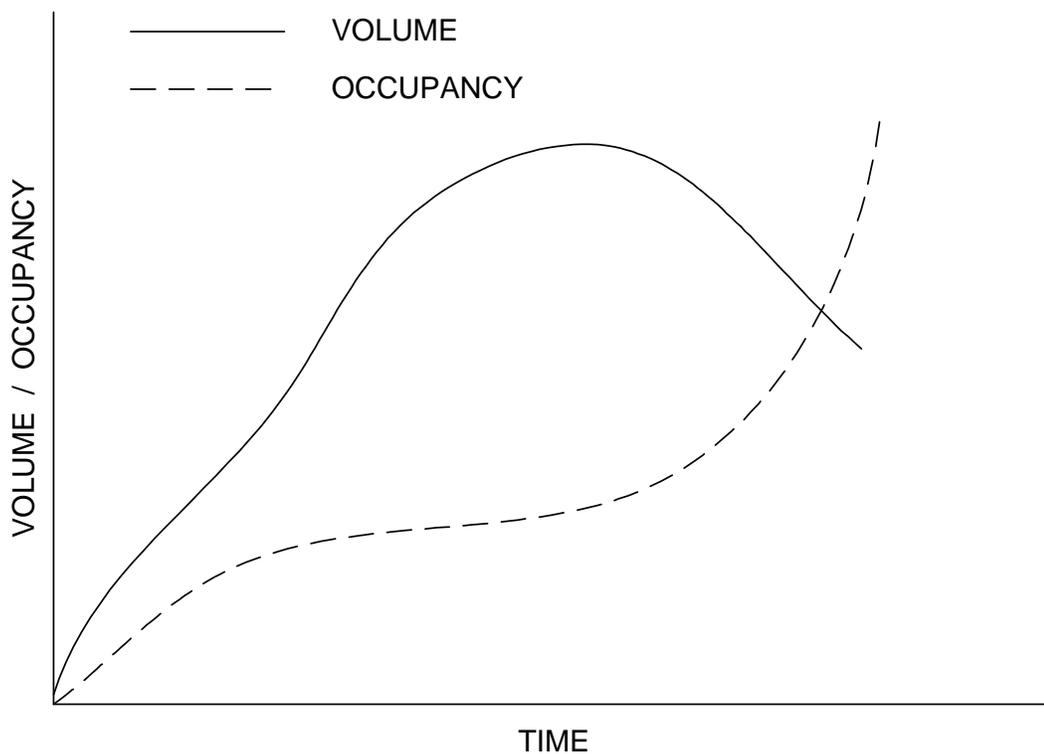


Figure 8-10: Relationship Between Volume and Occupancy [Econolite, 1996]

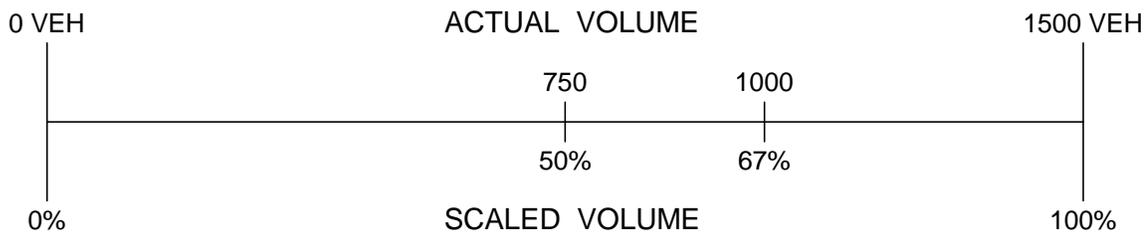


Figure 8-11: Comparison Between Actual Volume and Scaled Volume

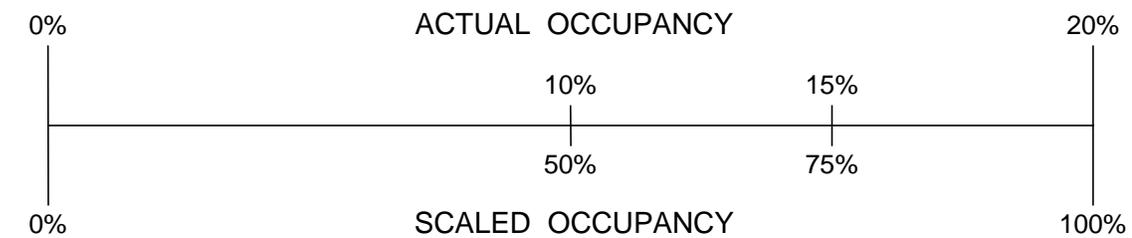


Figure 8-12: Comparison Between Actual Occupancy and Scaled Occupancy

NODE	1	1	1	2	3	4	4	4
MOVEMENT	EB	NB	SB	SB	NB	WB	NB	SB
MID_DAY	851	106	174	370	265	433	259	3
AM_PEAK	851	106	87	621	610	661	120	3
PM_PEAK	1559	150	150	565	260	537	377	3
IN_GAME	851	170	87	715	810	861	208	3
OUT_GAME	2575	150	150	565	260	337	377	3

Table 8-1: System Entry Volumes (Reference Figure 8-1)

INT	TIME	MID-DAY	AM PEAK	PM PEAK	GAME IN	GAME OUT
PROGRESS DRIVE RED CLOUD	EBLT	8	8	4	8	5
	EBTH	83	83	89	83	89
	EBRT	9	9	7	9	6
	WBLT	4	6	7	5	8
	WBTH	83	86	79	89	75
	WBRT	13	8	14	6	17
	NBLT	39	39	34	62	34
	NBTH	7	7	5	4	5
	NBRT	54	54	61	34	61
	SBLT	69	67	73	25	73
	SBTH	4	8	1	8	1
	SBRT	27	25	26	67	26
	JCT I-65 (SOUTH)	EBTH	82	82	81	82
EBRT		18	18	19	18	22
WBLT		3	7	4	8	5
WBTH		97	93	96	92	95
SBLT		29	9	30	8	30
SBRT		71	91	70	92	70
JCT I-65 (NORTH)	EBLT	23	23	22	12	32
	EBTH	77	77	78	88	68
	WBTH	83	84	75	89	68
	WBRT	17	16	25	11	32
	NBLT	80	84	77	88	77
	NBRT	20	16	23	12	23
MEIJER ENTRANCE	EBLT	0	0	0	0	0
	EBTH	55	55	67	55	73
	EBRT	45	45	33	45	27
	WBLT	6	8	6	6	9
	WBTH	94	92	94	94	91
	WBRT	0	0	0	0	0
	NBLT	97	82	97	91	97
	NBTH	0	0	0	0	0
	NBRT	3	18	3	9	3
	SBLT	33	33	33	33	33
	SBTH	34	34	34	34	34
	SBRT	33	33	33	33	33

Table 8-2: System Turning Percentages (Reference Figure 8-1)

SR 26 (SOUTH ST)		POCKET LENGTHS (FT)		STOP BAR DETECTOR LENGTHS (FT)			RACEWAY DETECTORS (FT)	
INT	MOVE	LEFT	RIGHT	LEFT	THRU	RIGHT	THRU	DIST
1	EB	165	60	36	--	--	6	300
1	WB	140	140	36	--	--	6	300
1	NB	--	--	36	36	--	--	--
1	SB	--	--	--	36	--	--	--
2	EB	--	175	--	--	--	6	300
2	WB	130	--	36	--	--	6	300
2	SB	--	--	36	--	36	--	--
3	EB	180	--	36	--	--	6	300
3	WB	--	100	--	--	--	6	300
3	NB	--	--	36	--	36	--	--
4	EB	105	PREV	--	--	--	6	300
4	WB	--	--	--	--	--	6	300
4	NB	--	--	36	--	36	--	--
4	SB	--	--	--	36	--	--	--

NOTE: "PREV" DENOTES THAT THE TURNING BAY BEGINS AT THE PREVIOUS INTERSECTION.

Table 8-3: Intersection Pocket Lengths and Detector Locations

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
1	EBLT	5	105	PRS
1	EBTH	2	102	PRS
1	EBTH	10	110	PRS
1	WBLT	1	101	PRS
1	WBTH	6	106	PRS
1	WBTH	14	114	PRS
1	NBLT	3	103	PRS
1	NBTH	16	116	PRS
1	SBTH	4	104	PRS
1	SBTH	12	112	PRS

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
2	EBTH	2	202	PRS
2	EBTH	10	210	PRS
2	WBLT	1	201	PRS
2	WBTH	17	217	PRS
2	WBTH	18	218	PRS
2	SBLT	4	204	PRS
2	SBRT	12	212	PRS

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
3	EBLT	5	205	PRS
3	EBTH	19	219	PRS
3	EBTH	20	220	PRS
3	WBTH	6	206	PRS
3	WBTH	14	214	PRS
3	NBLT	8	205	PRS
3	NBRT	16	216	PRS

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
4	EBTH	2	302	PRS
4	WBTH	6	306	PRS
4	NBLT	8	308	PRS
4	NBLT	16	316	PRS
4	NBRT	17	317	PRS
4	SBTH	4	304	PRS

NOTE: INTERSECTION 2 & 3 DETECTORS ARE TIED TO THE SAME CONTROLLER (DIAMOND).

Table 8-4: Intersection Detector Configuration (CID Logic Only)

INT	MOVE- MENT	DET NUM	LOCK / N-LCK	DELAY (SEC)	CALL PHASE	DETECTOR TYPE
1	EBLT	5	N-LCK	--	5	STANDARD (NORMAL)
1	EBTH	2	LOCK	--	2	STANDARD (NORMAL)
1	EBTH	10	LOCK	--	2	STANDARD (NORMAL)
1	WBLT	1	N-LCK	--	1	STANDARD (NORMAL)
1	WBTH	6	LOCK	--	6	STANDARD (NORMAL)
1	WBTH	14	LOCK	--	6	STANDARD (NORMAL)
1	NBLT	3	N-LCK	--	3	STANDARD (NORMAL)
1	NBTH	16	N-LCK	10	8	EXTEND / DELAY (T-1)
1	SBLT	4	N-LCK	--	4	STANDARD (NORMAL)
1	SBTH	12	N-LCK	10	4	EXTEND / DELAY (T-1)
2	EBTH	2	LOCK	--	2	STANDARD (NORMAL)
2	EBTH	10	LOCK	--	2	STANDARD (NORMAL)
2	WBLT	1	N-LCK	--	1	STANDARD (NORMAL)
2	WBTH	17	LOCK	--	2	STANDARD (NORMAL)
2	WBTH	18	LOCK	--	2	STANDARD (NORMAL)
2	SBLT	4	N-LCK	--	4	STANDARD (NORMAL)
2	SBRT	12	N-LCK	20	4	EXTEND / DELAY (T-1)
3	EBLT	5	N-LCK	--	5	STANDARD (NORMAL)
3	EBTH	19	LOCK	--	6	STANDARD (NORMAL)
3	EBTH	20	LOCK	--	6	STANDARD (NORMAL)
3	WBTH	6	LOCK	--	6	STANDARD (NORMAL)
3	WBTH	14	LOCK	--	6	STANDARD (NORMAL)
3	NBLT	8	N-LCK	--	8	STANDARD (NORMAL)
3	NBRT	16	N-LCK	20	8	EXTEND / DELAY (T-1)
4	EBTH	2	LOCK	--	2	STANDARD (NORMAL)
4	WBTH	6	LOCK	--	6	STANDARD (NORMAL)
4	NBLT	8	N-LCK	--	8	STANDARD (NORMAL)
4	NBLT	16	N-LCK	--	8	STANDARD (NORMAL)
4	NBRT	17	N-LCK	20	8	EXTEND / DELAY (T-1)
4	SBTH	4	N-LCK	--	4	STANDARD (NORMAL)

NOTE: RACEWAY DETECTORS MUST BE IN LOCK MODE IF THEY ARE NOT IN VEHICLE RECALL.

Table 8-5: Intersection Detector Configuration (Controller)

INT	MOVE- MENT	DETECTORS		DET NUM	STAT ID	LOC TLM	TLM ADD	SYS NUM	PUL PRS
		THRU	DIST						
1	EBTH	6	-2200	9	109	1*	SDA1	1	PRS
1	EBTH	6	-2200	11	111	1*	SDA2	2	PRS
2	WBTH	6	600	13	213	2	SDA1	3	PRS
2	WBTH	6	600	15	215	2	SDA2	4	PRS
2	EBTH	6	680	9	209	2	SDB1	5	PRS
2	EBTH	6	680	11	211	2	SDB2	6	PRS
2	SBTH	6	-380	3	203	2	SDC1	7	PRS
3	NBTH	6	-380	7	207	2	SDC2	8	PRS
4	WBTH	6	1370	13	313	3	SDA1	9	PRS
4	WBTH	6	1370	15	315	3	SDA2	10	PRS

NOTE: A "*" REPRESENTS THAT AN ALTERNATE ADDRESS WAS USED DUE TO HARDWARE.

NOTE: ALL DISTANCES WITHOUT A "-" ARE MEASURED FROM THE UPSTREAM INTERSECTION.

Table 8-6: System Detector Configuration (CID Logic Only)

INT	DESCRIPTION (SEC)	1	2	3	4	5	6	7	8
1	MINIMUM GREEN	3	15	3	7	3	15	--	7
1	VEHICLE EXTENSION	2.5	5.0	2.5	3.0	2.5	5.0	--	3.0
1	MAXIMUM GREEN	35	80	20	45	35	80	--	45
1	YELLOW CLEARANCE	3.5	3.5	3.5	3.5	3.5	3.5	--	3.5
1	RED CLEARANCE	1.0	2.0	1.0	1.5	1.0	2.0	--	1.5
1	MINIMUM GAP TIME	2.5	3.0	2.5	3.0	2.5	3.0	--	3.0
2,3	MINIMUM GREEN	3	15	--	7	3	15	--	7
2,3	VEHICLE EXTENSION	2.5	5.0	--	3.0	2.5	5.0	--	3.0
2,3	MAXIMUM GREEN	35	80	--	45	35	80	--	45
2,3	YELLOW CLEARANCE	3.5	3.5	--	3.5	3.5	3.5	--	3.5
2,3	RED CLEARANCE	1.0	2.0	--	1.5	1.0	2.0	--	1.5
2,3	MINIMUM GAP TIME	2.5	3.0	--	3.0	2.5	3.0	--	3.0
4	MINIMUM GREEN	--	15	--	3	--	15	--	7
4	VEHICLE EXTENSION	--	5.0	--	3.0	--	5.0	--	3.0
4	MAXIMUM GREEN	--	80	--	12	--	80	--	45
4	YELLOW CLEARANCE	--	3.5	--	3.5	--	3.5	--	3.5
4	RED CLEARANCE	--	2.0	--	1.5	--	2.0	--	1.5
4	MINIMUM GAP TIME	--	3.0	--	3.0	--	3.0	--	3.0

NOTE: NODES 2 & 3 (DIAMOND INTERCHANGE) ARE CONTROLLED BY A SINGLE CONTROLLER.

NOTE: THE MAXIMUM GREEN TIMINGS SHOWN IN THIS TABLE ARE INHIBITED UNDER COORDINATION.

Table 8-7: General Phase Parameters (SR 26 – South)

INT	COS	CYC	OFF	1	2	3	4	5	6	7	8	LAG
1	111	80	0	12	40	12	16	12	40	--	28	--
1	211	90	0	12	50	12	16	12	50	--	28	--
1	311	90	0	12	50	12	16	12	50	--	28	--
1	411	140	0	19	91	14	16	12	98	--	30	--
1	511	160	0	20	112	12	16	20	112	--	28	--
2,3	111	80	78	12	46	--	22	18	40	--	22	1,5
2,3	211	90	83	14	32	--	44	18	34	--	38	1,5
2,3	311	90	3	12	43	--	35	27	41	--	22	1,5
2,3	411	140	21	18	52	--	70	18	47	--	75	1,5
2,3	511	160	21	12	88	--	60	58	74	--	28	1,5
4	111	80	34	--	60	--	12	--	60	--	12	--
4	211	90	38	--	66	--	12	--	66	--	12	--
4	311	90	34	--	62	--	12	--	62	--	16	--
4	411	140	136	--	112	--	12	--	112	--	16	--
4	511	160	41	--	122	--	12	--	122	--	26	--

NOTE: NODES 2 & 3 (DIAMOND INTERCHANGE) ARE CONTROLLED BY A SINGLE CONTROLLER.

NOTE: OFFSETS ARE REFERENCED FROM THE BEGINNING OF THE FIRST COORDINATED PHASE.

Table 8-8: SR 26 (South) Coordination Plans and Splits

STP	PRG	DAY	TIME	COS	SF1	SF2	SF3	SF4	TRP	OVR
1	1	M-F	0630	211	OFF	OFF	OFF	OFF	YES	NO
2	1	M-F	0900	111	OFF	OFF	OFF	OFF	YES	NO
3	1	M-F	1430	311	OFF	OFF	OFF	OFF	YES	NO
4	1	M-F	1900	111	OFF	OFF	OFF	OFF	YES	NO
5	1	M-F	2300	FREE	OFF	OFF	OFF	OFF	YES	NO
6	2	SAT	0730	111	OFF	OFF	OFF	OFF	YES	NO
7	2	SAT	2200	FREE	OFF	OFF	OFF	OFF	YES	NO
8	3	SUN	0900	111	OFF	OFF	OFF	OFF	YES	NO
9	3	SUN	2000	FREE	OFF	OFF	OFF	OFF	YES	NO

NOTE: TRP AS "YES" ENABLES THE TRAFFIC RESPONSIVE (TRP) PLAN AS "PLAN-IN-EFFECT".
NOTE: OVR AS "YES" ALLOWS TRP TO OVERRIDE TOD IF THE CYCLE COMMAND IS GREATER.

Table 8-9: Time of Day Programming Chart (SR 26 – South)

TLM ADD	CTR 1-24	SDA1 1-32	SDA2 1-32	SDB1 1-32	SDB2 1-32	SDC1 1-32	SDC2 1-32	SDD1 1-32	SDD2 1-32
1	1	1	2	0	0	0	0	0	0
2	2	3	4	5	6	7	8	0	0
3	3	9	10	0	0	0	0	0	0

NOTE: SYSTEM DETECTORS ARE WIRED TO THE NEAREST LOCAL CONTROLLER.
NOTE: THE NUMBERS ABOVE ARE THE ACTUAL MASTER SYSTEM DETECTOR NUMBERS.

Table 8-10: System Detector Mapping Table (Master Controller)

GROUP SETTINGS	1	2	3	4	5	6	7	8
ASSIGN SD TO LANE 1	1	5	7	1	3	0	0	0
ASSIGN SD TO LANE 2	2	6	8	2	4	0	0	0
ASSIGN SD TO LANE 3	3	9	0	5	9	0	0	0
ASSIGN SD TO LANE 4	4	10	0	6	10	0	0	0
DETECTORS REQUIRED	3	3	2	3	3	N/A	N/A	N/A
ASSIGN TO LEVEL	2	2	N/A	N/A	N/A	N/A	N/A	N/A
ASSIGN TO DIRECTION 1	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A
ASSIGN TO DIRECTION 2	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A
ASSIGN TO SPLIT A	AV	AV	N/A	AV	AV	N/A	N/A	N/A
ASSIGN TO SPLIT B	N/A	N/A	AV	N/A	N/A	N/A	N/A	N/A
ASSIGN TO ARTERIAL	2	2	N/A	2	2	N/A	N/A	N/A
ASSIGN TO NON-ARTERIAL	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A

NOTE: SYSTEM DETECTORS ONLY FUNCTION DURING TRAFFIC RESPONSIVE (TRP) OPERATION.

Table 8-11: Traffic Responsive Programming (System Detectors)

FUNCTION COMPUTATIONS	LEV	DR1	DR2	SPA	SPB	ART	NRT
TRAFFIC PARAMETER	CON						
VALUE OF THE GROUPS	1	1	1	2	2	AV	AV
SMOOTHING FACTOR (%)	30	30	30	30	30	30	30
UPDATE THRESHOLD (%)	20	20	20	20	20	20	20

NOTE: SAMPLE PERIOD FOR THIS STUDY WAS ONCE PER CYCLE (TRAFFIC RESPONSIVE).

NOTE: CON = CONCENTRATION WHICH INCLUDES BOTH VOLUME AND OCCUPANCY FUNCTIONS.

Table 8-12: System Detector Function Computations (SR 26 – South)

LEVEL (0-101%)		OFFSET (0-100%)		SPLIT (0-101%)		NRT-ART (0-100%)	
2>1	12	1>AV	15	2>1	10	NRT>ART	20
1>2	20	AV>1	20	1>2	20	ART>NRT	30
3>2	30	2>AV	15	3>2	20		
2>3	40	AV>2	20	2>3	30		
4>3	45			4>3	30		
3>4	60			3>4	40		
5>4	65						
4>5	80						

NOTE: LEVEL AND SPLITS ARE OMITTED BY ENTERING A PERCENTAGE GREATER THAN 100%.

Table 8-13: System Thresholds for Plan Selection (SR 26 – South)

LEVEL	DESCRIPTION	CLR	COS	SF1	SF2	SF3	SF4
LEVEL 1	DIRECTION 1 (DR1)	NO	FREE	OFF	OFF	OFF	OFF
LEVEL 1	DIRECTION 2 (DR2)	NO	FREE	OFF	OFF	OFF	OFF
LEVEL 1	AVERAGE (AV)	NO	FREE	OFF	OFF	OFF	OFF
LEVEL 1	NRT-ART (NRT/ART)	NO	FREE	OFF	OFF	OFF	OFF
LEVEL 2	DIRECTION 1 (DR1)	NO	111	OFF	OFF	OFF	OFF
LEVEL 2	DIRECTION 2 (DR2)	NO	211	OFF	OFF	OFF	OFF
LEVEL 2	AVERAGE (AV)	NO	111	OFF	OFF	OFF	OFF
LEVEL 2	NRT-ART (NRT/ART)	NO	211	OFF	OFF	OFF	OFF
LEVEL 3	DIRECTION 1 (DR1)	NO	311	OFF	OFF	OFF	OFF
LEVEL 3	DIRECTION 2 (DR2)	NO	211	OFF	OFF	OFF	OFF
LEVEL 3	AVERAGE (AV)	NO	211	OFF	OFF	OFF	OFF
LEVEL 3	NRT-ART (NRT/ART)	NO	411	OFF	OFF	OFF	OFF
LEVEL 4	DIRECTION 1 (DR1)	NO	311	OFF	OFF	OFF	OFF
LEVEL 4	DIRECTION 2 (DR2)	NO	411	OFF	OFF	OFF	OFF
LEVEL 4	AVERAGE (AV)	NO	311	OFF	OFF	OFF	OFF
LEVEL 4	NRT-ART (NRT/ART)	NO	411	OFF	OFF	OFF	OFF
LEVEL 5	DIRECTION 1 (DR1)	NO	511	OFF	OFF	OFF	OFF
LEVEL 5	DIRECTION 2 (DR2)	NO	411	OFF	OFF	OFF	OFF
LEVEL 5	AVERAGE (AV)	NO	511	OFF	OFF	OFF	OFF
LEVEL 5	NRT-ART (NRT/ART)	NO	411	OFF	OFF	OFF	OFF

NOTE: PLANS ARE AUTOMATICALLY SELECTED DURING TRAFFIC RESPONSIVE (TRP) OPERATION.

Table 8-14: Traffic Responsive Plan Selection Chart (SR 26 – South)

CASE PLAN	MIDDAY > MORNING PTN_111_211 (CASE_1)			MIDDAY > AFTERNOON PTN_111_311 (CASE_2)			MIDDAY > EVENT_IN PTN_111_411 (CASE_3)		
	TOD	TRP	DES	TOD	TRP	DES	TOD	TRP	DES
8:00	111	111	111	111	111	111	111	111	111
8:02	111	111	111	111	111	111	111	111	111
8:04	111	111	111	111	111	111	111	111	111
8:06	111	111	111	111	111	111	111	111	111
8:08	111	111	111	111	111	111	111	111	111
8:10	111	111	111	111	111	111	111	111	111
8:12	111	111	111	111	111	111	111	111	111
8:14	111	111	111	111	111	111	111	111	111
8:16	111	111	111	111	111	111	111	111	111
8:18	111	111	111	111	111	111	111	111	111
8:20	111	111	211	111	111	311	111	111	411
8:22	111	111	211	111	111	311	111	111	411
8:24	111	111	211	111	TRAN	311	111	111	411
8:26	111	111	211	111	TRAN	311	111	TRAN	411
8:28	111	111	211	111	311	311	111	TRAN	411
8:30	111	111	211	111	311	311	111	211	411
8:32	111	TRAN	211	111	311	311	111	211	411
8:34	111	211	211	111	311	311	111	211	411
8:36	111	211	211	111	311	311	111	TRAN	411
8:38	111	211	211	111	311	311	111	411	411
8:40	111	211	211	111	311	311	111	411	411
8:42	111	211	211	111	311	311	111	411	411
8:44	111	211	211	111	311	311	111	411	411
8:46	111	211	211	111	311	311	111	411	411
8:48	111	211	211	111	311	311	111	411	411
8:50	111	211	211	111	311	311	111	411	411
8:52	111	211	211	111	311	311	111	411	411
8:54	111	TRAN	211	111	311	311	111	TRAN	411
8:56	111	TRAN	211	111	311	311	111	211	411
8:58	111	411	211	111	311	311	111	211	411
9:00	111	TRAN	211	111	311	311	111	211	411
SYNC	100%	84%	N/A	100%	93%	N/A	100%	80%	N/A

Table 8-15: SR 26 (South) Pattern Select Table – Node 1 (Table 1 of 2)

CASE PLAN	MIDDAY > EVENT_OUT PTN_111_511 (CASE_4)			EVENT_IN > MIDDAY PTN_411_111 (CASE_5)			EVENT_OUT > MIDDAY PTN_511_111 (CASE_6)		
	TOD	TRP	DES	TOD	TRP	DES	TOD	TRP	DES
8:00	111	111	111	411	TRAN	411	511	511	511
8:02	111	111	111	411	TRAN	411	511	511	511
8:04	111	111	111	411	TRAN	411	511	511	511
8:06	111	111	111	411	211	411	511	511	511
8:08	111	111	111	411	TRAN	411	511	511	511
8:10	111	111	111	411	411	411	511	511	511
8:12	111	111	111	411	411	411	511	511	511
8:14	111	111	111	411	411	411	511	511	511
8:16	111	111	111	411	411	411	511	511	511
8:18	111	111	111	411	411	411	511	511	511
8:20	111	111	511	411	411	111	511	511	111
8:22	111	111	511	411	411	111	511	511	111
8:24	111	TRAN	511	411	411	111	511	511	111
8:26	111	TRAN	511	411	411	111	511	TRAN	111
8:28	111	TRAN	511	411	TRAN	111	511	TRAN	111
8:30	111	TRAN	511	411	TRAN	111	511	311	111
8:32	111	511	511	411	TRAN	111	511	TRAN	111
8:34	111	511	511	411	TRAN	111	511	TRAN	111
8:36	111	511	511	411	111	111	511	311	111
8:38	111	511	511	411	111	111	511	TRAN	111
8:40	111	511	511	411	111	111	511	TRAN	111
8:42	111	511	511	411	111	111	511	TRAN	111
8:44	111	511	511	411	111	111	511	TRAN	111
8:46	111	511	511	411	111	111	511	111	111
8:48	111	511	511	411	111	111	511	111	111
8:50	111	511	511	411	111	111	511	111	111
8:52	111	511	511	411	111	111	511	111	111
8:54	111	511	511	411	111	111	511	111	111
8:56	111	511	511	411	111	111	511	111	111
8:58	111	511	511	411	111	111	511	111	111
9:00	111	511	511	411	111	111	511	111	111
SYNC	100%	81%	N/A	100%	76%	N/A	100%	74%	N/A

Table 8-16: SR 26 (South) Pattern Select Table – Node 1 (Table 2 of 2)

CASE	PTN_111_211 (CASE_1)		PTN_111_311 (CASE_2)		PTN_111_411 (CASE_3)	
	TOD	TRP	TOD	TRP	TOD	TRP
1	100	84	100	93	100	80
2-3	100	85	100	98	100	63
4	100	83	100	88	100	70

CASE	PTN_111_511 (CASE_4)		PTN_411_111 (CASE_5)		PTN_511_111 (CASE_6)	
	TOD	TRP	TOD	TRP	TOD	TRP
1	100	81	100	76	100	74
2-3	100	81	100	72	100	78
4	100	70	100	85	100	74

Table 8-17: SR 26 (South) Percent In-Sync (%) Table – All Scenarios

Demand Volume	Plan (COS)	Operation	Cum. EB Travel Time (s/v)	STDEV Of Cum. EB Travel Time (s/v)	Cum. WB Travel Time (s/v)	STDEV Of Cum. WB Travel Time (s/v)
MID_DAY	111	TOD	148.4	2.0	157.5	2.0
AM PEAK	211	TOD	159.5	1.9	171.1	3.2
PM PEAK	311	TOD	163.7	2.7	166.8	3.2
IN_GAME	411	TOD	165.9	4.1	193.9	6.0
OUT_GAME	511	TOD	186.8	9.0	171.0	4.7
MID_DAY	211	TOD	158.4	2.5	165.2	1.9
MID_DAY	311	TOD	149.1	1.9	158.3	2.6
MID_DAY	411	TOD	501.9	207.6	162.1	7.0
MID_DAY	511	TOD	153.0	2.8	167.9	3.5
MID->AM	111	TOD	148.2	2.4	157.7	2.4
MID->AM	111->211	TRP	156.0	3.0	165.6	2.6
MID->AM	211	TOD	158.0	2.9	167.9	2.2
MID->PM	111	TOD	176.5	31.1	160.6	2.6
MID->PM	111->311	TRP	164.7	4.9	163.7	4.3
MID->PM	111->311	MAN	158.5	3.5	161.1	2.1
MID->PM	311	TOD	158.9	3.2	162.1	3.1
MID->IN	111	TOD	148.5	1.8	164.3	8.0
MID->IN	111->411	TRP	160.6	6.7	181.5	6.0
MID->IN	411	TOD	204.2	81.7	182.3	14.4
IN->MID	411	TOD	187.0	46.5	182.4	13.7
IN->MID	411->111	TRP	159.1	3.7	181.8	6.9
MID->OUT	111	TOD	531.5	34.9	160.7	3.1
MID->OUT	111->511	TRP	188.0	20.5	164.8	5.0
MID->OUT	511	TOD	175.6	8.6	169.7	4.4
OUT->MID	511	TOD	176.9	6.3	163.3	3.7
OUT->MID	511->111	TRP	182.8	11.6	165.0	4.9

Table 8-18: Summary of Arterial Travel Times Subject to Various Conditions

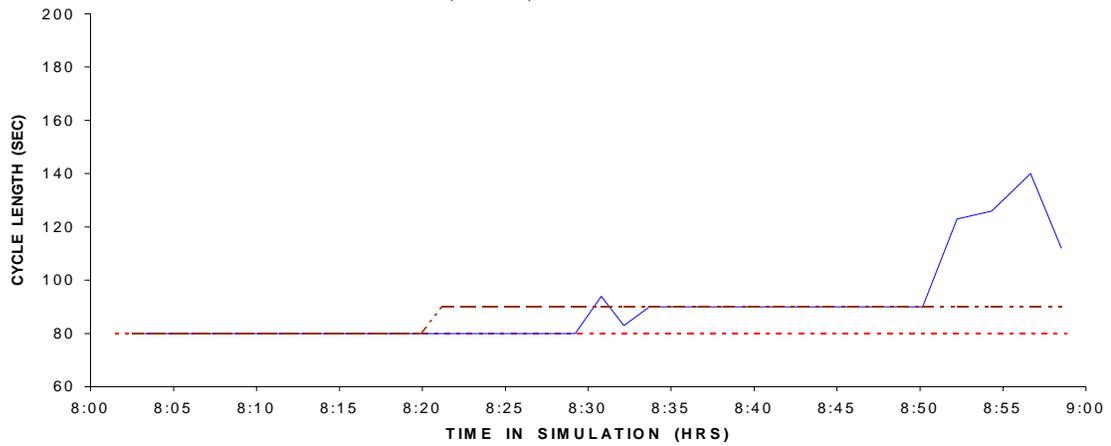
Demand Volume	Plan (COS)	Operation	Int 1 NB (s/v)	Int 1 SB (s/v)	Int 2 SB (s/v)	Int 2 WB LT (s/v)	Int 3 NB (s/v)	Int 3 EB LT (s/v)	Int 4 NB (s/v)
MID_DAY	111	TOD	75.6	86.5	76.8	51.4	93.5	50.3	89.9
AM PEAK	211	TOD	79.1	91.3	83.1	45.5	93.7	47.4	99.2
PM PEAK	311	TOD	79.2	91.8	82.2	55.8	94.2	47.9	93.0
IN_GAME	411	TOD	90.9	89.6	97.0	61.8	128.1	53.9	107.2
OUT_GAME	511	TOD	107.1	174.0	94.9	107.5	119.9	45.8	124.1
MID_DAY	211	TOD	78.4	90.2	77.8	46.9	86.1	58.9	94.6
MID_DAY	311	TOD	78.2	90.5	77.7	59.7	91.3	49.8	94.5
MID_DAY	411	TOD	170.0	161.0	132.0	128.6	101.0	565.3	119.1
MID_DAY	511	TOD	94.7	180.0	88.5	102.8	107.3	43.1	126.7
MID->AM	111	TOD	75.9	87.0	79.7	57.7	446.9	48.5	91.3
MID->AM	111->211	TRP	78.5	89.8	80.9	47.3	99.0	54.1	96.7
MID->AM	211	TOD	77.2	90.3	80.9	45.8	91.5	53.8	95.9
MID->PM	111	TOD	77.2	87.0	80.8	56.3	93.9	110.7	90.2
MID->PM	111->311	TRP	77.7	91.4	81.1	53.9	93.8	58.7	95.5
MID->PM	111->311	MAN	78.5	89.9	80.9	53.8	94.8	49.4	94.0
MID->PM	311	TOD	79.3	90.6	80.3	54.4	94.5	48.8	93.4
MID->IN	111	TOD	79.4	83.7	97.4	53.6	527.9	48.4	90.3
MID->IN	111->411	TRP	88.8	91.6	91.5	55.5	132.5	59.9	102.9
MID->IN	411	TOD	125.1	111.4	98.6	74.5	106.2	338.1	119.5
IN->MID	411	TOD	95.6	111.0	98.0	92.6	108.4	278.7	118.8
IN->MID	411->111	TRP	85.5	90.8	88.9	77.9	151.5	65.6	100.9
MID->OUT	111	TOD	218.9	184.0	166.8	110.9	93.6	207.7	89.9
MID->OUT	111->511	TRP	97.1	132.8	89.8	79.3	110.3	55.8	117.4
MID->OUT	511	TOD	103.3	172.5	92.0	98.3	112.8	42.8	124.2
OUT->MID	511	TOD	98.8	180.2	91.4	107.0	118.0	47.7	125.3
OUT->MID	511->111	TRP	91.3	108.7	85.1	90.7	104.7	52.2	112.7

Table 8-19: Summary of Minor Movement Delay Subject to Various Conditions

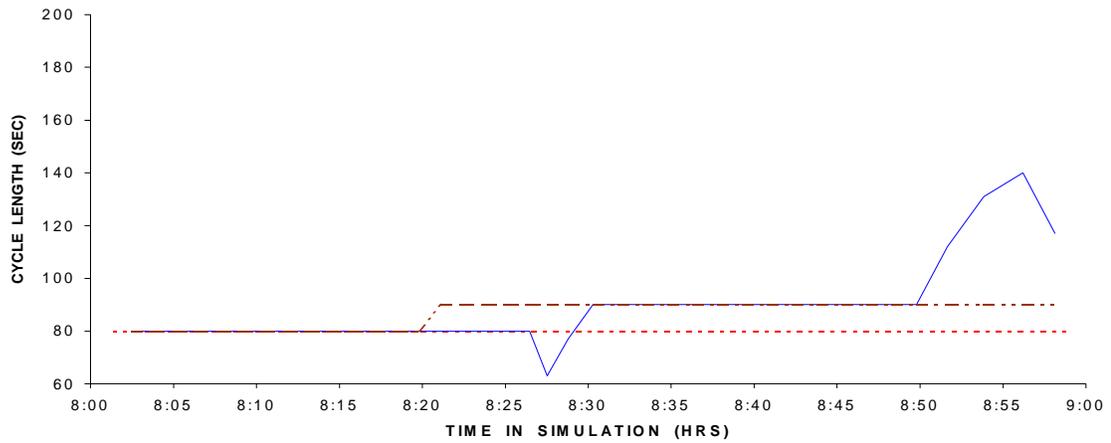
Demand Volume	Plan (COS)	Operation	EB Delay (v-m)	WB Delay (v-m)	SS Delay (v-m)	Left-Turns (v-m)	Total Delay (v-m)	% DIFF (TRP)
MID_DAY	111	TOD	265.1	386.6	544.0	242.1	1437.8	
AM PEAK	211	TOD	372.2	718.0	817.3	313.4	2220.9	
PM PEAK	311	TOD	821.8	565.0	768.3	368.0	2523.1	
IN_GAME	411	TOD	445.3	1573.0	1755.8	321.0	4095.1	
OUT_GAME	511	TOD	1898.6	443.6	1463.5	791.4	4597.1	
MID_DAY	211	TOD	346.2	455.4	553.9	274.3	1629.8	
MID_DAY	311	TOD	277.6	400.5	576.3	246.2	1500.6	
MID_DAY	411	TOD	3232.6	465.4	1292.4	1534.1	6524.5	
MID_DAY	511	TOD	305.4	478.4	1140.3	288.0	2212.1	
MID->AM	111	TOD	349.7	598.9	2444.6	355.2	3748.4	
MID->AM	111->211	TRP	442.5	730.3	766.9	392.9	2332.6	-38%
MID->AM	211	TOD	466.6	759.6	703.5	392.8	2322.5	-38%
MID->PM	111	TOD	1060.0	601.8	666.3	743.1	3071.2	
MID->PM	111->311	TRP	819.4	654.2	712.0	467.9	2653.5	-14%
MID->PM	111->311	MAN	715.6	611.1	704.6	406.9	2438.2	-21%
MID->PM	311	TOD	726.6	626.3	697.0	407.8	2457.7	-20%
MID->IN	111	TOD	362.1	883.1	3289.6	317.2	4852.0	
MID->IN	111->411	TRP	529.0	1281.5	1422.9	411.5	3644.9	-25%
MID->IN	411	TOD	1188.0	1304.0	1424.2	1296.1	5212.3	7%
IN->MID	411	TOD	855.4	1379.4	1171.1	1089.5	4495.4	
IN->MID	411->111	TRP	508.9	1315.7	1342.0	508.6	3675.2	-18%
MID->OUT	111	TOD	7594.5	523.7	1733.6	1667.5	11519.3	
MID->OUT	111->511	TRP	1707.0	571.2	1124.6	765.3	4168.1	-64%
MID->OUT	511	TOD	1395.1	614.2	1314.5	677.5	4001.3	-65%
OUT->MID	511	TOD	1455.7	556.6	1277.3	761.7	4051.3	
OUT->MID	511->111	TRP	1635.2	571.7	916.9	772.1	3895.9	-4%

Table 8-20: Summary of System Delay Subject to Various Conditions

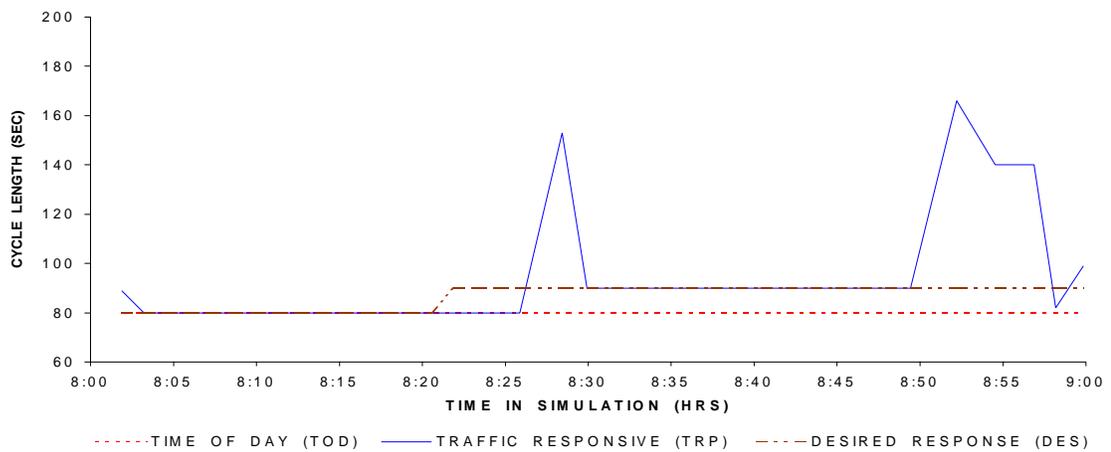
COMPARISON OF TRANSITIONING ALGORITHMS (111_211)
SR 26 (SOUTH) - CYCLE GRAPHS



a) Node 1: SR 26 & Red Cloud / Progress



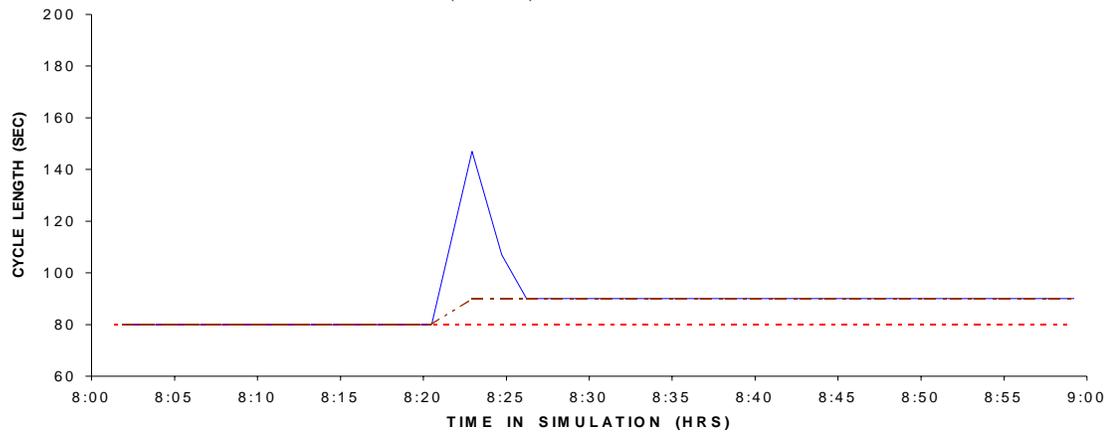
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



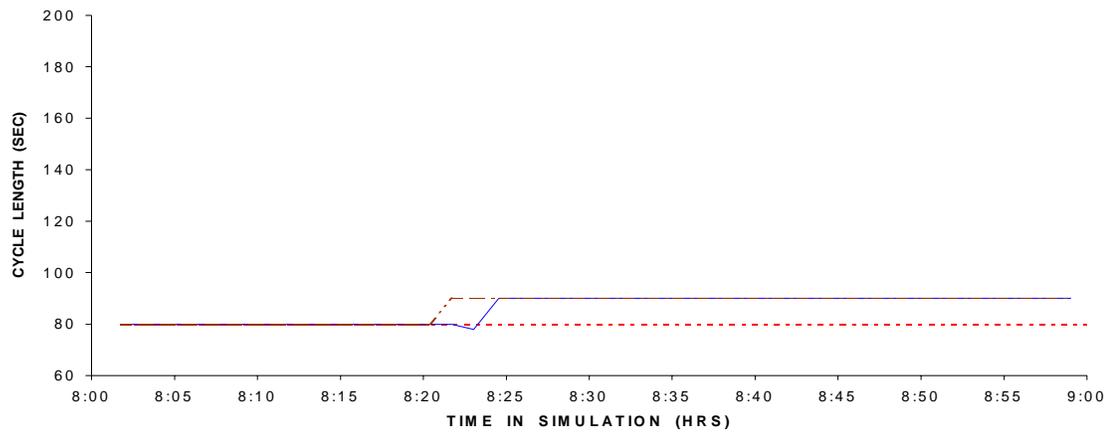
c) Node 4: SR 26 & Meijer Entrance

Figure 8-13: SR 26 (South) System Cycle Graphs – Pattern 111 to 211

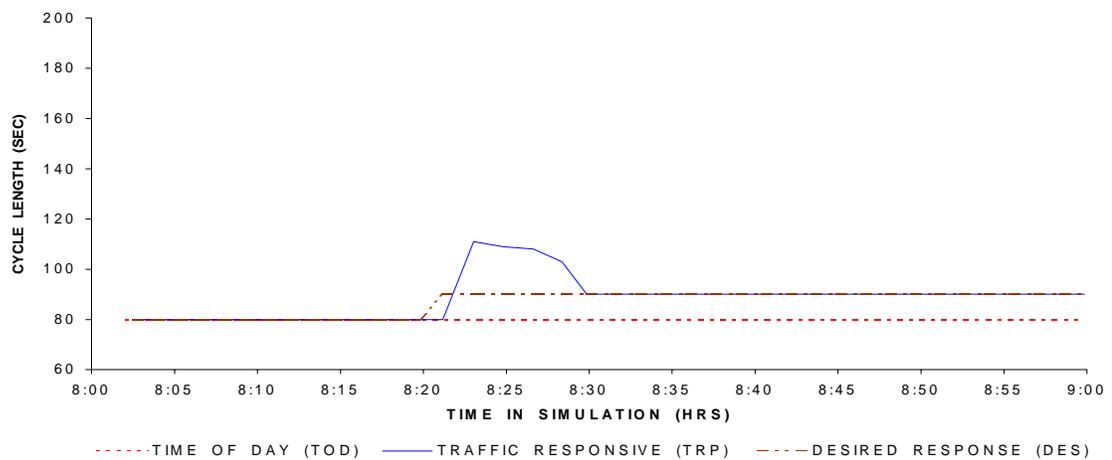
COMPARISON OF TRANSITIONING ALGORITHMS (111_311)
SR 26 (SOUTH) - CYCLE GRAPHS



a) Node 1: SR 26 & Red Cloud / Progress



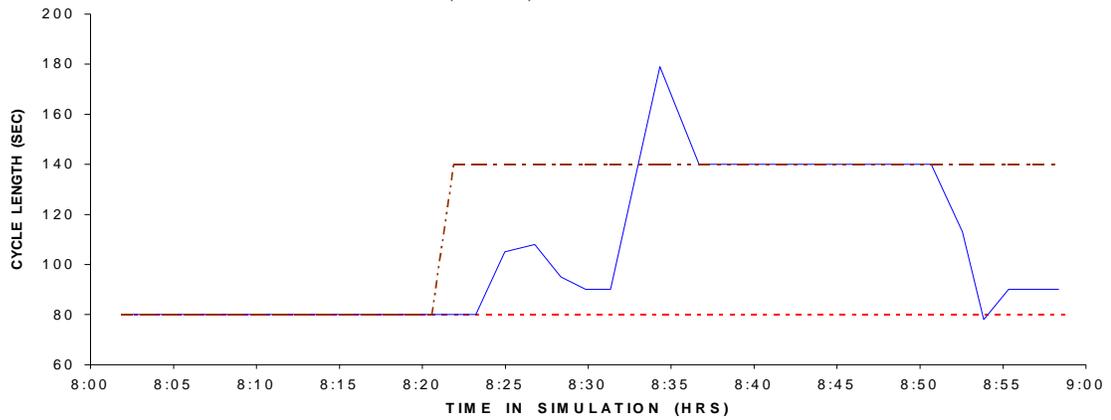
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



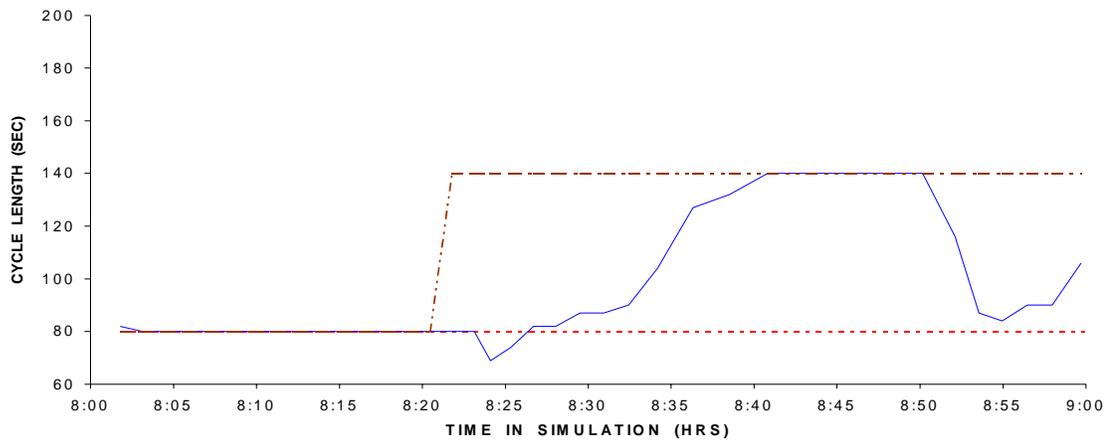
c) Node 4: SR 26 & Meijer Entrance

Figure 8-14: SR 26 (South) System Cycle Graphs – Pattern 111 to 311

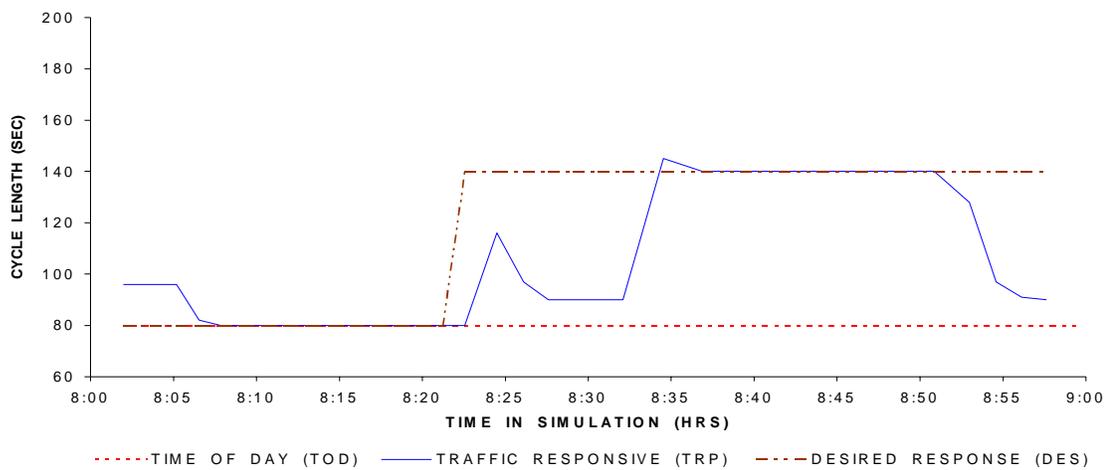
COMPARISON OF TRANSITIONING ALGORITHMS (111_411)
SR 26 (SOUTH) - CYCLE GRAPHS



a) Node 1: SR 26 & Red Cloud / Progress



b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)

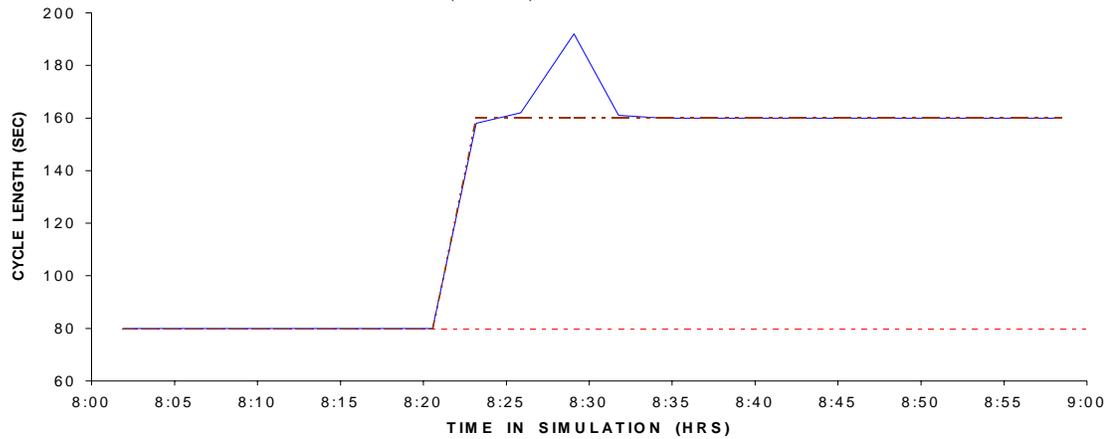


c) Node 4: SR 26 & Meijer Entrance

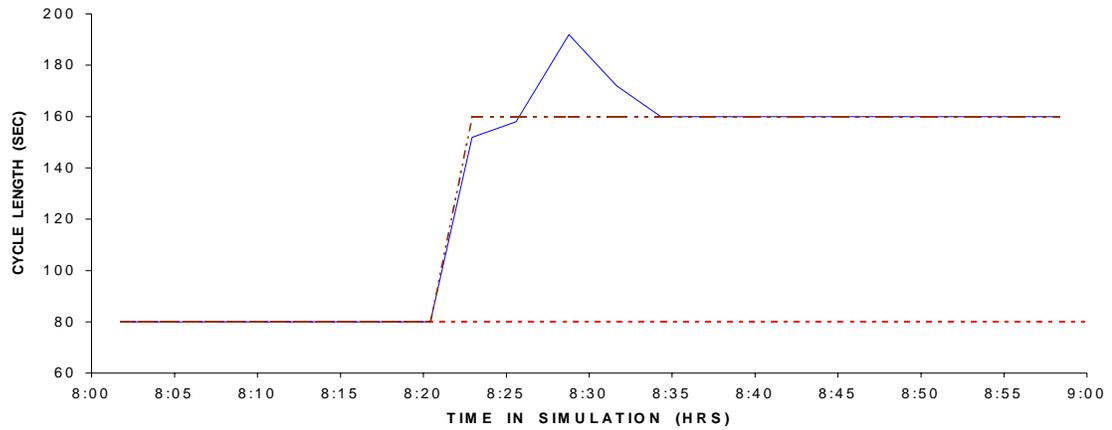
Figure 8-15: SR 26 (South) System Cycle Graphs – Pattern 111 to 411

..... TIME OF DAY (TOD) ——— TRAFFIC RESPONSIVE (TRP) - - - - DESIRED RESPONSE (DES)

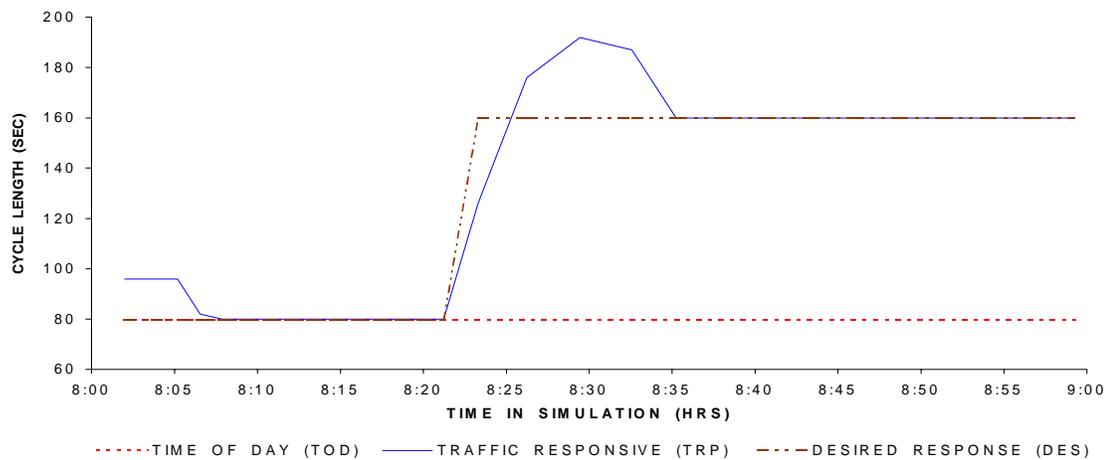
COMPARISON OF TRANSITIONING ALGORITHMS (111_511)
SR 26 (SOUTH) - CYCLE GRAPHS



a) Node 1: SR 26 & Red Cloud / Progress



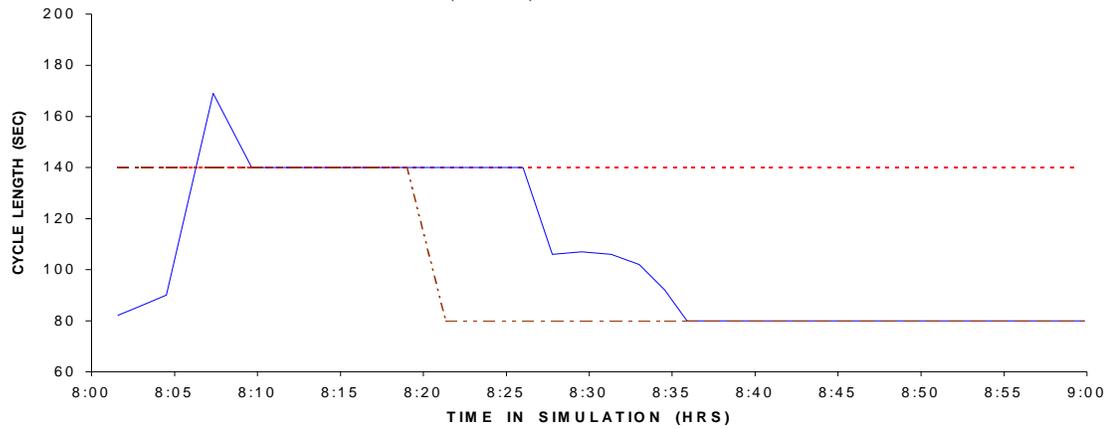
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



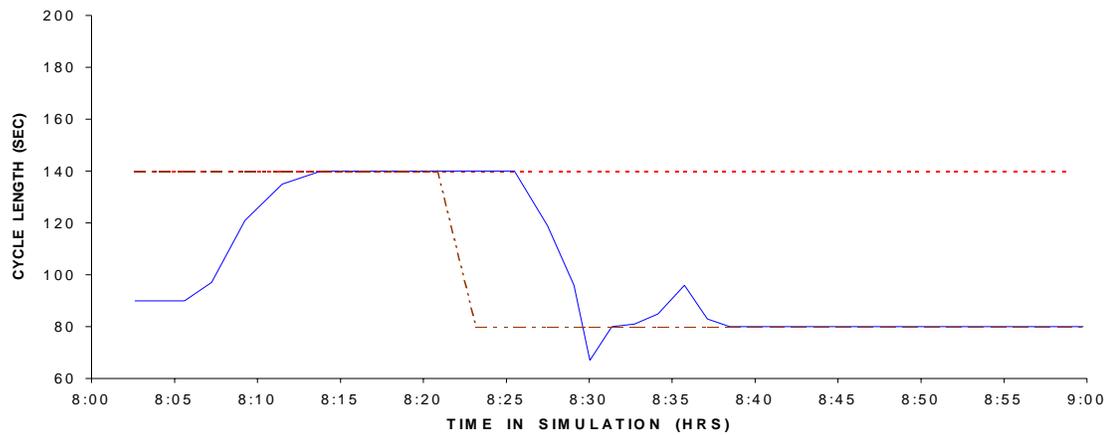
c) Node 4: SR 26 & Meijer Entrance

Figure 8-16: SR 26 (South) System Cycle Graphs – Pattern 111 to 511

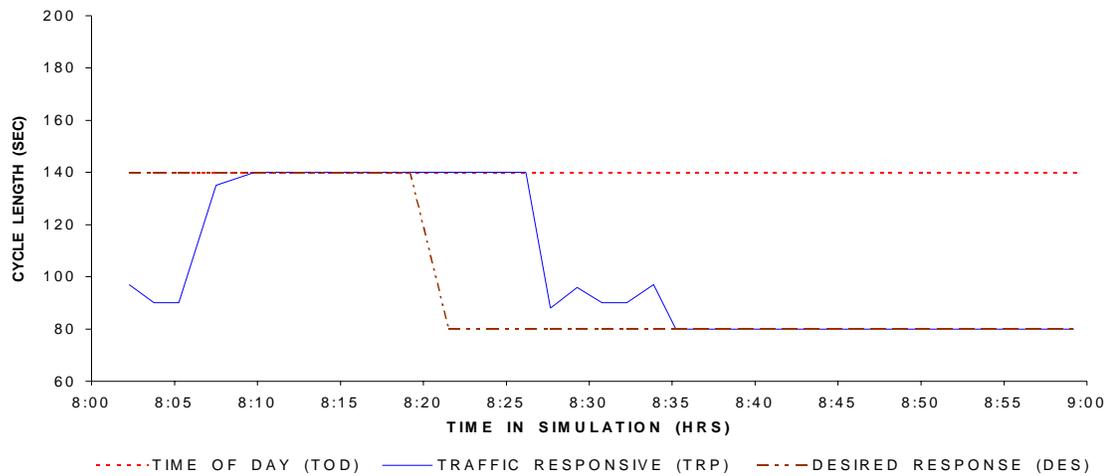
COMPARISON OF TRANSITIONING ALGORITHMS (411_111)
SR 26 (SOUTH) - CYCLE GRAPHS



a) Node 1: SR 26 & Red Cloud / Progress



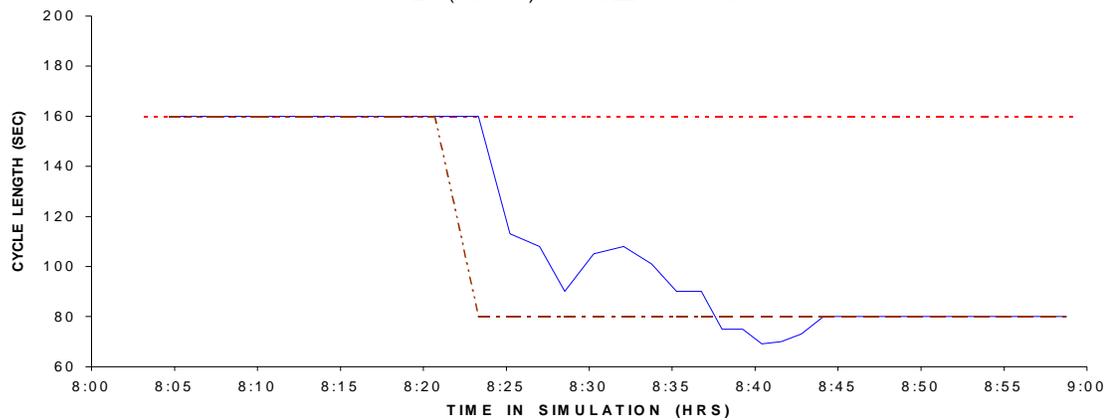
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



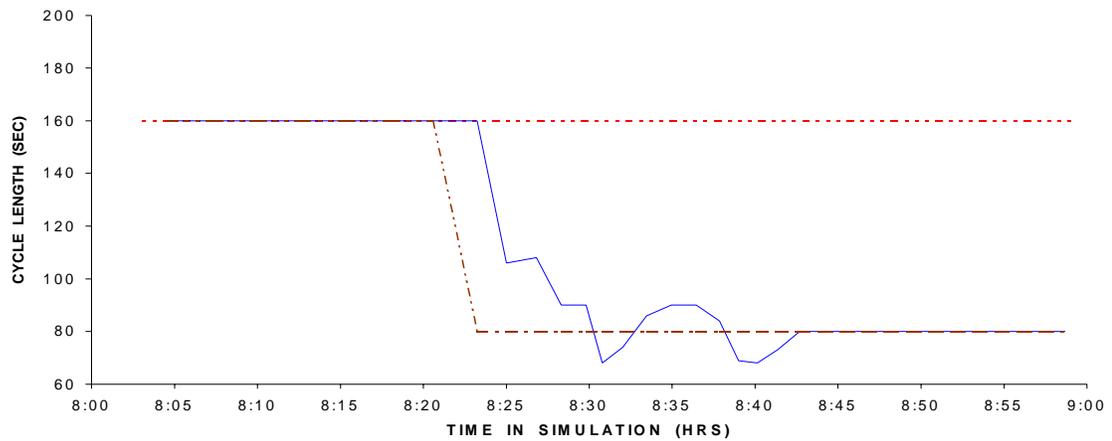
c) Node 4: SR 26 & Meijer Entrance

Figure 8-17: SR 26 (South) System Cycle Graphs – Pattern 411 to 111

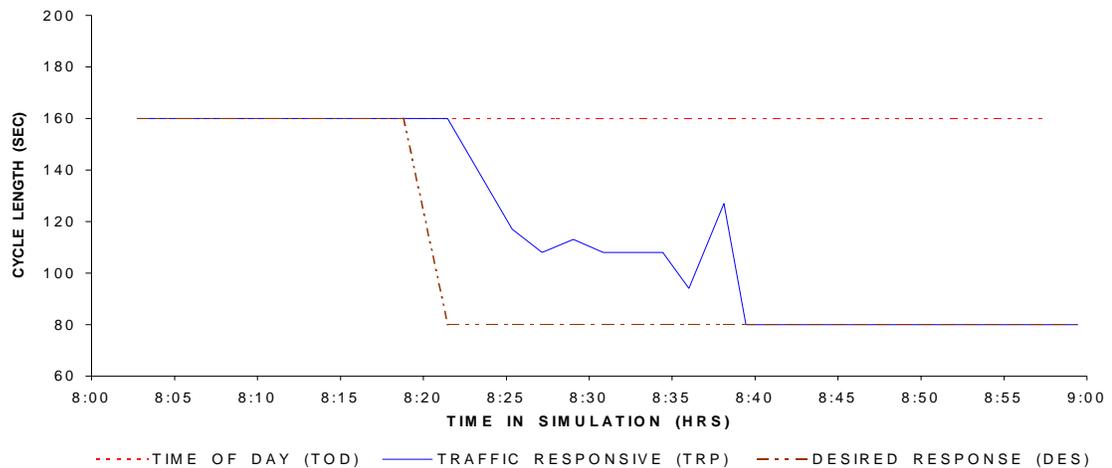
COMPARISON OF TRANSITIONING ALGORITHMS (511_111)
SR 26 (SOUTH) - CYCLE GRAPHS



a) Node 1: SR 26 & Red Cloud / Progress



b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



c) Node 4: SR 26 & Meijer Entrance

Figure 8-18: SR 26 (South) System Cycle Graphs – Pattern 511 to 111

CUMULATIVE TRAVEL TIME (MIDDAY PEAK)

EASTBOUND ROUTE 26 (PROGRESS DRIVE TO MEIJER ENTRANCE) - THRU VEHICLES
> PLAN_111 (MIDDAY) TO PLAN_211 (MORNING) <

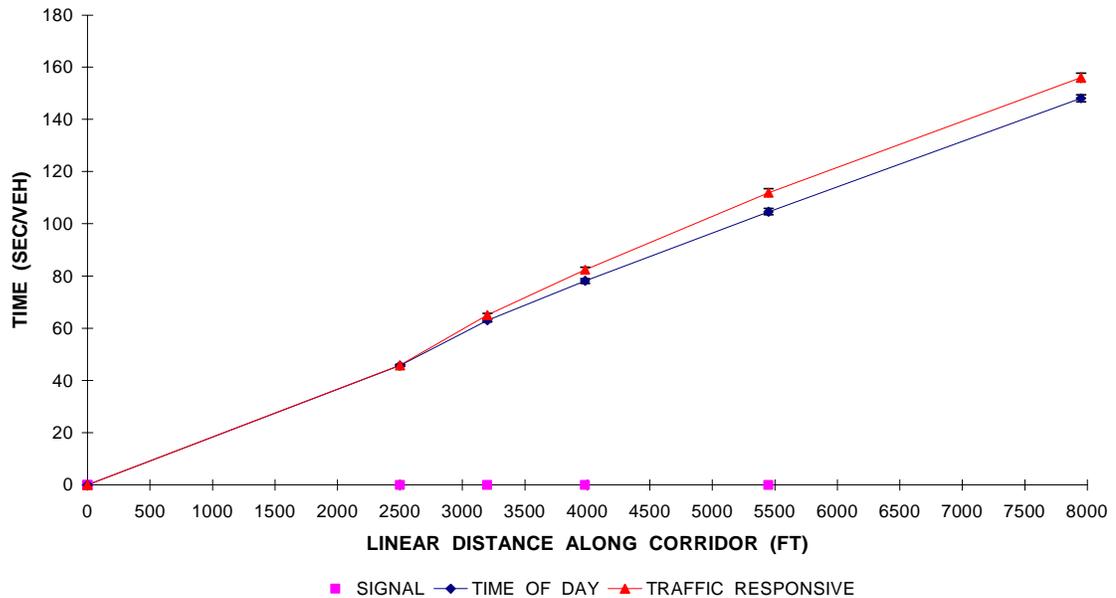


Figure 8-19: Cumulative Eastbound Travel Time (S/V) – Pattern 111 to 211

CUMULATIVE TRAVEL TIME (MIDDAY PEAK)

WESTBOUND ROUTE 26 (PROGRESS DRIVE TO MEIJER ENTRANCE) - THRU VEHICLES
> PLAN_111 (MIDDAY) TO PLAN_211 (MORNING) <

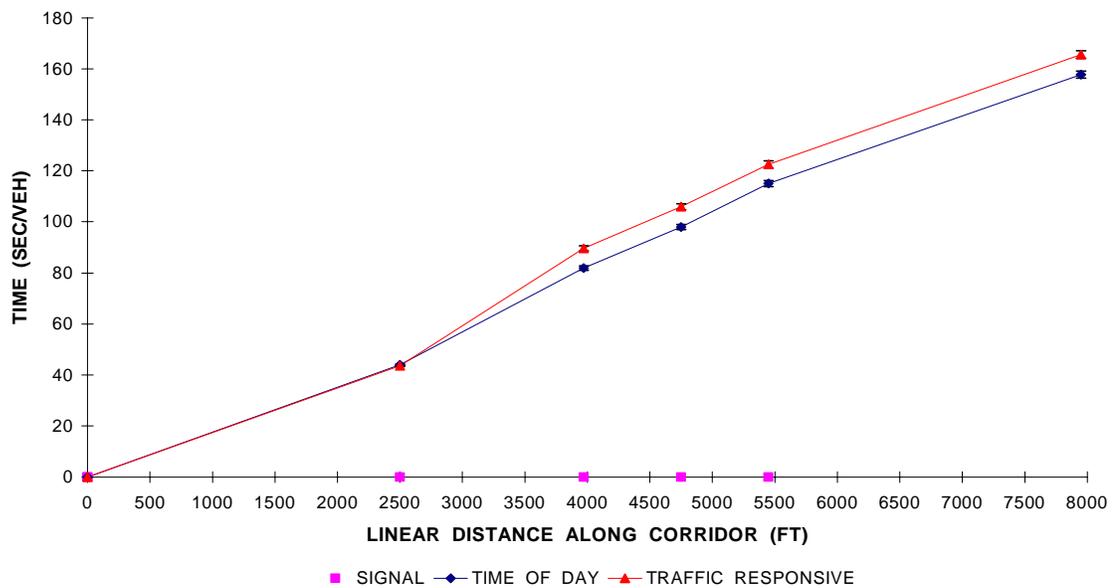


Figure 8-20: Cumulative Westbound Travel Time (S/V) – Pattern 111 to 211

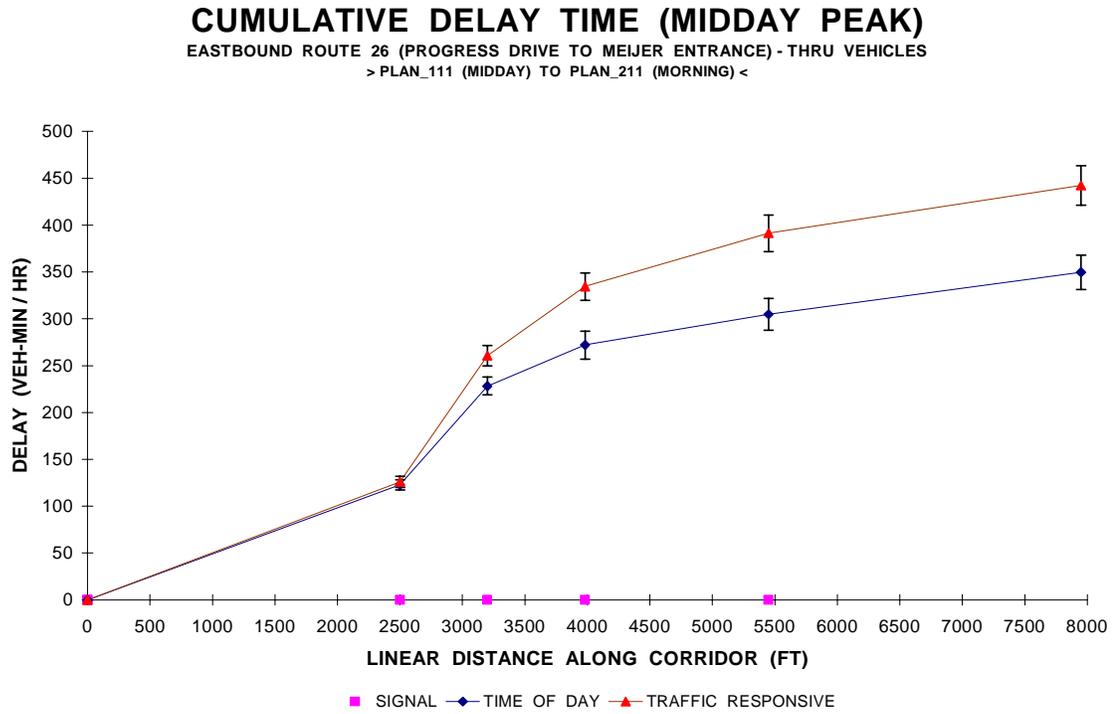


Figure 8-21: Cumulative Eastbound Delay Time (V-M) – Pattern 111 to 211

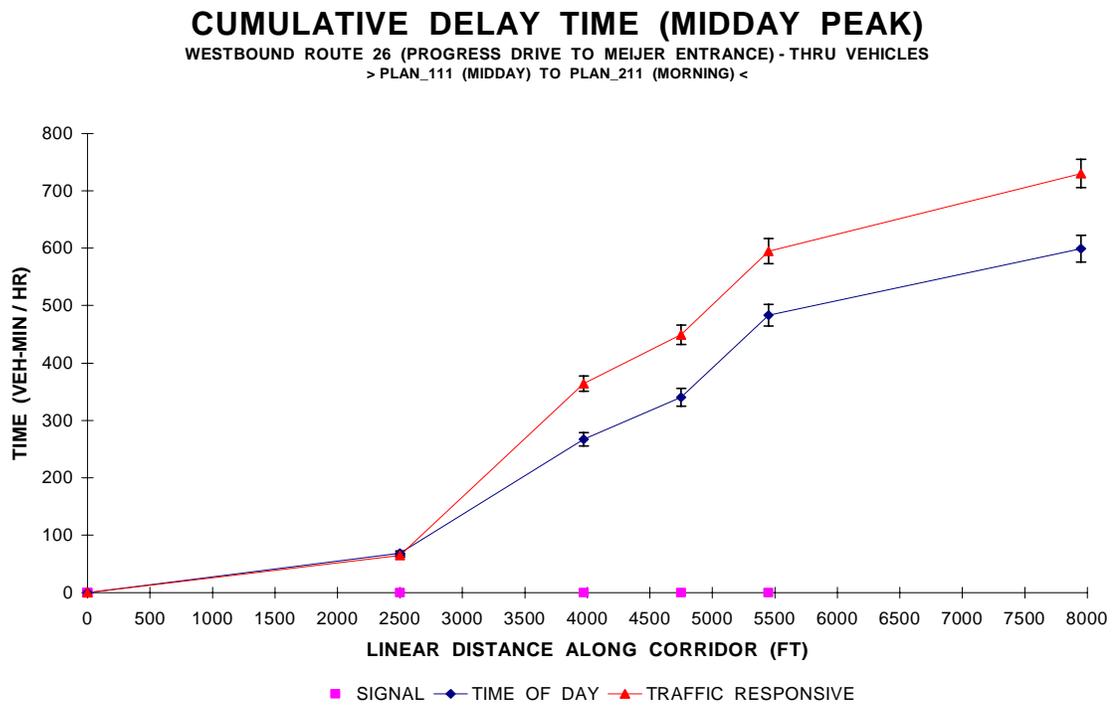


Figure 8-22: Cumulative Westbound Delay Time (V-M) – Pattern 111 to 211

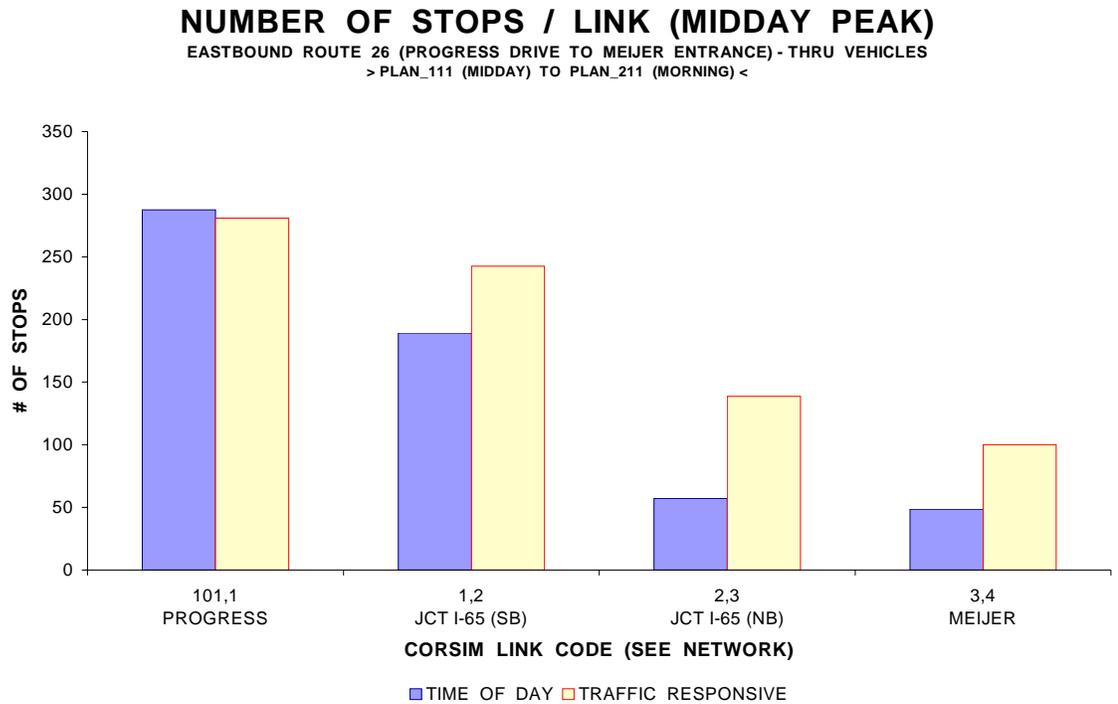


Figure 8-23: Eastbound Number of Stops per Link – Pattern 111 to 211

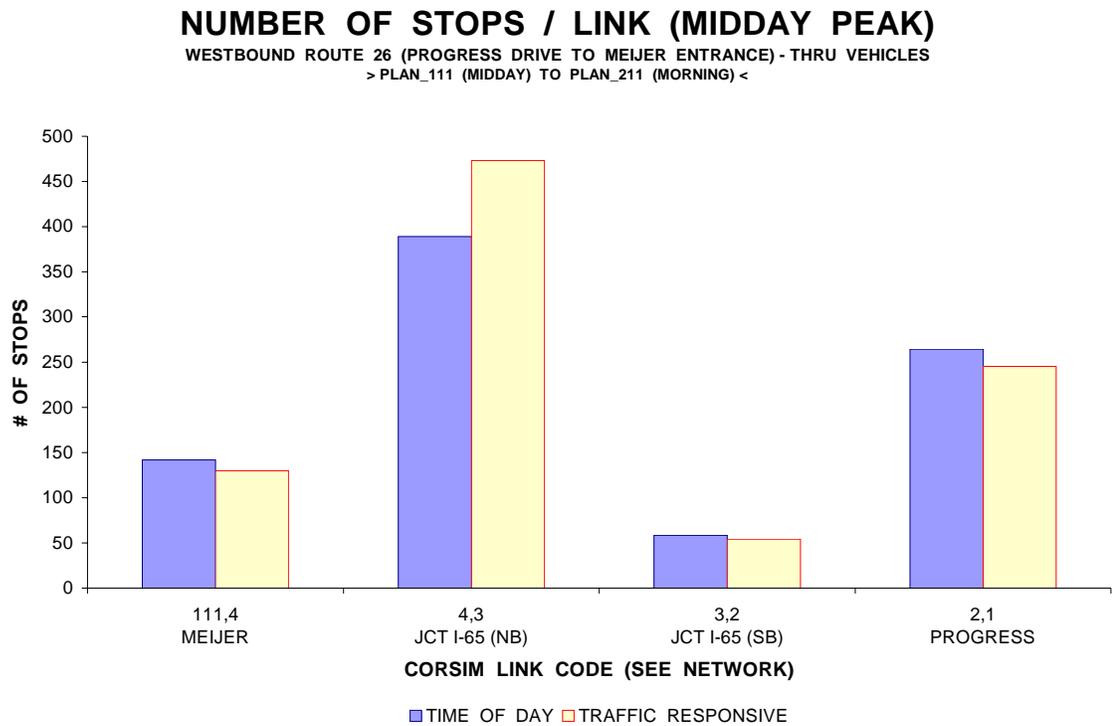


Figure 8-24: Westbound Number of Stops per Link – Pattern 111 to 211

SIDE STREET DELAY TIME (MIDDAY PEAK)

STATE ROUTE 26 (PROGRESS DRIVE TO MEIJER ENTRANCE) - ALL VEHICLES
 > PLAN_111 (MIDDAY) TO PLAN_211 (MORNING) <

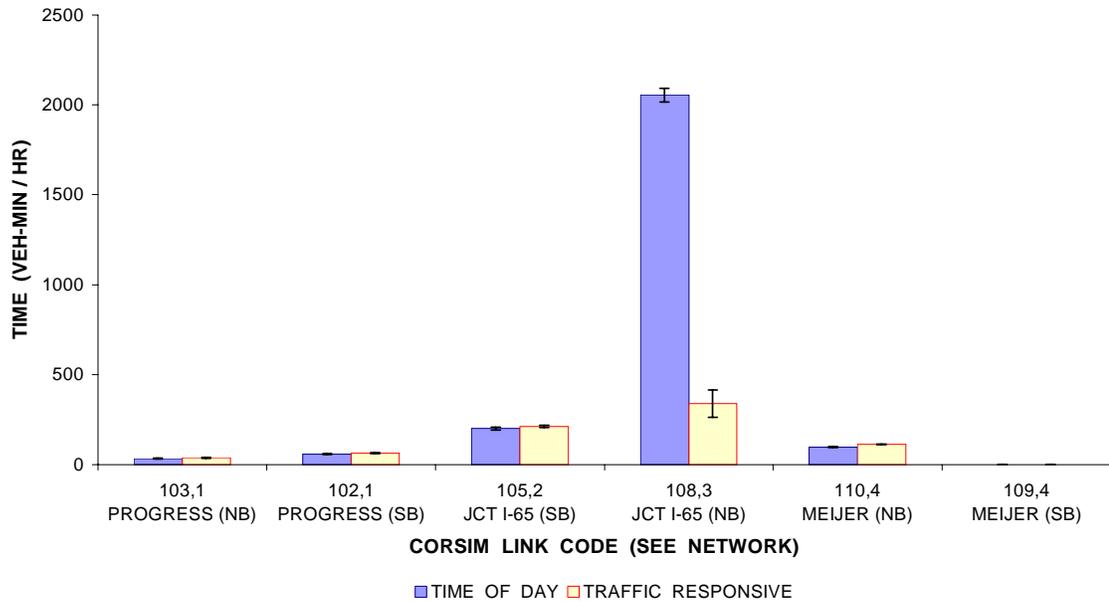


Figure 8-25: Side Street Delay Time (V-M) – Pattern 111 to 211

CUMULATIVE TRAVEL TIME (MIDDAY PEAK)

EASTBOUND ROUTE 26 (PROGRESS DRIVE TO MEIJER ENTRANCE) - THRU VEHICLES
 > PLAN_111 (MIDDAY) TO PLAN_311 (AFTERNOON) <

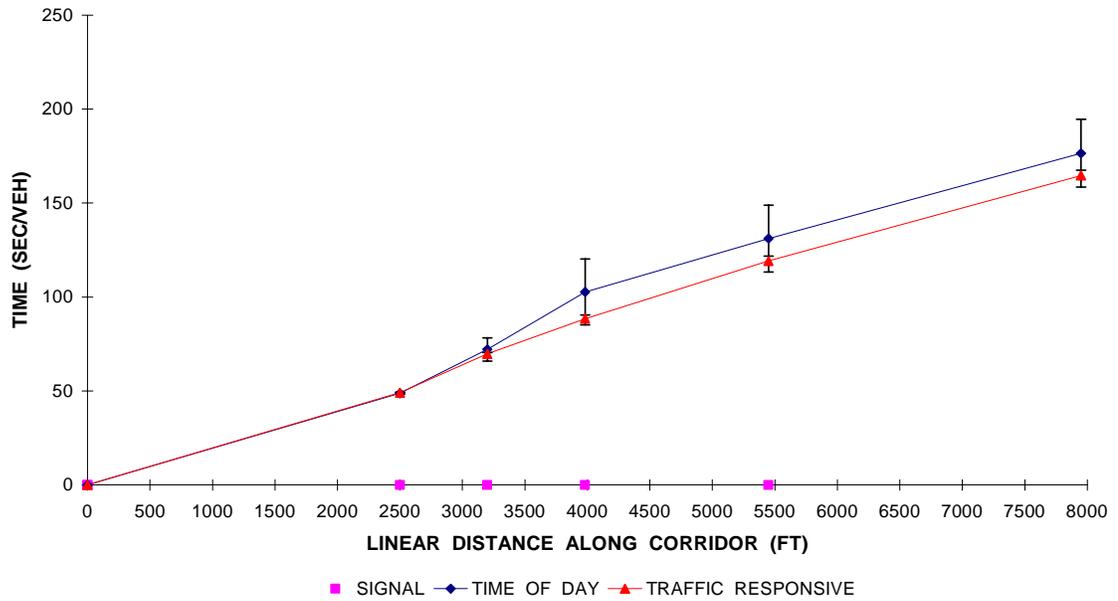


Figure 8-26: Cumulative Eastbound Travel Time (S/V) – Pattern 111 to 311

CUMULATIVE TRAVEL TIME (MIDDAY PEAK)

WESTBOUND ROUTE 26 (PROGRESS DRIVE TO MEIJER ENTRANCE) - THRU VEHICLES
 > PLAN_111 (MIDDAY) TO PLAN_311 (AFTERNOON) <

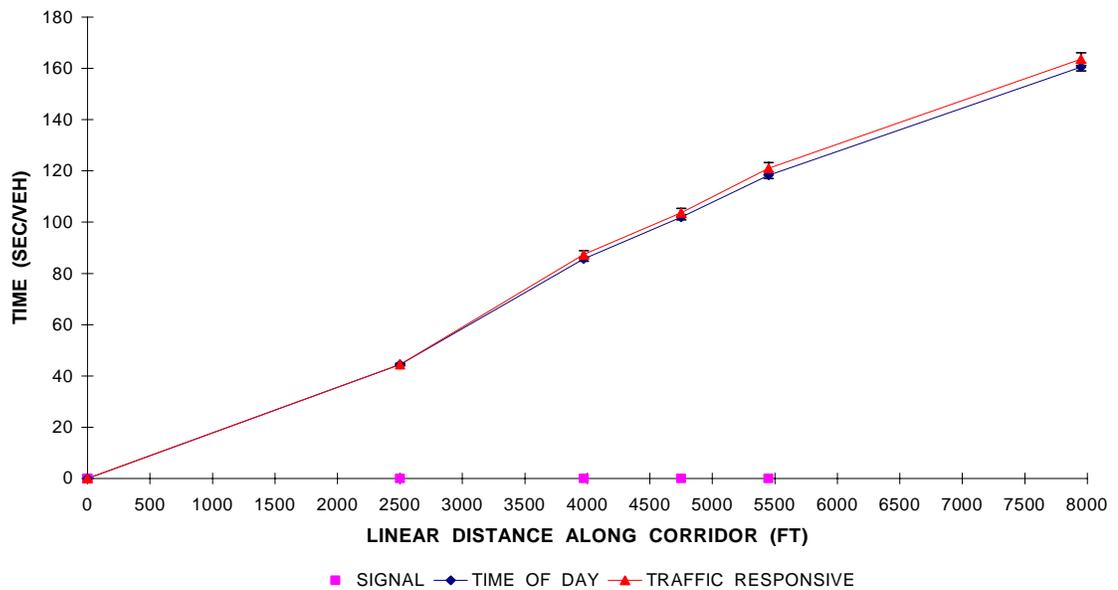


Figure 8-27: Cumulative Westbound Travel Time (S/V) – Pattern 111 to 311

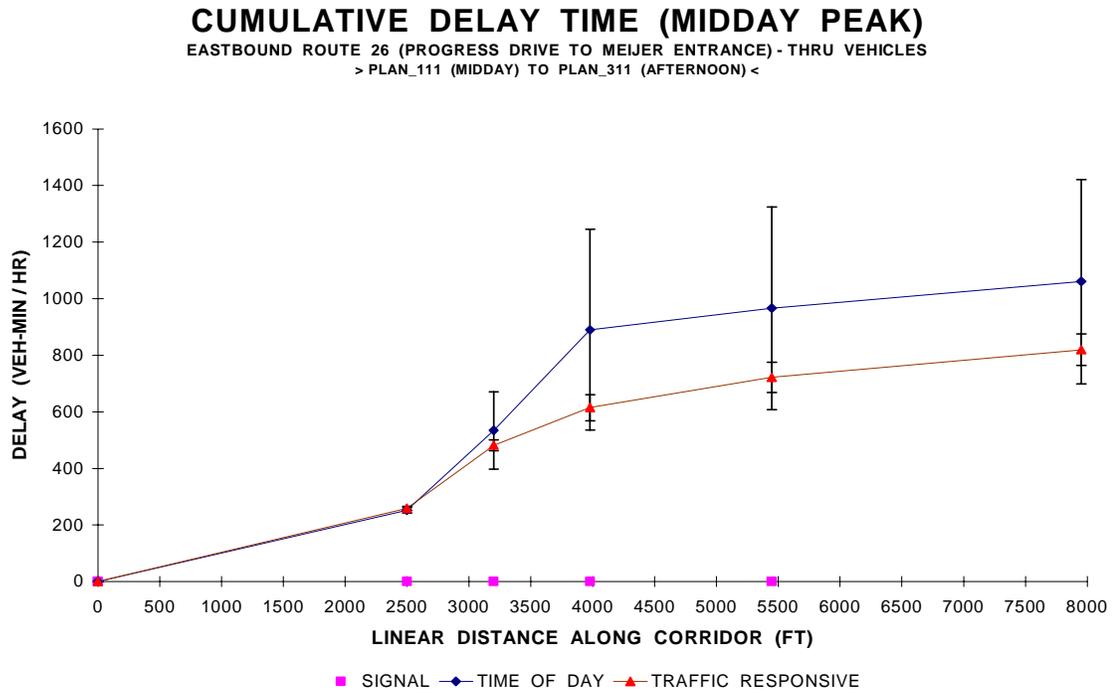


Figure 8-28: Cumulative Eastbound Delay Time (V-M) – Pattern 111 to 311

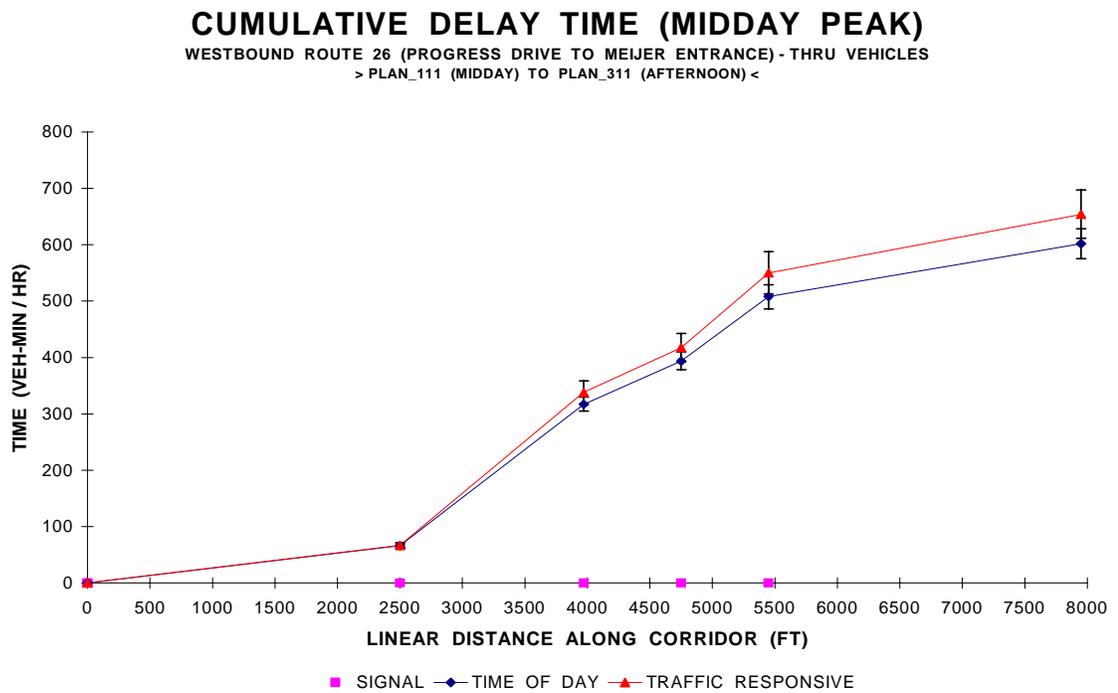


Figure 8-29: Cumulative Westbound Delay Time (V-M) – Pattern 111 to 311

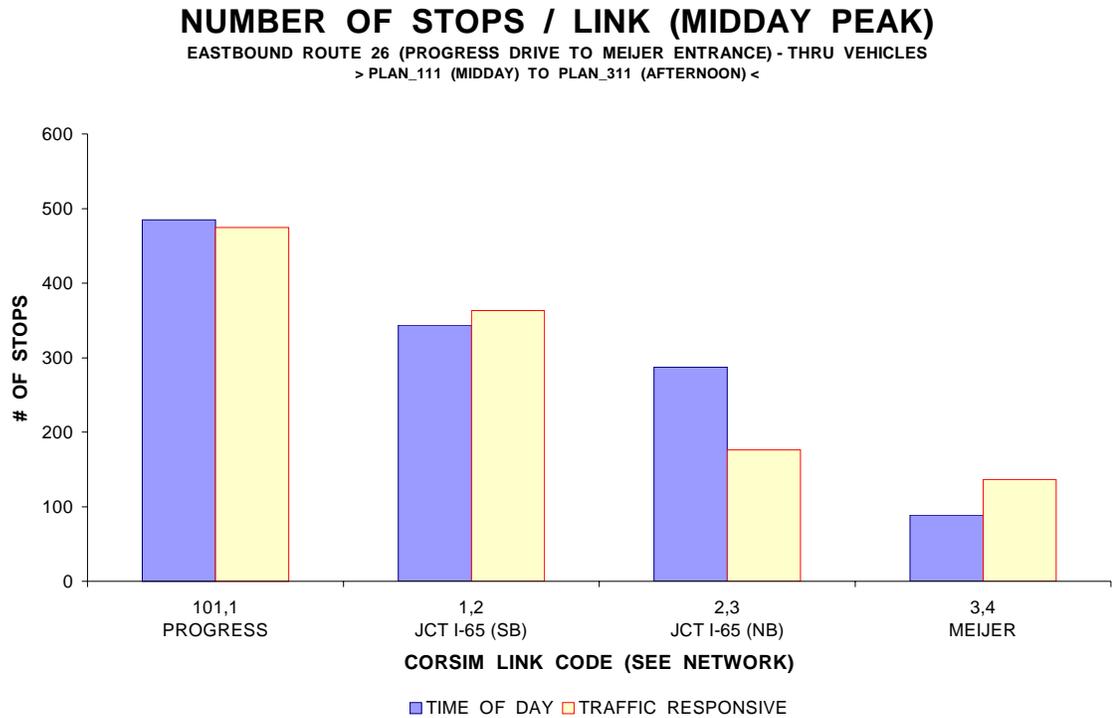


Figure 8-30: Eastbound Number of Stops per Link – Pattern 111 to 311

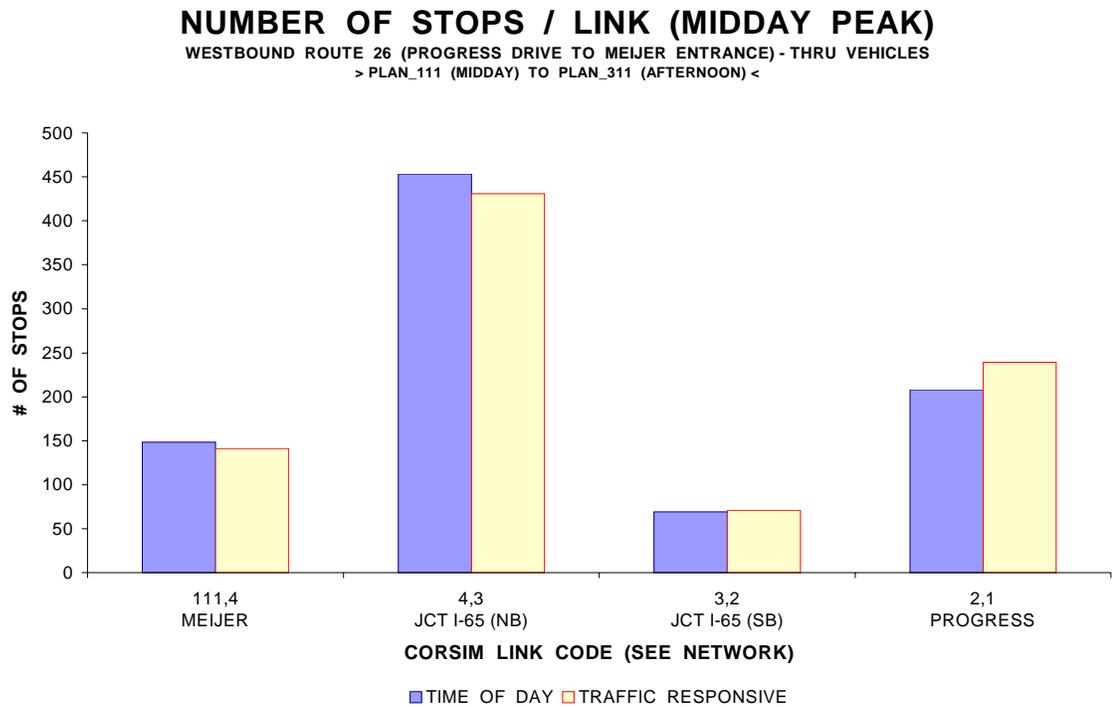


Figure 8-31: Westbound Number of Stops per Link – Pattern 111 to 311

SIDE STREET DELAY TIME (MIDDAY PEAK)

STATE ROUTE 26 (PROGRESS DRIVE TO MEIJER ENTRANCE) - ALL VEHICLES
 > PLAN_111 (MIDDAY) TO PLAN_311 (AFTERNOON) <

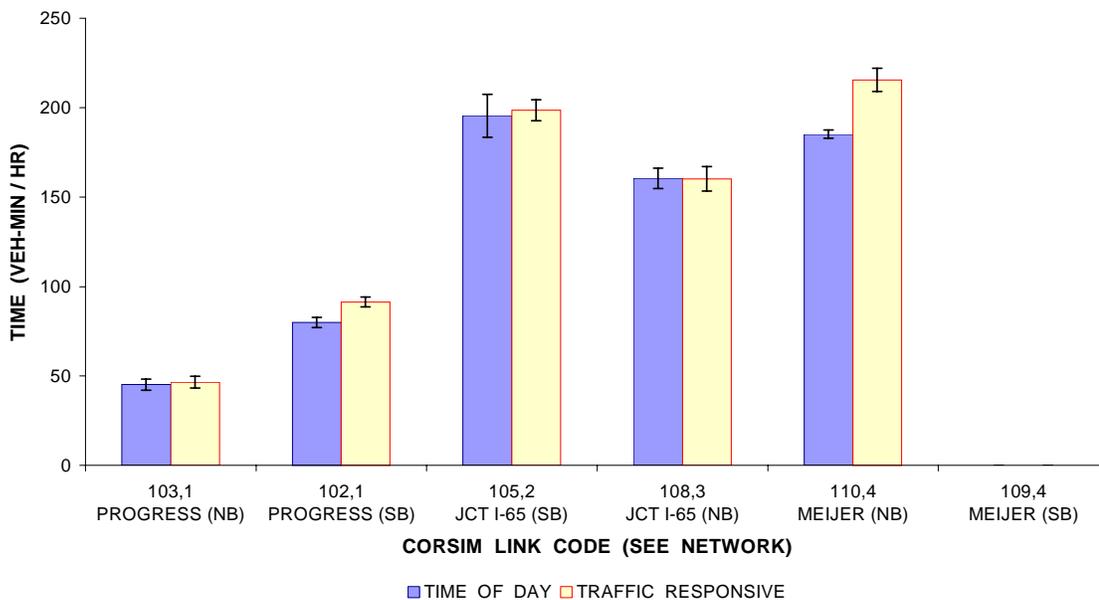


Figure 8-32: Side Street Delay Time (V-M) – Pattern 111 to 311

CUMULATIVE TRAVEL TIME (MIDDAY PEAK)

EASTBOUND ROUTE 26 (PROGRESS DRIVE TO MEIJER ENTRANCE) - THRU VEHICLES
 > PLAN_111 (MIDDAY) TO PLAN_511 (GAME OUTBOUND) <

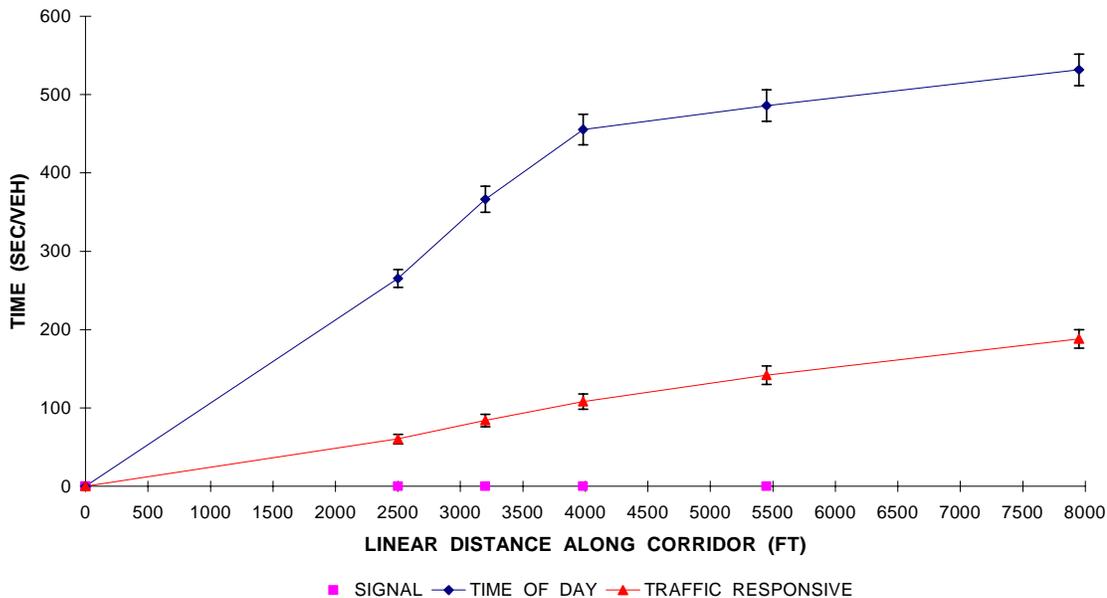


Figure 8-33: Cumulative Eastbound Travel Time (S/V) – Pattern 111 to 511

CUMULATIVE TRAVEL TIME (MIDDAY PEAK)

WESTBOUND ROUTE 26 (PROGRESS DRIVE TO MEIJER ENTRANCE) - THRU VEHICLES
 > PLAN_111 (MIDDAY) TO PLAN_511 (GAME OUTBOUND) <

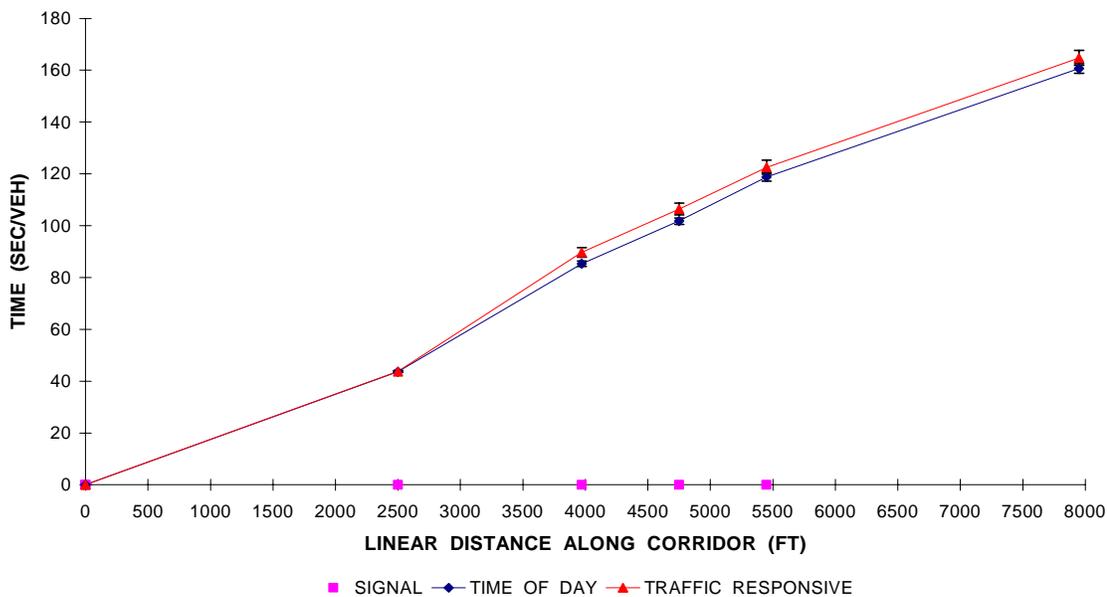


Figure 8-34: Cumulative Westbound Travel Time (S/V) – Pattern 111 to 511

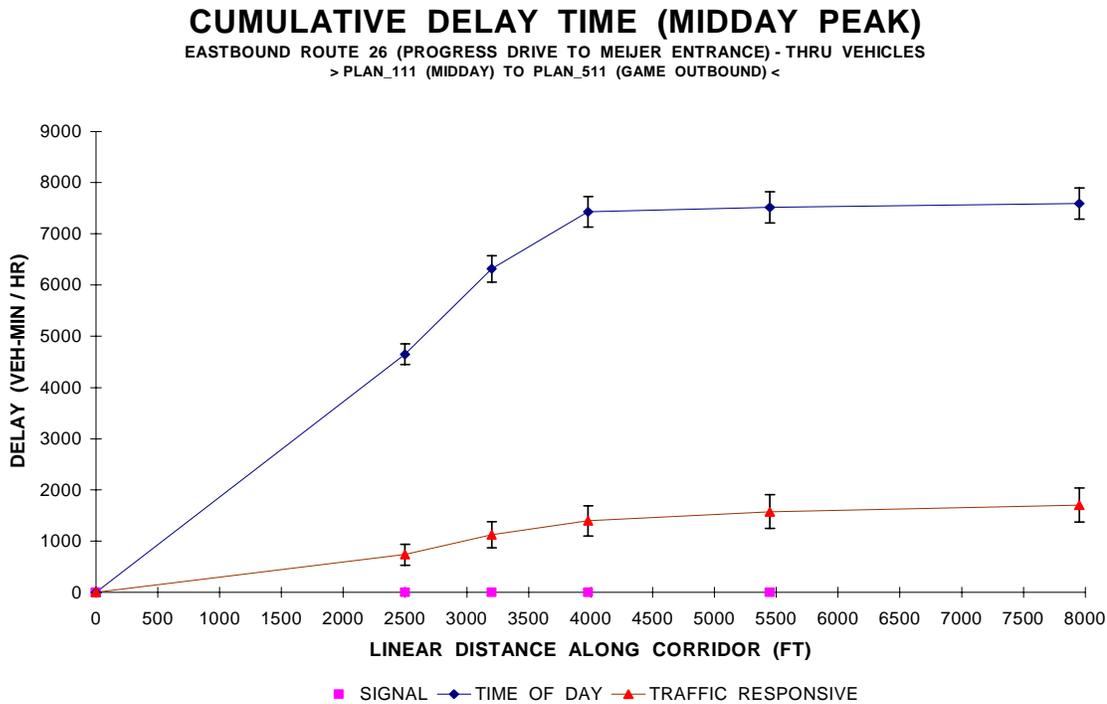


Figure 8-35: Cumulative Eastbound Delay Time (V-M) – Pattern 111 to 511

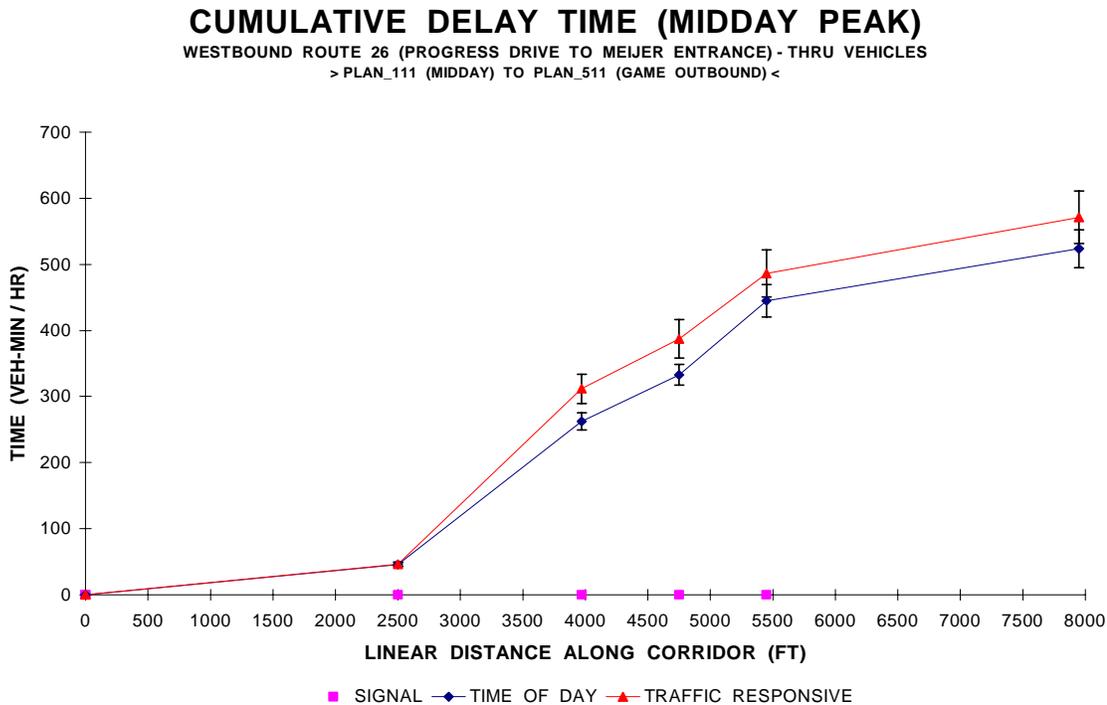


Figure 8-36: Cumulative Westbound Travel Time (V-M) – Pattern 111 to 511

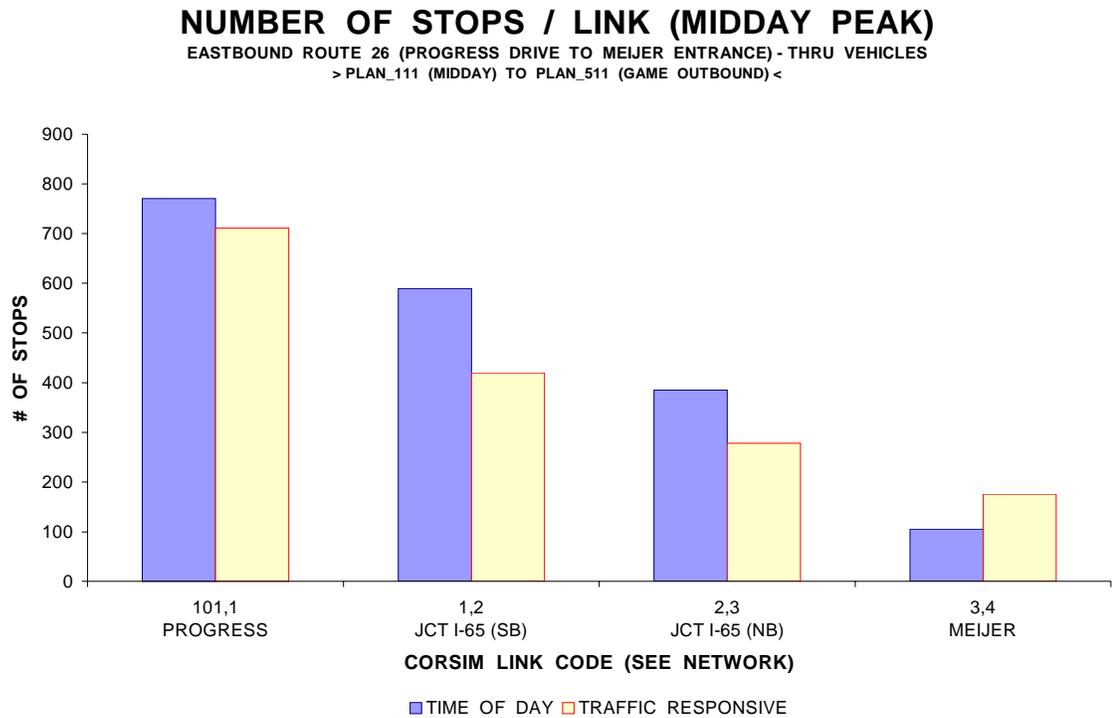


Figure 8-37: Eastbound Number of Stops per Link (S/V) – Pattern 111 to 511

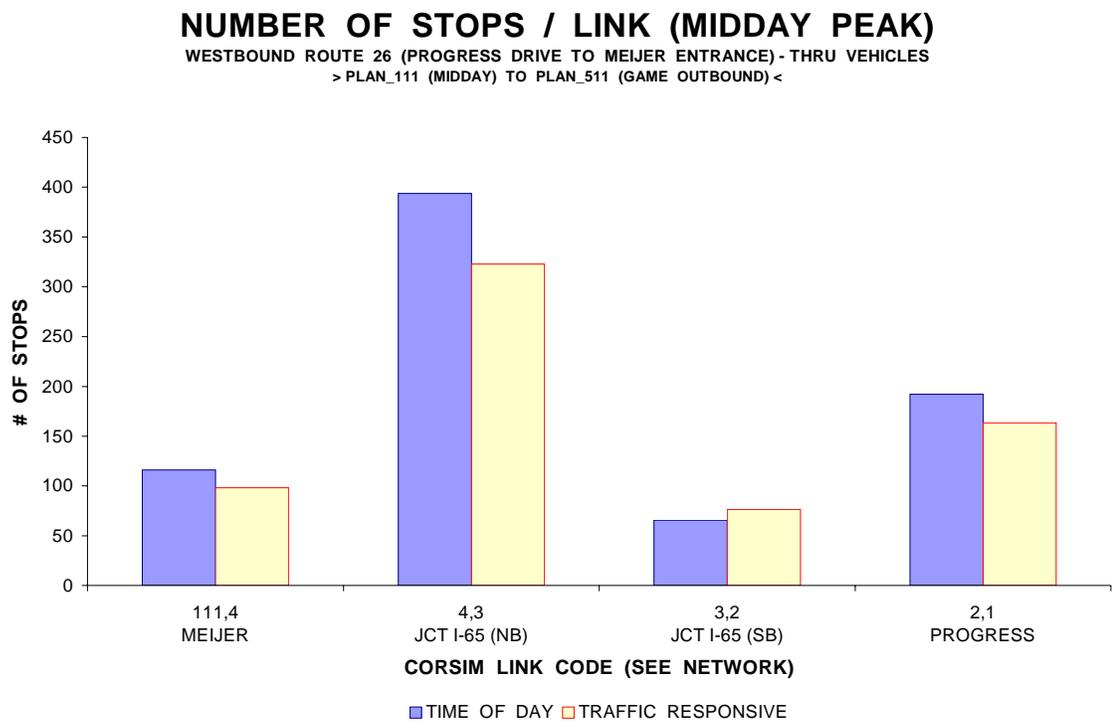


Figure 8-38: Westbound Number of Stops per Link – Pattern 111 to 511

SIDE STREET DELAY TIME (MIDDAY PEAK)

STATE ROUTE 26 (PROGRESS DRIVE TO MEIJER ENTRANCE) - ALL VEHICLES
 > PLAN_111 (MIDDAY) TO PLAN_511 (GAME OUTBOUND) <

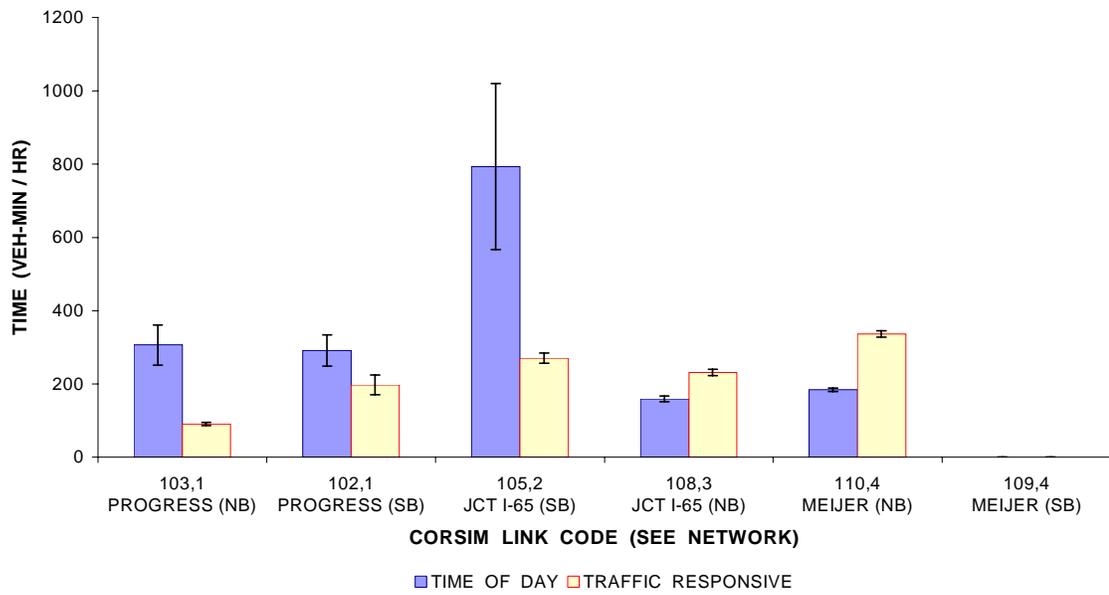


Figure 8-39: Side Street Delay Time (V-M) – Pattern 111 to 511

CHAPTER 9 – TRAFFIC RESPONSIVE ANALYSIS FOR THE SR 67 (KENTUCKY) NETWORK – INDIANAPOLIS, IN

Chapter Overview

This chapter will use the evaluation procedures previously discussed and apply them to a corridor on the Southwest side of Indianapolis, where weekday traffic counts were available, on an hourly basis, for each of the intersections in the system. These counts, which were supplied by the Indiana Department of Transportation (INDOT), were entered into the CORSIM simulation package on an hourly basis, so that the entry volumes could adjust on a more gradual basis. This study consisted of five different volume scenarios, which were analyzed to help better understand the differences between Time-of-Day (TOD) and Traffic Responsive (TRP) procedures, for each of the scenarios.

Like the previous chapter, all of the scenarios consisted of 5 runs for each of the two control strategies (TOD / TRP). The main difference in this study is that each of the runs spanned an entire day, and not just 1 Hour, as was done for the previous network. The hourly traffic counts ranged from 6:00am to 6:00pm, therefore, this simulation consisted of 12 periods, each of which had their own volume scenario and were 1 Hour in length. This was done in order to coincide with the hourly count sheets that were obtained from INDOT. Therefore, the total time per simulation was 12 hours. Recall that the previous chapter had a specific volume scenario for each case, of which only two scenarios were analyzed in a period which spanned 1 Hour. Conversely, this analysis had multiple volume scenarios that were suitable with a particular Traffic Responsive (TRP) plan.

Overview of Network and Volume Scenarios

The network used for this analysis is shown in Figure 9-1, and consists of five intersections on SR 67 (Kentucky), which is located on Southwest side of Indianapolis. The system ranges from the Mendenhall / Heathrow to the JCT I-465 North and South Ramps. The relative spacing between each of the intersections are also depicted in the figure, making for a total network length of approximately 2.2 miles. Currently, only the interchange (Nodes 4 & 5) is coordinated while the remainder of the network is running independently (Free). This interchange is unlike those discussed in previous chapters, since the entry and exit ramps are located on the same side of the interchange. This is often referred to as a half-diamond or partial cloverleaf. When referring to Figure 9-1, it can be determined that all ramps at the interchange (Nodes 4 & 5) are located on the East Side of SR 67 (Kentucky) which is primarily a North / South route.

Recall from the previous section that there were five cases analyzed, each of which contained slightly different (12 Hour) volume scenarios. The corresponding volumes for Cases 1 to 5 are found in Table 9-1 to Table 9-5, respectively. Note that Case 1, shown in Table 9-1, is the base case, since it contains the actual volumes that were obtained from the Indiana Department of Transportation (INDOT). These cases all consisted of 12 periods, which ranged from 6:00am to 6:00pm and were 1 Hour in length. Another resemblance was that the total number of vehicles for each of the cases was held constant. Hence, the entry volumes were only shifted between periods for a particular link so that the sum of the rows in Table 9-2 to Table 9-5, equal that of the relative entry link (row) in Table 9-1. This was done so that the total vehicular delay (Veh-Mins) could still be compared between each of the cases.

Looking at Table 9-1 to Table 9-5 (Cases 1 to 5), it can be determined that the format of these tables are similar. Note how they all consist of 12 periods (Columns) and 10 Rows, which correspond to the entry links found in Figure 9-1.

For example, the “1” and “NB” found in Row 1 means that the entry volumes, for each of the periods listed in that row, correspond to the Northbound direction of Intersection 1. Looking at Figure 9-1, it can be found that the volumes in this row are for Link 101,1. This very same procedure applies for the remainder of the entry links in the system. Recall that Nodes 4 and 5 (Interchange) were nearly the same, however it can be seen from the tables that Intersection 5 has an additional entry link then Intersection 4. When viewing Figure 9-1, this makes sense since Intersection 5 is at the end of the system and requires an additional entry link for the Southbound arterial movement. Hence, the “WB” is for the ramp, while the “SB” is for the arterial (SR 67).

The base case (Case 1) used for this analysis, is shown in Table 9-1. Cases 2 to 5 (Table 9-2 to Table 9-5) consist of volume modifications that were made to the original case, shown in Table 9-1. These changes are identified by the light gray shading that is found in the corresponding cells. Looking at Table 9-2, it can be determined that changes were made to the morning and evening peak periods for SR 67 (Kentucky). Notice how the 8:00am and 9:00am volumes in Table 9-1 were moved to 6:00am and 7:00am respectively, while the 6:00am and 7:00am volumes were moved to the 8:00am and 9:00am period in Table 9-2, respectively. Looking at the last 4 periods in Table 9-2, it can be seen that similar changes were made here as well, however the Southbound volumes at Intersection 5 were shifted over so that they would occur an hour earlier, with the exception of the 2:00pm volume in Table 9-1, which was moved to the 5:00pm period (Table 9-2). Notice how the total volumes were conserved for all cases.

Case 2 (Table 9-2) looked at what would happen if the morning rush on SR 67 (Kentucky) began two hours latter, while the afternoon rush began one hour earlier. Using similar methodologies described above, Case 3 will look at what would happen if the brunt of the morning traffic was delayed for one hour at Node 3 (High School Road). Let us also examine the shortcoming resulting from

an accident on the interstate, which forces traffic to prematurely exit at JCT I-465 Southbound Ramp, prior to the afternoon rush hour. When referring to Table 9-1, it can be seen that there were changes made to the Westbound directions of Intersections 3 and 4, as evident in Table 9-3. Referring to this table, notice how these changes occurred between the hours of 7:00am and 9:00am at Intersection 3, and 2:00pm to 6:00pm at Intersection 4. Note again how the entry volumes were conserved.

Case 4, shown in Table 9-4, looks at what would occur if there was a serious accident in the Southbound direction at 7:00am that hindered virtually all through traffic for a 2 Hour period. After the clearance of the accident, it is then assumed that all traffic will try and clear this link in the next 4 Hours, at which time the volumes would return to normal for the Southbound direction at Intersection 5. Hence, according to Table 9-4, it can be seen that the total disturbance ranges from 7:00am to 1:00pm. This case is slightly different from the others, in that the entire base volume was not exchanged between periods, but rather only portions of the volumes. When comparing Table 9-4 to that of the base case (Table 9-1), it can be seen that there were 700, 300, and 200 vehicles that were subtracted from the first three updated periods. This makes a total of 1,200 vehicles which were then added to the existing volumes for the remaining three updated periods. Hence, there were 500, 500, and 200 vehicles that were added to these periods, respectively. Again, notice how the total overall volume is conserved for this link.

The last case follows the methodologies used for Case 4, in order to help better examine what would occur if there was a shift in the midday volumes for the Westbound direction of High School Road (Intersection 3) because of some event at Decatur High School. As can be seen from Table 9-5 (Case 5), the volume fluctuations also cover a 6 Hour period, however in this case they range from 9:00am to 3:00pm. Following the methodologies from the previous case, it

can be determined that there were 100 vehicles removed from each of the first three updated periods, which were then applied to the existing volumes (Table 9-1) for the three remaining updated periods. With this case, it is easy to illustrate how the overall volume has been conserved. Note that the relative turning percentages, shown in Table 9-6, remain constant and apply to all cases, regardless of the respective entry volumes.

System Phasing and Ring Structures

The geometric lane and detector configuration for each of the intersections are shown in Figure 9-2, while the precise locations of the pockets and detector locations are identified in Table 9-7. Referring to Figure 9-2, it can be seen that all of the minor movements have detectors located at the stopbar, while the major arterial movements on SR 67 (Kentucky) have detectors located 300 feet back from the stopbar. The phasing used for each of the intersections in the system can be found on Figure 9-3, while the relative ring structures are shown in Figure 9-4. Notice how the phasing diagrams and ring structures for the interchange (Nodes 4 and 5) are nearly identical, with the exception of the right-turn overlap at the JCT I-465 North Ramp (Node 5). This can be verified by examining (Part d and e) Figure 9-3 and Figure 9-4, respectively. When viewing the geometric layout of the interchange in Figure 9-2, it can be seen that they are nearly identical, other than Node 5, which has an additional Westbound through lane that becomes a left-turn lane at Node 4.

Since the traditional NEMA phasing scheme has been used at the interchange (Figure 9-3) and the spacing between the junctures is relatively large (1,100 feet), as seen from Figure 9-1, the interchange at JCT I-465 and SR 67 (Kentucky) will be controlled using separate traffic signal controllers. This is necessary since the same phase numbers are being used at both the junctions, which is evident when examining Figure 9-3 (Part d and e). Had a single

controller been used here, a non-traditional ring structure would be required, in addition to longer conduit runs. Hence, controlling a partial cloverleaf (half-diamond) with a single controller is typically not justifiable. Therefore all intersections in this system, including the interchange, will run the traditional quad type operation shown in Figure 9-4.

Notice from Figure 9-3 that all arterial movements in the system, with the exception of Sterling Point Drive (Node 2), use a protected only (single entry) type operation on the arterial. Recall that this is designated by the squares around the associated phase numbers in the diagram. Therefore, all left-turning movements are permitted only on the green arrow with the exception of Sterling Point Drive, where Phases 1 and 5 do not exist. This means that arterial left-turning traffic at this location may turn left only after yielding to the opposing through traffic on the green interval (permissive only). Hence, the circles around Phases 2 and 6 in Figure 9-3b imply a dual-entry type operation. Such an operation is more efficient since the mainline Phases 2 and 6 will always be up together, irrespective of demand. Conversely, the squares around Phases 4 and 8, in Figure 9-3a, mean that a single-entry type operation exists and only one approach can be active at a time. This case is also a “split phase” operation, which becomes more apparent after examining the ring structure in Figure 9-4a.

Recall that the Letter “A”, seen in the lower left corner of Figure 9-3e, designates a right-turn overlap. It can be active with either Phase 2 or 8, however the arrow is typically omitted while the corresponding green indication is active. The ring structure, shown in Figure 9-4e, clearly shows this overlap as a hollow arrow, which designates it as an overlap. Since the right-turning traffic is so heavy and over capacity in the morning peak, INDOT set this overlap so that it is active with the corresponding green indication as well as the ramp movement (Phase 8). This is safe for this situation since the opposing left-turn is protected-only, as seen from Figure 9-3e. Had this left-turn been protected-permissive,

then this would have been undesirable, since the left-turners would be able to turn on green, possibly colliding into those vehicles with the right-turn arrow. This is particularly probable if both movements share the same entry lane onto the interstate.

System CID File and Approach Labels

Figure 9-5 shows the relative approach labels, which are necessary for proper configuration of the CID file shown in Figure 9-6. Recall that the CID file is responsible for linking the control equipment to CORSIM, by telling the simulation exactly where to map each of the phase indications that are received from the control equipment. As in previous chapters, notice that the approach labels shown in Figure 9-5 go North, South, West, and East at each of the nodes. This has to do with the order the network was configured, as seen from Record Type 43 in Figure 9-8. Looking at Figure 9-6, it can be seen that both the node and approach number are required in order to properly define the appropriate location in the model. All assignments are similar to previous chapters, with the main exception being that two additional intersections have now been added.

Following the logic previously discussed and referring to Line 1 (under Phases) in Figure 9-6, it can be determined that the Northbound left-turn movement for Node 1, Approach 1, is tied to Phase 5, which is protected only. Recall that the phasing can be verified by examining both Figure 9-3a and Figure 9-4a. Looking at Figure 9-6 more closely, it can be seen the Westbound right-turn at Node 3, Approach 3, is tied to Phase 12, while the Northbound right-turn at Node 5, Approach 1, is tied to Phase 9. Therefore it is important to reiterate that Phase 9 and 12 are really Overlaps A and D, respectively. Likewise, if Phases 10 and 11 existed, they would be Overlaps B and C, respectively. Looking under the NodeAssign section of Figure 9-6, it can be verified that each of the nodes have been assigned to their respective CID. Recalling that each

CID requires two Base ID addresses (Input / Output), it can be seen that each Base ID number must increase by at least two for each CID.

Local and System Detector Configuration

Now that the outputs from the controller have been integrated to work with the simulation, we will now focus on configuring the internal detectors (inputs) to do the same. Recall that the inputs generally consist of all of the detector calls at each of the intersections (Table 9-8) along with all of the system detector inputs throughout the system. The configuration of these detectors is exactly like that discussed in the previous chapter at both the local and system levels. Figure 9-7 shows all the detectors for each of the intersections within the system, in addition to the location of all system detectors. Recall that system detectors are represented by the brackets “[]” shown on the figure. Remember that some of the system detectors were located beyond the extents of the image, and thus they are instead noted in the caption. For this particular study, it should become apparent that there are thirteen system detectors that are used.

Note that not all of the detectors shown in Figure 9-7 have the same number as their associated phase, since there are often additional detectors required (right-turn lanes) which are then linked to their associated phase through the actual control equipment. For example, looking at Intersection 5, shown in Figure 9-7e, it can be seen that Westbound Detectors 4, 8, and 16 all call Phase 8. This becomes very apparent after checking the relative phasing diagram and ring structure shown in Figure 9-3e and Figure 9-4e, respectively. It is important to note that in the field, Detector 8 would not be required since it is the same as Detector 4. However, because of the geometric configuration of this intersection, the additional detector was required to accomplish the desired operation. Notice that Intersection 4 had to be configured much the same way. Recall that all detector mapping can be verified by viewing the actual assignments in Table 9-9.

When viewing Figure 9-8, the coding for all of the local and system detectors can be examined. Notice that this configuration follows the same convention used in previous chapters. Hence, when looking at the first system detector found on Line 7 of Figure 9-8, and following the same procedure for local detectors, it can be determined that the first system detector is located on Link 2,1. It can also be noted that this detector is in the left through lane (Denoted by the “2” in Column 3) and is setback 3,546 feet from the stopbar. It has a Station ID number of 213 and a length of 6 feet. This detector (Number 13) can easily be found in Figure 9-7b, which is just to the left of the intersection. Similarly, the corresponding system detector (Number 15), shown in this image can be found by examining Line 8 in Figure 9-8. Notice how this information exactly matches Line 7 with the exception of Columns 3 and 5. Recall that the Number 1, in Column 3, implies that the detector is in the right lane, while the different Station ID number allows these detectors to operate independently.

Following this same procedure, one can configure the remainder of the local and system detectors shown in Figure 9-8, as depicted on Figure 9-7. Based on discussions in the previous chapters, one can recall that system detectors can be easily identified by the setback distances in Column 4 (Figure 9-8). This was not necessary for this example, since all the system detectors have been commented, however if this were not the situation, one could recall that most local detectors are either positioned at the stopbar, which means they have a zero setback distance, or they are located anywhere from 250 to 300 back from the intersection for dilemma zone protection. This would result in a blank for Column 4 (stopbar) or a number on the order of 2,500 to 3,000 using the CORSIM coding. Any other number not in this range most probably denotes a system detector, as shown in Figure 9-8. This is because the setback distances are typically only slightly less than the intersection spacing.

Looking at Figure 9-8, it can be seen that these detectors all have setback distances greater than 800 feet. Since this is a relatively long system and the spacing between intersections is great, nearly all system detectors are setback more than 2,800 feet. Notice that there were no system detectors between the interchange (Link 4,5 or Link 5,4), hence it can be determined that those system detectors with setback distances on the order of 2,800 feet are located on either Link 3,4, or Link 4,3, which has a distance of 3,013 feet, as evident in Figure 9-1. Notice that those system detectors with the greater setback distances are found on the longer links. This is because most of the system detectors were located anywhere from 100 to 300 feet after the intersection, which thereby places them on the link to the upstream intersection. Recall that this coding is what the simulation model (CORSIM) understands, and hence, it must be adopted.

Like in the previous chapter, the only exceptions to these setback distances are those system detectors that are actually located on the approach to the intersection. Again this occurred at the interchange where it was desirable to have system detection on the ramps in order to adjust for volume surges. In this case the setback distance on the ramps were 850 feet, as can be determined from Figure 9-8. They were placed this far back since the geometric configuration of the half-diamond allowed it, and normal queuing on the ramps are typically heavy during the peaks. This setback is far enough that it would be unlikely for traffic to queue over them, except during extreme situations (accidents) on the interstate that force traffic to divert. These detectors could have been placed 380 feet back, like for the diamond, however it is likely that traffic would have queued over these detectors on a more regular basis, since the demands are much greater at this particular interchange.

It is important to realize that the system detectors can only be placed as far back as the ramp will permit. The total length of roadway for this particular half-diamond (off-ramp) is much greater than that of a diamond, as a result of the

geometric configuration. The off ramps used for this particular interchange involve a 180 degree curve, where interstate traffic must turn before intersecting the arterial at a perpendicular angle. This type of arrangement requires more land area, but in turn provides more storage on the ramp, which thereby increases the distance that the system detectors can be setback from the intersection. If immense queuing is expected during the typical peak periods, like for the JCT I-465 (South Ramp) during the afternoon peak, then it is desirable to place these detectors further back so that they can still obtain adequate count data. This way, the event plan can be reserved for times when there really is an event or accident that requires diversion to the arterial.

Mapping of System Detectors

Table 9-7 shows all the pocket geometry along with the lengths and setback distances for the local detectors. Such information matches that shown in Figure 9-7, which corresponds to the coding discussed in Figure 9-8. Recall that all detectors require a station identification number, so that they can properly communicate with the actual control equipment. These assignments, for local detectors only, are summarized in Table 9-8 on a per intersection basis. As seen from this table, all detectors are running in presence mode. Table 9-9 shows some of the additional parameters associated with the local detectors. As discussed in the previous chapter, the most important piece of information is the actual phase that each of the detectors are assigned to. Other information included in this table is the detector number, operational mode, detector delay, and the detector type, all of which have been previously discussed.

Now that the local detectors have been configured, Table 9-10 will focus on the mapping of the thirteen system detectors that will be used for selecting the desired traffic responsive plan. Recall that this table is similar to Table 9-8, however it also includes additional information that is only pertinent to system

detectors. The detector length and setback distance, which can also be obtained from Figure 9-8, are also shown in this table. Since system detectors are rarely located at the stopbar, only one 6 by 6 loop is typically required, which usually has its own amplifier. It is generally undesirable to connect parallel system detectors in series, since the master controller would not be able to receive discrete lane information. In addition, traffic counts may be missed and the occupancy calculations might be off, considering that the information would be from two lanes. Such a configuration would also require a different scale factor, particularly if there were also system detectors on one lane approaches.

Based on the above discussion and looking at Table 9-10, it can be determined that all system detectors have a length of 6 feet and that the first four (system detectors) are in pulse mode. This can be verified in Figure 9-8, by the Number 1 that is found in Column 7 next to these detectors. Also notice that both the Station ID and detector numbers match those found in Figure 9-8 for system detectors. Recall that the last two digits of the Station ID are the detector number, while the first number specifies the CID that the detector is mapped to. Looking at the first line of Table 9-10, it can be determined that the Station ID of 213 is really local Detector 13. When viewing the Station ID column in Table 9-10, it can be determined that no two station numbers are identical. The same goes for the local station numbers shown in Table 9-8. Recall that Station ID's can be used only once, and hence, those address found in Table 9-10 will not be found in Table 9-8, and vice versa.

Looking at Table 9-8 and Table 9-10, it can be seen how the same detector numbers are used more than once, however it is important to realize that each of these are at a different intersection, thereby resulting in a different Station ID. Recall that the system detector data must end up at the master controller or central control center. As discussed in the last chapter, this is typically done through the telemetry, by wiring each of the system detectors to

the nearest intersection. This is not a problem with local detectors, since they are traditionally located on one of the approaches to the intersection, however with system detectors, they are often located after the intersection, which is the approach to the downstream intersection. This is again why some of the setback distances found in Figure 9-8 are so large. These same distances are found in Table 9-10, recalling that a “-“ in front of the distance means that the system detector is referenced the traditional way, indicating that it is on the approach to the respective intersection.

Looking at Table 9-10, it can be seen that there is also a telemetry number, telemetry address, and system number that must be assigned for each of the system detectors. Recall that telemetry addresses are important, since they differentiate the controllers from one another. These address can be any number within the given constraints, realizing that no two controllers in the same system can have the same address. Hence, it is good to begin with the Number 1 at the Westernmost or Southernmost intersection, and increment sequentially through the system, realizing that one address is required for each controller. This means that one address will be needed for each of the interchange ramps, since separate controllers were used at each junction.

Since only one CID is required for each controller, it is best that the CID numbers directly match the controller telemetry addresses, found in Table 9-10. Recall that this can be verified by comparing the first column of the Station ID with the local telemetry address. Although this is not a requirement, it makes the entire process easier to remember and configure. If possible, the node numbers shown in Figure 9-1 should also match the telemetry and CID numbers, as was done for this research. As was discussed in the previous chapter, the next column (Table 9-10) shows the system telemetry addresses, which include SDA1, SDA2, SDB1, SDB2, SDC1, SDC2, SDD1, and SDD2. This is again the convention understood by this master controller, noting that each of the

addresses listed here correspond with the eight local system detector addresses available at each of the local signal controllers.

Looking at Table 9-10, it can be seen that the telemetry addresses start over at SDA1 each time the local telemetry number in the previous column changes. Like in the previous chapter, these detectors have been sorted by the system detector number. Hence the local detectors were listed by intersection from South to North with the left-arterial travel lane first, for simplicity. Given this methodology (regardless of direction), the system detector in the left lane will always have a lower detector number than a parallel detector in the right lane. Note that the detector numbers in Table 9-10 are only local detector numbers, which are then converted over to system detector numbers in Table 9-14. Looking at Table 9-10, it can be seen that there are 4, 3, 4, and 2 system detectors assigned to Intersection 2, 3, 4, and 5, respectively. The same is true when referring to Table 9-14. Hence detectors 13, 15, 9, and 11, shown in Lines 1 to 4, are now System Detectors 1, 2, 3, and 4.

Notice that the telemetry address (SDA1, etc) in Table 9-14 directly match those shown in Table 9-10. Also realize that there were no system detectors designated at Intersection 1, and hence there was nothing assigned for Controller 1, as evident in Table 9-14. This becomes apparent when noting that there is nothing but zeros in Row 1, which corresponds to that particular controller and telemetry address. Looking down the list for the SDB2 assignments in Table 9-14, it can be seen that only System Detectors 4 and 11 are assigned to this address, which matches the information in Table 9-10. This is the case because the SDB2 address is reserved for the fourth system detector, and there are only two intersections that have at least four system detectors (Intersections 2 and 4). Notice that the SDC1 to SDD2 addresses contain zeros for all five of the intersections. This is because there is no intersection in the

system that contains more than four system detectors. Note that none of the system detector numbers in Table 9-14 can be used more than once.

Configuration of System Timing Plans

Table 9-11 shows some of the general timing parameters that were used to control each of the intersections in the system, while Table 9-12 shows the coordination splits that were used for each of the periods, given the base volume scenarios and turning percentages shown in Table 9-1 and Table 9-6, respectively. The cycle lengths, offsets, and pattern numbers for each of the intersections are also shown in Table 9-12, in addition to any left-turning movements that were designated as lagging. As with the previous system, there were five different timing plans that were generated, based on bandwidth optimization strategies. These include Patterns 111, 211, 311, 411, and 412, which are the midday, morning, afternoon, event-inbound, and event-outbound plans, respectively. Notice that 412 was used instead of 511 for the event-outbound plan. This is because this plan used the same cycle length as the event-inbound plan of 150 seconds, as evident in Table 9-12. It would have been acceptable to use Pattern 511, however an additional cycle parameter would have needed to be configured in the master controller.

As mentioned in the previous chapter, these plans are typically arranged in the order of demand, with the midday being the lightest and the event traffic being the heaviest. Although it is not required that the cycle lengths increase with the cycle level (with this equipment), it is generally common practice, which is why heavier plans are typically associated with the higher number. The three numbers that make up the pattern number, such as 412 are the cycle length, offset, and split (COS). For this study, it is essentially the cycle length that distinguishes between the various patterns. The subsequent sections will use these pattern numbers to distinguish between the various plans. Notice from

Table 9-12, that lagging left-turns were used at Intersections 3 and 4, for some of the patterns. When examining the phasing diagrams in Figure 9-3, it can be determined that Phase 5 is for the Northbound left-turn, while Phase 1 is for the Southbound left-turn, at all intersections in the system.

Time-of-Day Configuration

The configuration of the Time-of-Day (TOD) parameters are much like that discussed in the previous chapter. The configuration used for this particular study can be found in Table 9-13, noting that system detectors are not required for this operation. Looking at this table it can be seen that the morning pattern (111) runs from 5:55am to 9:00am. Similarly, the midday plan (211) runs from 9:00am to 2:00pm, at which time the afternoon plan (311) would run until 7:00pm. After 7:00pm the midday plan (111) would run again until 11:00pm, at which time the system would run independently (Free). Since this study ran for an entire weekday (6:00am to 6:00pm), the majority of this weekday schedule was used. Weekend plans were generated (Table 9-13) to show that alternate plans typically run on the weekends, although they were not examined as part of this study. Recall that it is the different program numbers that represent the day of the week. Also realize that the event plans (411 and 412) are not part of this schedule, since they are not recurring plans.

Traffic Responsive Configuration

Now that the system detectors have been mapped to the actual control equipment, and the time-based (TOD) operation is now configured and understood, this section will focus on assigning the various traffic responsive parameters to each of the system detectors. Looking at Table 9-15, one can recall that the four parameters include the Level, Directionality (1 or 2), Split Demand (A or B), and Arterial / Non-Arterial Demand. Please refer to the previous chapter for details behind each of these parameters. When examining

Table 9-15, one will recall that there are eight groups, each of which can contain up to four system detectors (Lane 1 to 4). This creates a matrix of up to 32 system detectors that can be configured. Looking at the table, it can be seen that Detectors 1, 2, 3, and 4 have been assigned to Group 1, all of which are on the arterial. This can be verified by referencing Table 9-10, and then referring to Figure 9-7b, which shows the detector locations.

When looking at Group 1, and referring to Table 9-10, it can be determined that all of these detectors run in pulse mode. Using these same sources, one will also notice that Detectors 1 and 2 are assigned to the Southbound direction, while Detectors 3 and 4 are assigned to the Northbound direction. This implies that none of the directionality parameters should be assigned for this group. From Table 9-15, it can also be seen that at least three of the detectors in Group 1 should be working properly, in order to ensure valid operation. Looking at Table 9-15, one will see that the second highest scaled volume is assigned to the Level parameter. Also notice that the averages of all functional detectors in the group are assigned to Split Demand "A", while the second highest scaled volume is linked to the Arterial Demand parameter. Realize that the scaled occupancy is irrelevant for this group, since the detectors are operating in pulse mode.

Notice that Group 2 uses similar traffic functions as Group 1, with the main exception being that Detectors 5, 6, 3, and 4 now make up the group and the directionality parameter has now been assigned. When referring to Table 9-10 and examining Figure 9-7, it can be seen that all detectors in this group are in the Northbound direction. Hence, referring to Table 9-15, the averages of the higher scaled volume or occupancy will be assigned to Direction 1 for this group. Scaled occupancy is a consideration for System Detectors 5 and 6, since they operate in presence mode. Notice that all detectors in Group 2 are also located

on the arterial, as were the Group 1 detectors. Hence, it was decided to keep the remaining assignments in Table 9-15, the same as Group 1.

Notice that System Detectors 3 and 4 were used in both Groups 1 and 2. This was done to illustrate that system detectors can be assigned to multiple groups. Realize however, that this may not be the best configuration, as the results can become skewed, if such detectors were to be dominant in more than one group. This is particularly the case if the parameters are being repeated amongst the groups, as in this instance. Group 3, in Table 9-15, is much the same as Group 2, however this time System Detectors 1 and 2 are repeated and all the detectors in this group are for the Southbound arterial direction. Hence, the average of higher scaled volume or occupancy will be assigned to Direction 2. Like with Group 2, Detectors 8 and 9 operate in presence mode, and thus occupancy calculations are relevant for these detectors. As seen from Table 9-15, all other parameters are configured like the first two groups.

Group 4 is different from the first three groups in that the system detectors are not located on the arterial. They are instead located 850 feet back from the stopbar on each of the JCT I-465 exit ramps. Note that System Detectors 10 and 11 are on the South Ramp, while Detectors 12 and 13 are located on the North Ramp. Looking at Table 9-15, it can be seen that at least three of these detectors must be working in order to ensure valid operation. This is because two failed detectors can result in one of the ramps not sending any system information to the master. Since all of the detectors in this group run in presence mode, the average of the higher scaled volume or occupancy will be assigned to Split Demand "B", while the highest value will be assigned to the Non-Arterial Demand function, as evident in Table 9-15.

Group 5 is different from all the others, in that, it contains only System Detector 7. Looking at Table 9-10 and referring to Figure 9-7c, it can be

determined that System Detector 7 is really local System Detector 13, which is in an extended right-turn lane for the JCT I-465 (North Ramp). Normally, system detectors can be omitted from right-turn lanes, however since the right-turning traffic is very heavy (dominant) during the morning rush hour, it was considered in the computations. Given that traffic would queue over this detector on a frequent basis, it was decided to place this detector in presence mode so that the queuing can be detected. According to Group 5 of Table 9-15, this would ensure that Direction 1 is considered dominant under such circumstances. Notice that none of the other parameters were assigned here, since queuing occurs at the location on a frequent basis.

To assign this particular system detector to the Level parameter would have been unwise, since it is known that a longer cycle lengths would not clear the congestion during the morning peak. Hence, this detector only ensures that the Northbound direction is considered dominant during such circumstances. This is provided that the function computations, discussed in the subsequent section, are configured properly. Notice that the Number 1, used for Direction 1 in Table 9-15, could have had a Number 2 or Average (AV) assigned to it, considering that it is the only detector in the group. It can also be determined from Table 9-15 that this detector must be working in order to Traffic Responsive (TRP) to work. If it were desirable that traffic responsive still run with the failure of this detector, then a zero should be entered under Group 5 for the number of detectors required.

Traffic Responsive Function Computations

Once the groups and traffic parameters have been assigned, as in Table 9-15, it is then necessary to aggregate the data between the groups so that each of the traffic parameters can be summarized. This is done with the careful configuration of Table 9-16. Looking at the table, it can be seen that the four

parameters include the Level, (LEV), Directionality (DR1 / DR2), Split (SPA / SPB), and Arterial / Non-Arterial Demand (ART / NRT). Below these parameters are the type of computation (volume / occupancy), the value of the group, the Smoothing Factor (SMF), and the Update Predictor Threshold (UPT), all of which were explained in the previous chapter. Notice that all computations are summarized on a per parameter basis, once all the groups have been sorted according to the configuration shown in Table 9-16. Hence, this information applies to the traffic parameters and not the groups shown in Table 9-15.

Recall that the 1, 2, and AV found for value of the groups, in Table 9-16 mean the same as they did in Table 9-15, however this time the values represent the actual traffic parameter and not the group. Hence, the Number 1 would imply that the highest value amongst the groups be used, while the Number 2 would indicate that the second highest value should be used. Average (AV) would mean that the average of all the groups assigned to the relative parameter be used. Hence, referring to Table 9-16, it can be seen that the highest Level (LEV) and Directionality (DR1 / DR2) parameters will be used, while the second highest Split Demand (SPA / SPB) will be summarized. Similarly the averages amongst the groups that use the Arterial / Non-Arterial Demand (ART / NRT) will be utilized. Recall that these values can consist of volume, occupancy, or both volume and occupancy counts, which depend on the parameter coding.

Based on the parameter coding found in Table 9-16, it can be determined that concentration (CON) will be used for summarizing all the parameters, which implies that both the scaled volume and occupancy data will be considered for the computations. Recall that in order for occupancy to be considered, the relative system detectors must operate in presence mode so that the counts will be valid. VOL implies that only the scaled volume will be applied for the relative parameter, while OCC means that only the occupancy data will be incorporated into the computation. No matter which coding is used, it is important that the

scale factors be configured properly so that both the scaled volume and scaled occupancy range between 0 and 100% for the extreme cases, as discussed in the previous chapter. Notice how the Smoothing Factor (SMF) and Update Predictor Threshold (UPT), shown in Table 9-16, are assigned at 30% and 20% respectively, for all the traffic parameters.

Traffic Responsive Plan Selection

Once the appropriate traffic parameters have been computed, according to the configuration shown in Table 9-16, it is then necessary for the master to determine the most appropriate plan to be running, given the computations. Note that Table 9-17 shows the thresholds that were used for each for the four traffic functions. Recall that all thresholds are expressed as a percentage, so that they can be compared with the scaled volume or occupancy values. As seen from Table 9-16, the higher of these values (CON) are applied to Table 9-17, for all traffic parameters, in order to determine the most appropriate plan. As discussed in the previous chapter, each column in Table 9-17 represents a different traffic function. Looking at the Level (LEV) thresholds (Column 1), it can be seen that there are up to 5 Levels. However, only 4 Levels are used, since the last one has been omitted by the 101%, as evident in Table 9-17.

Applying the knowledge from the previous chapter, it can be determined that a threshold value of 22% is required in order for the system run coordinated operation, by moving from Level 1 to Level 2. Similarly, the values of 50% and 85% are thresholds required, in order to move to Level 3 ($2 > 3$), and Level 4 ($3 > 4$), respectively. Following similar strategies, it can be seen that a value of 12% is required for moving from coordinated operation to free operation (Level 2 to Level 1). Recall that this value ($2 > 1$) should be considerably less than the reverse process, which was 22% in this particular case ($1 > 2$). As seen from Column 1 of Table 9-17, the value required to drop to Level 2 ($3 < 2$) and Level 3

(4>3) are 35% and 70%, respectively. Again notice how these values are all considerably less than their parent values, which minimizes the potential for undesirable pattern changes.

Recall that Column 2 in Table 9-17 is used to determine the heavier direction. According to the table, it can be determined that both Direction 1 (DR1) and Direction 2 (DR2) must be greater than the difference of both thresholds (absolute value) by more than 10% ($AV > 1$ or $AV > 2$), in order for one of the directions to be considered dominant, otherwise they would be counted as equal (average). Had one of the directions already been determined as dominant, then the difference between the thresholds must be less than or equal to 5% ($1 > AV$ or $2 > AV$), as seen from Column 2. Note that the parameters for each of the directions (DR1 / DR2) can be different, even though they were equal for this study. Recall that Direction 1 (DR1) is for Northbound movement, while Direction 2 (DR2) was reserved for the Southbound movement.

The split computations, shown in Column 3, were configured for illustration purposes only. Like for the previous network, this parameter was not used since a zero was never entered for the split in the traffic responsive plans (COS of 210 instead of 211) where the function was to take effect. Since the configuration is identical to that of the previous chapter, please refer to that section for further details about this parameter. The last parameter, shown in Column 4 of Table 9-17, is also better discussed in the previous chapter, since no changes were made to the configuration of these thresholds. Recall that the parameter in Column 4 is used to determine the Arterial / Non-Arterial Demand (ART / NRT) preference, which allows up to five additional plans to be selected. The four parameters are then summarized, at which time the pattern selection chart, shown in Table 9-18, is used to select the appropriate plan. The subsequent section will use this configuration to analyze five different volume scenarios.

Overview of the Study

The primary purpose behind this study was to determine the pros and cons to using traffic responsive operation during unknown volume scenarios, recalling that such an operation (TRP) works best when the timing plans are developed from known volume scenarios. The five cases that follow will be compared to the traditional Time-of-Day (TOD) procedures that would normally be running during these unexpected volume fluctuations. This study analyzes five different volume scenarios, which had a length of 12 Hours each. There were 5 runs that were studied for each of the scenarios using both the Time-of-Day (TOD) and Traffic Responsive (TRP) methodologies. In all cases, fluctuations were made to the existing volume scenario, shown in Table 9-1. The explanation behind these scenarios were discussed earlier in the chapter.

Scenario Results and Cycle Analysis

Based on the concepts discussed in the previous section and the Traffic Responsive (TRP) programming found in Table 9-18, the results of the pattern changes for all the scenarios will be analyzed according to Table 9-19, which is for High School Road (Node 3). Node 3 was chosen for the cycle analysis because the volumes were heavy enough to make the coordinated phases terminate consistently. Recall that all controllers in the system change plans at approximately the same time, hence it is only the transitioning that is slightly different. Notice that each of the five cases shown in Table 9-19 consist of the Time-of-Day (TOD) and Traffic Responsive (TRP) pattern changes. Also recall that the volumes for each of these cases change on an hourly basis, for each of the twelve periods that run from 6:00am to 6:00pm.

When examining Table 9-19, it can be determined that the 12 Hour simulation periods were broken into 15 Minute increments. This is not to be confused with the previous chapter, where the cycle transitions were analyzed in

2 Minute increments. Larger increments were used here because of the longer simulation time. Since it was desirable to summarize all the pattern information in a single table, the 15 Minute increments were selected. Notice that the Percent In-Sync (% In-Sync) values, shown at the bottom of the table, are all well above 90%. This means that Node 3 was in coordination for more than 90% of the time, for all scenarios, which usually implies that the other controllers in the system had approximately the same performance. This becomes evident when examining Table 9-20, which shows the coordination ratios at the JCT I-465 (North / South Ramps) as well (Nodes 4 and 5).

Realize that the coordination ratios (% In-Sync) obtained here are much greater than that of previous chapter, where most of the values ranged in the lower 80's. These improvements are due to the longer simulation period, which was longer by 11 Hours. This minimizes the overall effect that transitioning has on the overall system performance, if everything else were to be held constant. Since there were essentially only three patterns to choose from, many of the coordination patterns were valid with more than one volume scenario. Hence, the total amount of time that the system actually transitioned was minimal. As can be seen from Table 9-19, the event patterns (411 and 412), were never activated, since there were not any volume scenarios that warranted the operation, given the configuration that was previously discussed.

When referring to Appendix B, it can be determined that the coordination ratios (% In-Sync) for the preemption case study were significantly lower, for the majority of the cases. This is again because of the short duration time (22 Minutes) that was used, in addition to the fact that preemption was constantly throwing the system out of coordination. Generally, the more preempts, the lower the coordination ratios, as can be seen from the study. In some cases, these ratios got as low as 9%. The corresponding graphs which illustrate this, can also be found in Appendix B, for each of the intersections used in that network.

Lastly, it should be noted that these ratios (% In-Sync) were obtained directly, by taking the percent of time that the intersection was in coordination and dividing by the total simulation time.

Tables such as Table 9-19, are generally not accurate enough to obtain this value, particularly for shorter simulations, since there is no way to determine the amount of time in the interval (2 or 15 Minutes) that the controller was actually transitioning. For example, looking at Column 2 (TRP) for Case 1, in Table 9-19, it can be determined that the controller was transitioning at 9:30am and 5:30pm. However, it is not possible to determine the amount of time that the controller was transitioning on either side of this interval, other than it is most likely much less than 15 Minutes. Hence, such tables should be good for giving the reader a rough idea of which patterns were running at what time, and not necessarily for determining how often the scenario was in coordination. This value (% In-Sync) for all the studies contained herein, was established using a spreadsheet package, where such information could be directly determined.

Further examination of Table 9-19 shows that the Time-of-Day (TOD) pattern changes were essentially the same for all the cases, except for Case 1, where the afternoon pattern (311) began an hour later than the other cases. Looking at the timed-based (TOD) operation for Cases 2 to 5, it can be easily determined that morning plan (211) ends at 9:00am, at which time the midday plan (111) begins. Notice that the midday plan does not appear until the 9:15am interval for all the cases. This is because the plan was not in coordination until the 9:15am interval, which makes sense, since few transitions instantly take effect. Similarly, it can be determined that the afternoon plan (311) for Cases 2 to 5 was not detected until 2:15pm interval, although it was set to begin at 2:00pm. These cases, with the exception of Case 1, directly match the Time-of-Day (TOD) schedule shown in Table 9-13 for a typical weekday (Program 1).

Looking at Case 1, in greater detail, it can be determined that the only difference in the time-based (TOD) operation was with the afternoon plan (311), which began an hour later at 3:00pm (3:15pm according to Table 9-19). This was the original time-based schedule for the system, however after the first sequence of simulations, it was determined that the afternoon plan began too late and it was adjusted accordingly in order to activate an hour earlier, as evident in Cases 2 to 5. This is why Case 1A was created in Table 9-21, as it was desirable to compare the base Traffic Responsive (TRP) procedure to both of the Time-of-Day (TOD) schedules. After doing so, it was determined that the newer schedule did much better, as the total system delay dropped from 66,053 Veh-Min to 57,741 Veh-Min. Detailed analysis of these quantitative results are further discussed in the subsequent section.

Now that the time-based (TOD) operations for both Case 1 and Case 1A have been determined, it is now time to examine the cycle analysis for the Traffic Responsive (TRP) procedure using the base case (Case 1). Hence, looking at Column 2 of Case 1 in Table 9-19, it can be determined that the TRP procedure transitioned to the morning plan (211) by 6:30am before transitioning to the midday plan (111) at 9:30am. Comparing this to the TOD column, it can be seen that the midday plan began approximately a half an hour later. Similarly, it can be determined that the TRP afternoon plan (311) was in coordination by 2:30pm, which is nearly 45 Minutes earlier than the original TOD schedule. Figure 9-9 graphically shows these comparisons (Nodes 3 to 5) for Case 1, while Figure 9-10 shows the comparisons for Case 1A. Realize that the same TRP data was used for both cases, as it was only the TOD data that changed as a result of the update that was made to the TOD schedule.

Notice how the transitions for the relative scenarios occurred at the same time for all the intersections (3 to 5) shown in Figure 9-9 and Figure 9-10. The only differences were the slight moderations (Parts a to c) in how each of the

controllers actually transitioned, which should be apparent in both figures. Notice that these figures are essentially the same, until 2:00pm where the TOD cycle line to the afternoon pattern occurred an hour earlier, as evident in Figure 9-10. Notice that Figure 9-9 closely resembles Table 9-19 for Case 1. Hence, TRP responds earlier to Pattern 311 than the TOD scenario in Figure 9-9, while it responds latter in Figure 9-10. Looking at the TRP procedures for either of the figures, it can be seen how there was a slight glitch in the operation, where it transitioned out of and back into Pattern 311. This glitch shows up in Table 9-19 as well, since the system was transitioning at the start of the 5:30pm interval.

Based on this information, and looking at Table 9-18, it is likely that the system slipped from the Level 2, Non-Arterial Demand (NRT), where in was in Pattern 311, to Level 2, Direction 2 (DR2), when it tried to transition to Pattern 111. At this instant, it is likely that the JCT I-465 (South Ramp) quickly queued up over the system detectors and again reverted the system back to Non-Arterial Demand (NRT), where in began transitioning back to Pattern 311, as evident in Table 9-18. This implies that the system was not in the Level 3 position, as was desirable for the afternoon rush hour. If it were in this position, there had to be a glitch in the coordination, as there is no feasible way using the thresholds in Table 9-17 that it could have dropped to Level 2 only to immediately return to Level 3. The same is true for jumping up to Level 4 (event plans) and then immediately returning back to Level 3.

Looking at the first half of the graphs for the TRP operation in either Figure 9-9 or Figure 9-10 and then referring to Table 9-18, it can be determined that the system started out in Free operation (Level 1) before transitioning to Level 3, Direction 1 (DR1) which is the morning pattern (211). It then stayed in this pattern until the volumes became light enough to drop to the Level 2, Arterial Demand (ART) parameters that run the midday pattern (111). The system then rested in the midday pattern until the volumes increased enough on the JCT I-

465 (South Ramp), in order to revert the system over to Level 2, Non-Arterial Demand (NRT), which is the afternoon pattern (311), according to Table 9-18. This essentially concludes the analysis for Case 1 and Case 1A. The following four cases will be examined much the same way, but in less detail.

Referring to Case 2 in Table 9-19, it can be determined that the TOD schedule is the same as Case 1A, and only the TRP operation will be different. Realize that the volumes in Table 9-2 now apply for both the TOD and TRP procedures. When viewing the morning portion of the TRP operation, it can be seen that it does not closely resemble the TOD operation. This likely implies that one of the two scenarios (TOD or TRP) are going to perform significantly better than the other. Based on the information in Table 9-19, it can be seen that the TRP procedure runs Pattern 111 (midday), until the morning pattern (211) kicks in just before the 8:30am interval. It then stays here before transferring back to Pattern 111 around 10:30am, at which time it remains there until 1:45pm. Looking at Column 2 for Case 2 (TRP) in Table 9-19, it can be determined that the system fluctuates multiple times among Pattern 111 and Pattern 311 between the hours of 1:30pm and 2:45pm. This is exactly why the coordination ratio (% In-Sync) for Case 2 was the lowest (94%) of all the cases.

Notice that Figure 9-11 greatly illustrates these TRP fluctuations for Nodes 3 to 5. From this figure, it is very evident that there are significant differences between the operations before 11:00am. The pattern fluctuations between 1:30pm and 2:45pm are also well depicted here. The most obvious difference should be that TRP is running a 100 second cycle (midday), while the TOD operation was running at 140 seconds (morning), at which time they meet up around 8:10am for a little over a half-hour, before reversing the process until about 10:30am. Again, notice how this closely resembles the information in Table 9-19. Referring to Table 9-18, it is likely that the TRP operation began in the Level 2, Arterial Demand (ART) parameters, which runs Pattern 111 until

approximately 8:10am, where it appeared to shift to the Level 3, Direction 1 (DR1) parameter that runs the morning Pattern 211. It then stayed in this operation until the demand was low enough to revert back to the Level 2, Arterial Demand (ART) parameters that run the midday pattern (111).

Looking at the hours between 1:30pm and 2:45pm in Figure 9-11 and referring to Table 9-18, the TRP procedure appeared to fluctuate on Level 2, between the Non-Arterial Demand (NRT) parameters that run Pattern 311, and the Arterial Demand (ART) parameters, which run Pattern 111. It is believed that these fluctuations have much to do with the issue that became apparent in Case 1 at 5:30pm. The system was designed with the intention that the system would be on Level 3 for the afternoon rush, where Pattern 311 (Outbound) is dominant for nearly all the parameters. Notice that Direction 1 (DR1) was the only exception for this level, since it was reserved for morning (Inbound) plan, like Pattern 211 for this case. The setting of Pattern 311 for the Level 2, Non-Arterial Demand (NRT) parameters, was made to help quickly switch to the afternoon plan, if one (or both) of the ramps were to become congested. This was done considering that Pattern 311 had much more time allocated to the ramps, since they are the dominant movements during the afternoon peak, particularly at the JCT I-465 (South Ramp), which is also Node 4.

Based on the cases examined thus far, it is apparent that the system does not appear to be making it to Level 3 during the afternoon peak, as desired. Hence, this may indicate that the threshold value (50%) in Table 9-17 for the transition from Level 2 to Level 3 (2>3) may be too high and should be adjusted (lowered) accordingly. However, when doing so, one should be aware that such a change could result in the afternoon plan (311) beginning earlier than desired, according to the current settings in Table 9-18. The threshold from Level 3 to Level 2 (3>2) should most likely stay at 35%, since the system appears to be dropping levels at the appropriate time, according to the base case (Case 1).

Otherwise such a change could make it take longer to drop from the peak plans down to the off-peak (midday) patterns, that are dominant in Level 2. Given this constraint, the threshold value of 50% for Level 2 to Level 3 (2>3) should probably be set to no lower than 40%.

Another change that could be made, given the configuration shown in Table 9-18, would be to increase both the Arterial Demand (ART) and Non-Arterial Demand (NRT) thresholds in Table 9-17. This could help avoid the amount of transitioning that occurs on Level 2, once the master determines that Non-Arterial Demand (NRT) is dominant. Since the Non-Arterial Demand (NRT) was usually determined by traffic queuing over the system detectors (100% occupancy) on the ramps, these increases would generally not slow the response. However, increasing NRT>ART threshold (20%) in Table 9-17 would slow the rate that the system would return to Arterial Demand (ART), which would be desirable given the current configuration, provided that it is not too extreme. An extreme case would result in the system being in Non-Arterial Demand (NRT) for the majority of the day, which is undesirable. Hence, values of 30% and 40% for the NRT>ART and ART>NRT, respectively, may be reasonable given the results examined for Cases 1 and 2.

It should be noted from Table 9-18, that switching between Arterial Demand (ART) and Non-Arterial Demand (NRT) on Level 3 would have had no effect for the afternoon rush (311), provided that Direction 1 (DR1) was not selected. Since Direction 2 (DR2) is dominant (Outbound) during this peak, this was not of major concern. Hence, being on Level 3 for the afternoon peak (311) would thereby eliminate the difficulties encountered on Level 2, for the cases examined thus far. This same logic applies to Level 4, had the event patterns (411 or 412) been selected for the scenarios. It should also be noted that Table 9-17 and Table 9-18 are not the final word on the configuration of the TRP parameters. It is possible that this system may have run better with fewer levels,

however the assignments shown in Table 9-18 were held fixed, and the previous examples only changed the thresholds in Table 9-17. This was done primarily for illustration purposes.

Looking at Cases 3 to 5 in Table 9-19, it can be determined that they all closely match the time-based (TOD) operation. None of them were off by more than 45 Minutes and most of them were in a half-hour of the Time-of-Day (TOD) pattern change. Recall that the volume scenarios used here can be found in Table 9-3 to Table 9-5, respectively, while the turning percentages shown in Table 9-6 were constant for all the scenarios. The corresponding cycle graphs for Cases 3 to 5 can be found in Figure 9-12 to Figure 9-15, respectively. Looking at the big picture for Traffic Responsive (TRP) operation for Cases 3 to 5, it can be determined that the system started out in the Level 3, Direction 2 (DR2) setting where it ran Pattern 211 (morning), at which time it dropped to the Level 2, Arterial-Demand (ART) preferences that run Pattern 111 (midday). It then stayed in this pattern until the demand became great enough to revert over to the Level 2, Non-Arterial Demand (NRT), at which time it ran Pattern 311 (afternoon), which had a cycle length of 140 seconds.

When viewing Figure 9-12 for Case 3, it can be determined that the operation was very close to that of the time-based (TOD) operation. However, notice that the Traffic Responsive (TRP) procedure took some time to transition from Free operation to Pattern 211, as evident from the beginning of the graphs (Parts a to c). Case 4, shown in Figure 9-13, had much the same issue, however with this particular TRP scenario, it can be seen that the system tried to switch out of the morning pattern (211) at approximately 6:30am, which was shortly after the system reached coordination at 6:20am. This is also evident in Table 9-19 for Case 4, as it was transiting at the beginning of 6:30am interval. The fact that Pattern 211 is shown on both sides of the interval, most likely implies that the system temporarily slipped out of the Level 3, Direction 1 (DR1) demand that

runs Pattern 211 and moved to some other Level 3 parameter, which runs Pattern 311, as evident in Table 9-18.

Case 5 had a similar occurrence, however this time it happened in the afternoon peak, at around 3:20pm, as seen from the cycle graphs in Figure 9-14. The explanation for this is the same as for Cases 1 and 2, in that the system was in the Level 2, Non-Arterial Demand (NRT), instead of Level 3. Then, when the volumes became lighter on the ramps, the system temporarily reverted to the Level 2, Arterial Demand (ART) parameters that run the midday pattern (111). The splits were then reduced on the ramps, at which time the traffic queued up, and again activated the Non-Arterial Demand (NRT) parameter, that runs the afternoon pattern (311). Notice how this particular transition interval does not appear in Table 9-19, for the Traffic Responsive (TRP) procedure in Case 5. This is because the transitioning for this case occurred during the actual intervals, and not between them, which reinforces the concept that Table 9-19 should not be used for calculating the coordination ratios (% In-Sync).

Since there is typically more transitioning associated with the Traffic Responsive (TRP) procedures, it can be seen that the coordination ratios (% In-Sync) in Table 9-19, are all less than that of the time-based (TOD) operation. Table 9-20 shows the same results, however Nodes 4 and 5 are also included here. It should also be apparent that Cases 3 to 5 did a good job of adjusting to the various volume scenarios. This can be verified in Table 9-21, in that all the delay values (Cases 3 to 5) are within 1,000 Veh-Min of the TOD operation. Case 5 did even better than the time-based (TOD) procedure by slightly more than 480 Veh-Min. Notice how Cases 1 and 2 had greater variations in the overall delay time. This tends to imply that it is not necessarily the transitioning that degrades the overall system performance, but rather the wrong plan being selected at the wrong time. The following section will focus on more substantially examining the quantitative data associated with these pattern changes.

Analysis of Quantitative Results

As discussed in the previous section, the quantitative data obtained in Table 9-21 is simply a summation of the total cumulative delay (Veh-Min) for all intersections within the system. Realize that such information is not very helpful, unless there are alternative scenarios that also use the same demand volumes. Recall that the volumes for all of the scenarios have been conserved, hence the vehicles have only been moved around between the cases and not added or subtracted. This can be verified by summing up all entry volumes in Table 9-1 to Table 9-5 and observing that the total volume for all the scenarios are equal. This allows all of the values in Table 9-21 to be compared with one another. When doing so, one will see that the values ranged between 46,631 Veh-Min to 66,053 Veh-Min. Appendix C shows the breakdown of these values by both approach and movement for all of the scenarios examined as part of this study.

Looking at Figure 9-15 and Figure 9-16, one will be able to view the Traffic Responsive (TRP) travel time graphs (Sec/Veh) on a per period basis (Case 1), for both the Northbound and Southbound directions, respectively. When doing so, one would be able to determine that there is considerable congestion in the morning between the hours of 7:00am and 9:00am in the Northbound direction, as evident in Figure 9-15. This is the case for nearly all the scenarios, since there is a capacity problem during those periods at the JCT I-465 (North Ramp), where the majority of the traffic is trying to make a right-turn onto the Interstate. Thus, traffic frequently spills out of the turning bay, hindering the through movement, thereby nearly doubling the travel time relative to the other periods. Notice that the Southbound direction was reasonable for all the periods, as evident in Figure 9-16. For both cases, notice that the higher travel times were during the peak periods, as expected.

Figure 9-17 compares the total delay time, in vehicle-minutes (Veh-Min) for Traffic Responsive (TRP) operation and the existing Free operation, using the

base volume scenario in Table 9-1. This is an interesting figure, since the Free operation did better for all periods, except from the one in the morning peak (7:00am to 8:00am) where the right-turning bay was over capacity. The direct improvement for the oversaturated Link 4,5 went from 3,048.7 Veh-Min with the Free operation to 2,422.9 with the Traffic Responsive (TRP) procedure. The timed-based (TOD) procedure came in at 2,818.0 Veh-Min, which is still less than that for Free operation. These can all be verified in Appendix B by summing the NBTH and NBRT movements at the JCT I-465 (North Ramp). Reference Tables B-1, B-4, and B-7 for the Free, TOD, and TRP values, respectively.

Note that the difference between the Free and Traffic Responsive (TRP) operation, from 7:00am to 8:00am, appears to be small. This occurs because the unsaturated intersections in the system tend to dilute the significance of the improvement at the saturated intersection, considering that this table incorporates the total delay from all intersections (Figure 9-17). When summing the Northbound through movements (7:00am to 8:00am) for the system (Intersections 1 to 5), it can be determined that the corresponding delay values are 7,584 Veh-Min, 6,048 Veh-Min, and 5,049 Veh-Min for the Free, TOD, and TRP scenarios, therefore again showing that coordination can help reduce the overall travel time on the saturated links for this particular case. Note that during unsaturated conditions, coordination generally helps reduce the total delay for the through movements at the expense of the minor movements.

Figure 9-18 compares the total number of stops for both the Traffic Responsive (TRP) procedure and the existing Free operation for Case 1. From here it can be seen that coordination considerably reduces the total number of stops for all the periods. This is contradictory to what was found in Figure 9-17, which compared the total delay of both the Free and TRP procedures. Based on these figures, it can be observed that coordination reduces the total number of stops (arterial), at the expense of overall total delay. Figure 9-19 helps verify this

by summing the cumulative delay for the entire 12 Hour simulation period. Notice how these lines were close for the first two periods, when the system was congested, at which time they separated by slightly less than 20,000 Veh-Min at the end of the simulation. As seen from Case 1 of Table 9-21, the TRP delay for the scenario was 59,995 Veh-Min, which means that the Free delay time was around 40,000 Veh-Min, as evident in Figure 9-19.

Notice how none of the delay values in Table 9-21 are less than 40,000 Veh-Min that was determined for the Free operation. This is because coordinated operation typically increases the overall delay, which makes such a value nearly impossible to beat, however it should still serve as a target value. Figure 9-20 and Figure 9-21 show the total delay and total number of stops for Case 1, by comparing the Traffic Responsive (TRP) procedure just examined, to the first Time-of-Day (TOD) scenario. Notice from Figure 9-20 that the two scenarios are nearly identical, except for the period between 2:00pm and 4:00pm, where TRP did much better than TOD. This is where it was realized that the original TOD schedule had changed to the afternoon pattern an hour too late, and thus TRP was very helpful for this case. This is evident in Table 9-21 (Case 1), where the total delay was reduced from 66,053 Veh-Min to 59,995 Veh-Min.

Looking at Figure 9-21, it can be seen that the total number of stops for both the TOD and TRP procedures are nearly identical for all periods, since they are both coordinated operations. The only exceptions were during the hours of 2:00pm to 4:00pm where the time-based (TOD) schedule changed late, as previously mentioned. Lastly, Figure 9-22 shows the cumulative delay time comparison, which are essentially the same until the 2:00pm to 4:00pm period, at which time they diverge by 6,058 Veh-Min. Notice that TRP did better for this case, as evident in Table 9-21 (Case 1). Had the time-based schedule been set to activate the afternoon plan at 2:00pm instead of 3:00pm, the time-based (TOD) procedure would have done better, as shown in Figure 9-23. Note that

this particular set of runs (5) for the TOD schedule (Case 1A) did better in the 7:00am to 9:00am interval, than the previous set of runs (TOD) with the same volume scenarios (Case 1). This illustrates the uncertainty that oversaturated conditions cause, in terms of travel time and delay. Had error bars been shown, they would have been very apparent during this period.

Figure 9-24 and Figure 9-25 also use this updated time-based (TOD) schedule to illustrate the total delay time and total number of stops, respectively. From these figures, it can be determined that both procedures are very close in terms of both total delay and the total number of stops. However, there were minor differences during the congested periods of 7:00am to 9:00am, which favored the timed-based (TOD) operation in both instances. The relative total delay values can be found under Case 1A, in Table 9-21. For this particular case, the time-based (TOD) operation had a value of 57,741 Veh-Min compared to 66,053 Veh-Min with the afternoon plan that changed an hour later. Hence, this programming change made a significant improvement for the time-based (TOD) procedure and was, therefore, applied to the remaining scenarios.

The Case 2 travel time results (per period) can be found for the Northbound and Southbound directions in Figure 9-26 and Figure 9-27, respectively. Notice how there appears to be no problem in the Northbound direction, as there was for Case 1. This is because the heavy Northbound volumes for the 7:00am to 9:00am period were shifted according to Table 9-2. Conversely from the Southbound direction in Figure 9-27, it can be determined that there was a significant problem, particularly during the 8:00am to 9:00am period. This was the situation shown in Chapter 3, where the wrong plan was running, due to low volumes in the Northbound direction during that period. Southbound volumes were unchanged, so the heavy left-turns at the JCT I-465 (North Ramp) did not have enough time to clear because of inadequate split time

for this movement with the midday plan. They then spilled out of the turning bay and hindered the Southbound through movement.

Since the system detectors for this direction were located after this junction, there was no way for this queuing to be detected, so the best pattern for this scenario was never selected. This is because there were not enough vehicles that could clear the intersection (left-turn spillback) and activate the system detectors in order to justify the morning operation (Pattern 211), which had adequate time to clear the turning vehicles at this location. Hence, it may have been desirable to either place a system detector at the end of the this left-turn lane, to detect such an occurrence, or add some additional system detectors on the thru lanes of the congested link (102,5). Figure 9-28 shows similar results in regards to total delay, particularly during the 7:00am to 9:00am period. The 2:00pm to 3:00pm period also appeared to have problems with delay (TRP). This was attributed to the pattern fluctuations previously discussed, which occurred between 1:45pm and 2:30pm, according to Table 9-19 (Case 2).

The total number of stops shown in Figure 9-29 essentially remained unchanged for all the periods in Case 2. Notice that Figure 9-30 shows the cumulative delay time (Case 2), where the TOD procedure ended up doing significantly better from the very beginning. Looking at Table 9-21, it can be seen that the final delay values were 46,631 Veh-Min and 56,701 Veh-Min for the TOD and TRP procedures, respectively. This is a difference of 10,070 Veh-Min, as evident in Figure 9-30. Such a deviation shows that Traffic Responsive (TRP) procedures can be harmful to the overall performance of the system, if atypical scenarios such as this are not considered. This situation could have also resulted if the parameters in Table 9-15 were poorly configured for the system. In this particular case, better placement of the Southbound system detectors would have most likely prevented this situation from occurring.

Unlike the previous scenario, Case 3 shows a situation where Traffic Responsive (TRP) performed only slightly worse than the traditional time-based (TOD) procedure, as evident in Table 9-21. Recall that the TRP settings remained constant for all the scenarios examined as part of this study, hence it is only the new volume scenario, shown in Table 9-3, that changed from the previous case. Figure 9-31 and Figure 9-32 show the corresponding travel time graphs (Case 3), on a per period basis, for both the Northbound and Southbound directions, respectively. When examining these figures, it can be that they closely resemble Case 1 in that there are saturated conditions (Nodes 4 and 5) in the Northbound direction between the hours of 7:00am to 9:00pm. This is evident in Figure 9-31, however realize that the travel times are not as extreme for this case, which is likely attributed to the lower demand on the Westbound approach of Node 3, during the 7:00am to 8:00am interval, and the unpredictably of travel time that is typically associated with saturated conditions.

Likewise, notice that the total delay time was greatest during the 7:00am to 8:00am interval, for both the TRP and TOD operations, as seen in Figure 9-33. This closely resembles the results found in Case 1 for this period, but not as extreme, for reasons previously discussed. The remainder of the periods are similar to that of Case 1, except after 2:00pm, since the afternoon peak at the JCT I-465 (South Ramp) began earlier than expected, as apparent in Table 9-3. Also notice that the lunch hour between 12:00pm and 1:00pm had a greater total delay for both procedures (TOD and TRP) during the midday period, which spanned from 9:00am to 2:00pm. This is a common amongst all of the cases, because of the heavier volumes. Figure 9-34 shows the corresponding total number of stops for each of the periods (Case 3). Notice how both operating procedures yielded similar results for all periods, with TRP slightly lagging that of the time-based (TOD) operation.

This brief lagging interval with the Traffic Responsive (TRP) procedure is apparent in other scenarios as well. Such an occurrence is typically related to the additional transitioning that occurs with the Traffic Responsive (TRP) procedure, as evident by the coordination ratios (% In-Sync) shown in Table 9-20. Generally, the more transitioning that occurs, the greater the number of stops, since the coordinated green intervals are not beginning at their programmed times when the platoons are expected to arrive. Such an occurrence typically impacts the travel time and delay, in much the same manner. Notice that the cumulative delay time, shown in Figure 9-35, also yields similar results, even though both procedures transitioned at the same time (Case 3), as evident in Table 9-19. The values, shown in Table 9-21, are 50,751 Veh-Min and 51,365 Veh-Min for both the TOD and TRP procedures, respectively.

Figure 9-36 and Figure 9-37 show the cumulative travel time graphs for Case 4 on a per period basis for each of the directions. Looking at these figures, it can be seen that there was a slight congestion problem in the Northbound direction between Nodes 4 and 5, as evident in Figure 9-36. However, they were not nearly as significant as Case 1, as there was an accident in the Southbound direction, which greatly reduced the amount of time that the Southbound left-turn remained active at the JCT I-465 (North Ramp). Recall that Table 9-4 shows the volume scenarios for this case, which have the reduced volumes during the critical interval (7:00am to 8:00am). Since the Southbound left-turn was not active as much, the Northbound green was permitted to stay active longer. This helped reduce the total amount of delay encountered during the period, which occurs on a regular basis. Figure 9-37 shows the Northbound travel times, which were reasonable for all periods.

Notice that the total delay time and total number of stops shown in Figure 9-38 and Figure 9-39, where virtually similar for all periods, with the exception of the last one. Unfortunately, there is no good explanation for this, other than

possible pattern fluctuations during this period for the other runs (4) that were not illustrated graphically. Note that Figure 9-40 shows the cumulative travel time graph for Case 4. As seen from this figure, the delay values are nearly identical for all periods. When looking at Table 9-21, it can be determined that this appears to be correct, since there was only a difference of 935 Veh-Min between the TOD and TRP operations. Time-of-Day (TOD) did slightly better with a value of 55,014 Veh-Min, as evident in Figure 9-40. Likewise the TRP procedure has a value of 55,949 Veh-Min.

The volume scenarios for the last case can be seen in Table 9-5. Notice that there were not any changes made during the peak periods. Also realize that all changes were made to the Westbound direction of High School Road (Node 3). Hence, the volumes are fluctuating from the base case on the side street, like in Case 3, and not the arterial. Given this information and looking at Figure 9-41 and Figure 9-42, it can be determined that these figures are almost exactly like Case 1, which had severe congestion in the Northbound direction between 7:00am and 9:00am. Conversely, the Southbound travel times appeared to be reasonable for all periods, as evident in Figure 9-42. The total delay and travel times shown in Figure 9-43 and Figure 9-44 also appear to be similar to Case 1, however there was less deviation occurring during the oversaturated interval, which ranges from 7:00am to 9:00am. Hence, nearly all the periods were identical, as can be seen from the figures.

Finally, the total cumulative delay for Case 5 can be seen in Figure 9-45. Notice how both procedures are nearly identical, with the Traffic Responsive (TRP) procedure doing slightly better. This makes sense considering that the information is basically a summation of the period delay time that is found in Figure 9-43, which was also about the same. Looking at Table 9-21, this can be verified, since the difference between the two procedures (TOD vs TRP) was only 483 Veh-Min. Hence, the TOD delay was 59,914 Veh-Min, while the TRP

delay was 59,431 Veh-Min. Realize that even though the arterial volumes were the same as Case 1, there were still slight differences in the outcome of the results, particularly during oversaturated conditions where the minor differences become more apparent. Much of these differences had to do with where the actual control equipment was in its coordination cycle when each of the five simulation runs (per case) were started.

Summary of Results

This concludes the analysis of the traffic responsive procedures for the five cases analyzed in this chapter. Based on the examples and scenarios illustrated here, it should be apparent that Traffic Responsive (TRP) operation performs best when the volume scenarios closely resemble that of the known traffic patterns. When looking at the total vehicular delay in Table 9-21, it should be apparent that the Traffic Responsive (TRP) procedures slightly lagged the traditional time-based (TOD) procedures for nearly all the scenarios, except for Case 2. Recall that this was the situation where the wrong pattern was selected due to left-turn spillback that prevented the Southbound through movement from activating the system detectors. Unfortunately, much of the blame for this occurrence is directed toward the individual that designed the system (poor placement of system detectors), and not necessarily the actual control equipment, as such situations should have been considered in the initial stages of the design process well before implementation.

Given the occurrence in Case 2 and looking at the remainder of the delay values in Table 9-21, it can be determined that it is not necessarily the additional transitioning that hurts the overall performance of the Traffic Responsive (TRP) procedure, but rather the wrong plan being selected for the wrong scenario. Hence, the engineer or governing agency must decide whether the configuration of the such parameters are worth the effort. When looking at the total vehicular delay in Table 9-21, it is apparent that TRP slightly lags that of the traditional

time-based (TOD) procedure, for most cases. This is typically associated with the additional time that is required for the Traffic Responsive (TRP) procedure to respond to the traffic conditions. Hence, one must establish whether the sacrifice of 935 Veh-Min in Case 4 is worth the savings of 6,058 Veh-Min that TRP provides in Case 1, noting that TRP will sometimes perform better, as in Case 5.

Had the volumes been allowed to fluctuate more substantially and warrant the operation of the event patterns (411 or 412), then it is expected that the time savings (Veh-Min) for the TRP procedure would have been even more significant. This is because a good Traffic Responsive (TRP) configuration has the potential of doing comparable or even substantially better than the traditional time-based approach, as evident in Table 9-21. Using this information and referring to Appendix C, one will notice that a more complex arterial network has been included for a 15 intersection (crossing-arterial) system in Lafayette, IN. This network has already been configured and sample cycle analysis data have been made available for two different volume scenarios (typical and event). Hence, it is suggested that the reader use the knowledge gained from this research and critique the configuration shown in Appendix C, recognizing that the modification of certain settings can help obtain a more efficient operation.

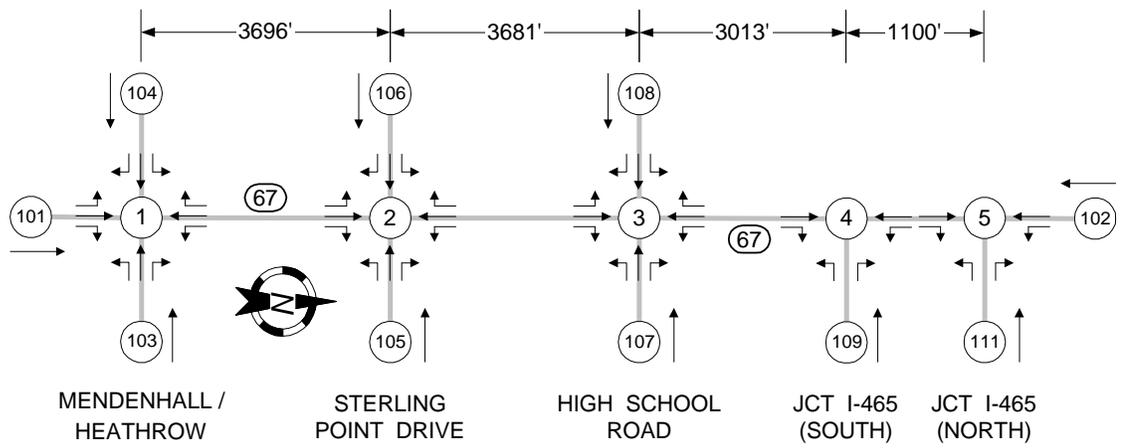
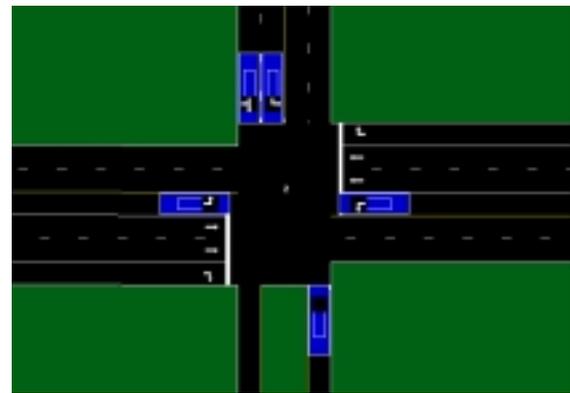


Figure 9-1: SR 67 (Kentucky) Network – Mendenhall to JCT I-465 (Ramps)



a) Node 1: SR 67 & Heathrow / Mendenhall



b) Node 2: SR 67 & Sterling Point Drive



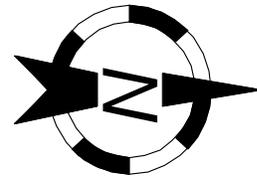
c) Node 3: SR 67 & High School Road

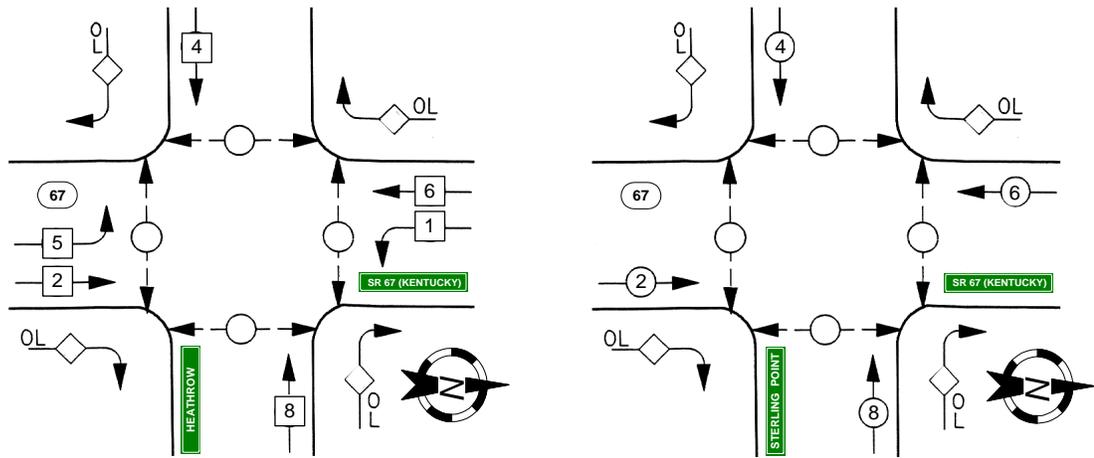


d) Node 4: SR 67 & JCT I-465 (South)



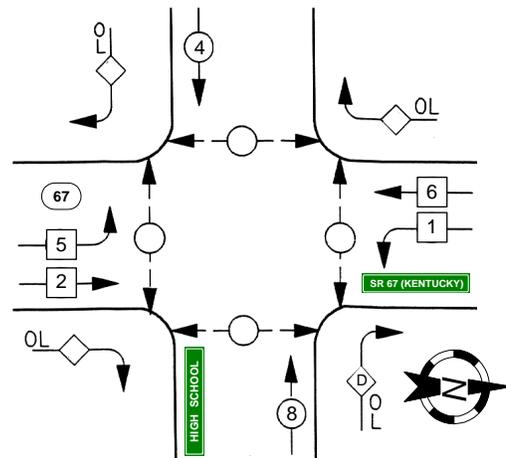
e) Node 5: SR 67 & JCT I-465 (North)

**Figure 9-2: SR 67 (Kentucky) Intersection Geometrics & Detector Locations**

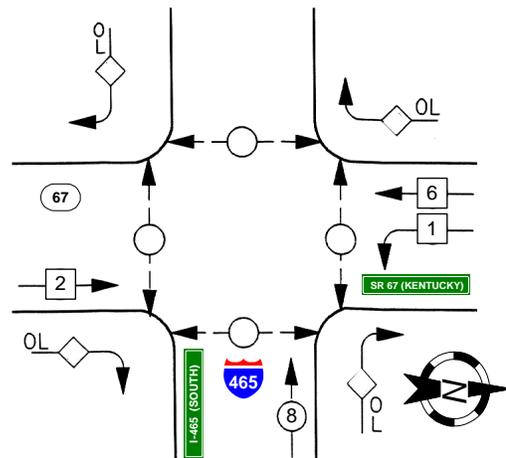


a) Node 1: SR 67 & Heathrow / Mendenhall

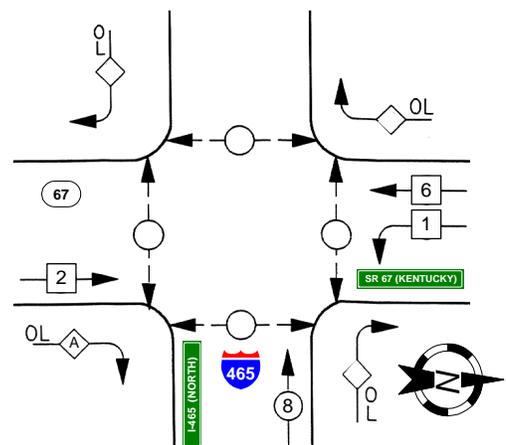
b) Node 2: SR 67 & Sterling Point Drive



c) Node 3: SR 67 & High School Road



d) Node 4: SR 67 & JCT I-465 (South)



e) Node 5: SR 67 & JCT I-465 (North)

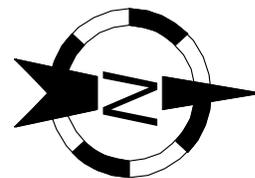
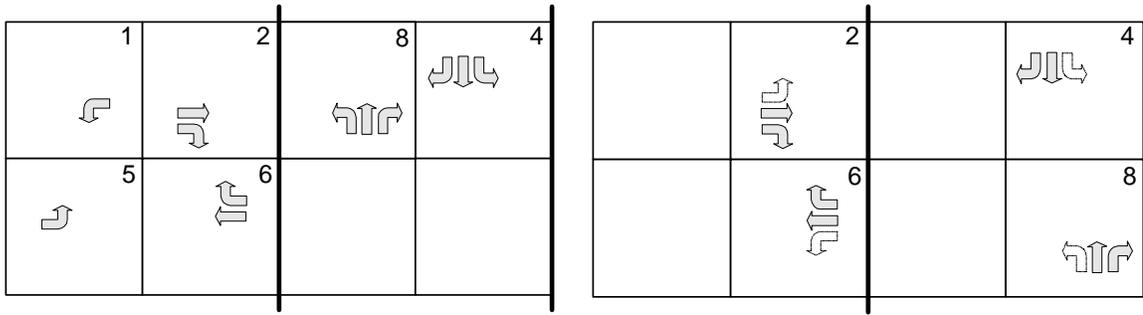
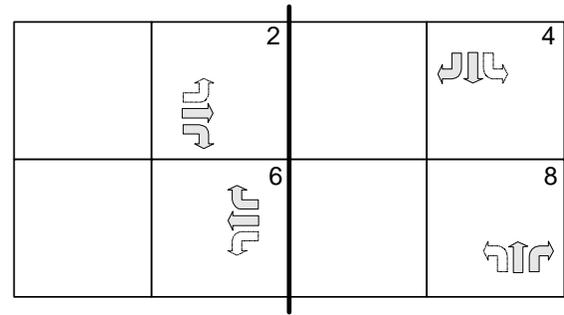


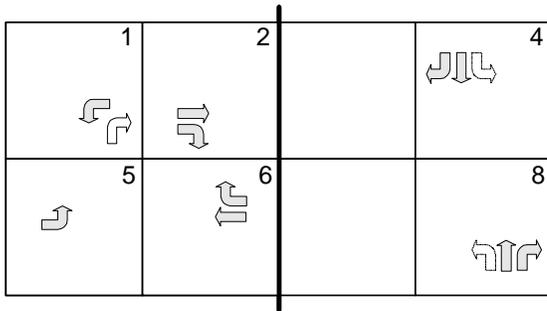
Figure 9-3: Intersection Phasing Diagrams (SR 67 – Kentucky)



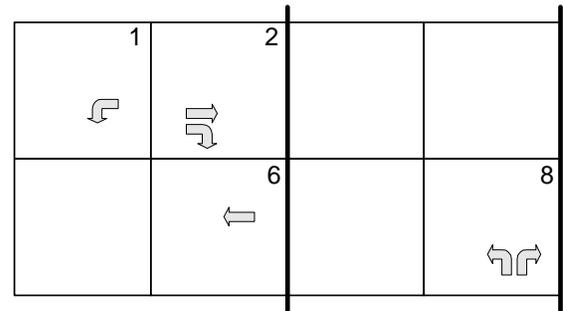
a) Node 1: SR 67 & Heathrow / Mendenhall



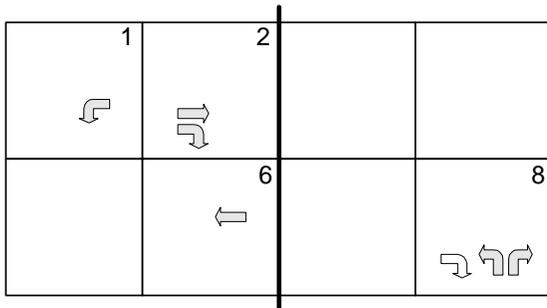
b) Node 2: SR 67 & Sterling Point Drive



c) Node 3: SR 67 & High School Road



d) Node 4: SR 67 & JCT I-465 (South)



e) Node 5: SR 67 & JCT I-465 (North)

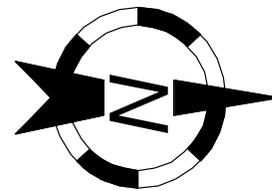


Figure 9-4: SR 67 (Kentucky) System Ring Structures

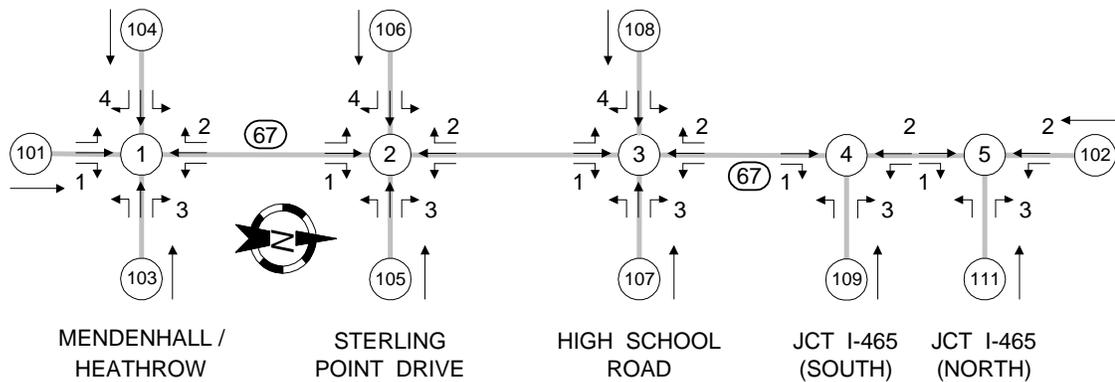


Figure 9-5: Intersection Approach Labels (Reference Figure 9-6)

COM [PortID]	2, 2, T, 6, Prot
1	2, 2, R, 6, Prot
CIDdef [CID, Base ID]	2, 3, L, 3, PP
1, 1	2, 3, T, 8, Prot
2, 3	2, 3, R, 8, Prot
3, 5	2, 4, L, 7, PP
4, 7	2, 4, T, 4, Prot
5, 9	2, 4, R, 4, Prot
NodeAssign[Node, CID]	3, 1, L, 5, Prot
1, 1	3, 1, T, 2, Prot
2, 2	3, 1, R, 2, Prot
3, 3	3, 2, L, 1, Prot
4, 4	3, 2, T, 6, Prot
5, 5	3, 2, R, 6, Prot
Phases [Node, Approach, L/T/R,	3, 3, L, 3, PP
Phase#, Pro/Per/PP]	3, 3, T, 8, Prot
1, 1, L, 5, Prot	3, 3, R, 12, Prot
1, 1, T, 2, Prot	3, 4, L, 7, PP
1, 1, R, 2, Prot	3, 4, T, 4, Prot
1, 2, L, 1, Prot	3, 4, R, 4, Prot
1, 2, T, 6, Prot	4, 1, T, 2, Prot
1, 2, R, 6, Prot	4, 1, R, 2, Prot
1, 3, L, 8, Prot	4, 2, L, 1, Prot
1, 3, T, 8, Prot	4, 2, T, 6, Prot
1, 3, R, 8, Prot	4, 3, L, 8, Prot
1, 4, L, 4, Prot	4, 3, R, 8, Prot
1, 4, T, 4, Prot	5, 1, T, 2, Prot
1, 4, R, 4, Prot	5, 1, R, 9, Prot
2, 1, L, 5, PP	5, 2, L, 1, Prot
2, 1, T, 2, Prot	5, 2, T, 6, Prot
2, 1, R, 2, Prot	5, 3, L, 8, Prot
2, 2, L, 1, PP	5, 3, R, 8, Prot

Figure 9-6: External Control File (CID) for Phasing (SR 67 – Kentucky)



a) Node 1: SR 67 & Heathrow / Mendenhall (CID_1)



b) Node 2: SR 67 & Sterling Point Drive (CID_2)



c) Node 3: SR 67 & High School Road (CID_3)



d) Node 4: SR 67 & JCT I-465 (South) (CID_4) – [SYS 17 / 19 – SOUTH APPROACH]



e) Node 4: SR 67 & JCT I-465 (North) (CID_5) – [SYS 17 / 19 – SOUTH APPROACH]

Figure 9-7: Intersection Detector Locations and Numbering

101	1	8	3000	102	60				42		
101	1	7		105	360				42		
	1	2	8	3000	202	60			42		
	1	2	7		205	360			42		
	2	1	8	3000	106	60			42		
	2	1	7		101	360			42		
	2	1	2	35460	213	60	1	[SYSTEM DETECTOR]	42		
	2	1	1	35460	215	60	1	[SYSTEM DETECTOR]	42		
	2	3	7		305	360			42		
	2	3	2	35310	209	60	1	[SYSTEM DETECTOR]	42		
	2	3	1	35310	211	60	1	[SYSTEM DETECTOR]	42		
	2	3	8	3000	302	60			42		
	3	2	8	3000	206	60			42		
	3	2	7		201	360			42		
	3	4	8	3000	402	60			42		
	3	4	3	28630	309	60		[SYSTEM DETECTOR]	42		
	3	4	2	28630	311	60		[SYSTEM DETECTOR]	42		
	3	4	1	28630	313	60		[SYSTEM DETECTOR]	42		
	4	3	8	3000	306	60			42		
	4	3	7		301	360			42		
	4	3	2	28630	413	60		[SYSTEM DETECTOR]	42		
	4	3	1	28630	415	60		[SYSTEM DETECTOR]	42		
	4	5	8	3000	502	60			42		
	5	4	3		401	360			42		
	5	4	2	3000	406	60			42		
	5	4	1	3000	414	60			42		
102	5	8	3000	506	60				42		
102	5	7		501	360				42		
103	1	1		108	360				42		
104	1	9		104	360				42		
105	2	1		208	360				42		
106	2	9		204	360				42		
107	3	1		308	360				42		
107	3	7		316	360				42		
108	3	1		304	360				42		
109	4	7		404	360				42		
109	4	2		408	360				42		
109	4	1		416	360				42		
109	4	2	8500	417	60			[SYSTEM DETECTOR]	42		
109	4	1	8500	419	60			[SYSTEM DETECTOR]	42		
111	5	7		504	360				42		
111	5	2		508	360				42		
111	5	1		516	360				42		
111	5	2	8500	517	60			[SYSTEM DETECTOR]	42		
111	5	1	8500	519	60			[SYSTEM DETECTOR]	42		
	1	101	1	2	1	103	1	104	1	2	43
		2	1	2	3	2	105	2	106	2	43
		3	2	3	4	3	107	3	108	3	43
		4	3	4	5	4	109	4		2	43
		5	4	5	102	5	111	5		2	43

Figure 9-8: Sample External Detector File (SR 67 – Kentucky)

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
1	NB	1321	1862	899	879	859	839	809	799	774	679	713	680
1	EB	13	31	32	46	71	91	102	89	123	186	175	153
1	WB	36	32	23	19	27	12	18	27	24	21	13	31
2	EB	13	29	18	16	14	13	12	8	6	5	10	4
2	WB	7	72	35	35	35	35	35	35	48	125	96	88
3	EB	178	209	149	133	120	145	205	150	197	248	271	298
3	WB	444	614	421	296	220	282	296	239	268	376	409	362
4	WB	302	522	570	469	515	545	596	625	1061	1021	1439	1340
5	WB	180	425	225	222	200	187	243	214	296	296	343	329
5	SB	293	790	315	412	356	477	558	537	624	1077	1111	1102

Table 9-1: Entry Volumes per Period (VPH) – Case_1

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
1	NB	899	879	1321	1862	859	839	809	799	774	679	713	680
1	EB	13	31	32	46	71	91	102	89	123	186	175	153
1	WB	36	32	23	19	27	12	18	27	24	21	13	31
2	EB	13	29	18	16	14	13	12	8	6	5	10	4
2	WB	7	72	35	35	35	35	35	35	48	125	96	88
3	EB	178	209	149	133	120	145	205	150	197	248	271	298
3	WB	444	614	421	296	220	282	296	239	268	376	409	362
4	WB	302	522	570	469	515	545	596	625	1061	1021	1439	1340
5	WB	180	425	225	222	200	187	243	214	296	296	343	329
5	SB	293	790	315	412	356	477	558	537	1077	1111	1102	624

Table 9-2: Entry Volumes per Period (VPH) – Case_2

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
1	NB	1321	1862	899	879	859	839	809	799	774	679	713	680
1	EB	13	31	32	46	71	91	102	89	123	186	175	153
1	WB	36	32	23	19	27	12	18	27	24	21	13	31
2	EB	13	29	18	16	14	13	12	8	6	5	10	4
2	WB	7	72	35	35	35	35	35	35	48	125	96	88
3	EB	178	209	149	133	120	145	205	150	197	248	271	298
3	WB	444	421	614	296	220	282	296	239	268	376	409	362
4	WB	302	522	570	469	515	545	596	625	1439	1340	1061	1021
5	WB	180	425	225	222	200	187	243	214	296	296	343	329
5	SB	293	790	315	412	356	477	558	537	624	1077	1111	1102

Table 9-3: Entry Volumes per Period (VPH) – Case_3

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
1	NB	1321	1862	899	879	859	839	809	799	774	679	713	680
1	EB	13	31	32	46	71	91	102	89	123	186	175	153
1	WB	36	32	23	19	27	12	18	27	24	21	13	31
2	EB	13	29	18	16	14	13	12	8	6	5	10	4
2	WB	7	72	35	35	35	35	35	35	48	125	96	88
3	EB	178	209	149	133	120	145	205	150	197	248	271	298
3	WB	444	614	421	296	220	282	296	239	268	376	409	362
4	WB	302	522	570	469	515	545	596	625	1061	1021	1439	1340
5	WB	180	425	225	222	200	187	243	214	296	296	343	329
5	SB	293	90	15	212	856	977	778	537	624	1077	1111	1102

Table 9-4: Entry Volumes per Period (VPH) – Case_4

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
1	NB	1321	1862	899	879	859	839	809	799	774	679	713	680
1	EB	13	31	32	46	71	91	102	89	123	186	175	153
1	WB	36	32	23	19	27	12	18	27	24	21	13	31
2	EB	13	29	18	16	14	13	12	8	6	5	10	4
2	WB	7	72	35	35	35	35	35	35	48	125	96	88
3	EB	178	209	149	133	120	145	205	150	197	248	271	298
3	WB	444	614	421	196	120	182	396	339	368	376	409	362
4	WB	302	522	570	469	515	545	596	625	1061	1021	1439	1340
5	WB	180	425	225	222	200	187	243	214	296	296	343	329
5	SB	293	790	315	412	356	477	558	537	624	1077	1111	1102

Table 9-5: Entry Volumes per Period (VPH) – Case_5

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
HEATHROW DRIVE / MENDENHALL	NBLT	4	7	5	7	5	11	8	5	5	4	4	7
	NBTH	96	91	93	89	93	87	91	93	94	92	95	89
	NBRT	0	2	2	4	2	2	1	2	1	4	1	4
	SBLT	4	15	4	4	4	4	4	4	8	3	3	2
	SBTH	95	84	95	95	95	95	95	95	91	96	96	98
	SBRT	1	1	1	1	1	1	1	1	1	1	1	0
	EBLT	92	68	72	72	86	81	82	93	80	76	75	76
	EBTH	0	10	6	6	6	1	6	1	1	4	3	3
	EBRT	8	23	22	22	8	18	12	6	19	20	22	21
	WBLT	0	3	0	5	4	0	6	0	4	0	8	0
	WBTH	6	16	4	5	0	0	11	0	4	10	7	6
WBRT	94	81	96	89	96	100	83	100	92	90	85	94	
STERLING POINT DRIVE	NBLT	0	0	0	0	0	0	0	0	0	0	0	0
	NBTH	99	96	98	98	98	98	98	98	98	97	97	95
	NBRT	1	4	2	2	2	2	2	2	2	3	3	5
	SBLT	4	15	4	4	4	4	4	4	8	3	3	2
	SBTH	95	84	95	95	95	95	95	95	91	96	96	98
	SBRT	1	1	1	1	1	1	1	1	1	1	1	0
	EBLT	69	66	100	83	83	83	83	83	83	100	50	50
	EBTH	0	28	0	0	0	0	0	0	0	0	40	25
	EBRT	31	6	0	17	17	17	17	17	17	0	10	25
	WBLT	29	24	43	43	43	43	43	43	25	38	39	50
	WBTH	0	3	0	0	0	0	0	0	0	4	2	2
WBRT	71	74	57	57	57	57	57	57	75	58	59	48	
HIGH SCHOOL ROAD	NBLT	4	7	5	7	5	11	8	5	5	4	4	7
	NBTH	96	91	93	89	93	87	91	93	94	92	95	89
	NBRT	0	2	2	4	2	2	1	2	1	4	1	4
	SBLT	19	32	25	21	22	22	22	21	25	20	24	24
	SBTH	77	65	72	72	73	75	71	75	71	77	72	72
	SBRT	4	3	3	7	5	3	7	4	4	3	4	4
	EBLT	64	46	57	58	51	46	54	47	48	42	32	35
	EBTH	28	38	28	31	38	32	32	36	30	40	37	45
	EBRT	8	16	15	11	11	22	14	17	22	18	31	20
	WBLT	5	9	9	13	14	17	16	17	16	14	20	19
	WBTH	21	18	21	21	15	23	27	19	18	21	15	20
WBRT	74	73	70	66	71	60	57	64	66	65	65	61	
JCT I-465 (SOUTH)	NBTH	90	91	90	85	87	86	88	87	85	80	82	86
	NBRT	10	9	10	15	13	14	12	13	15	20	18	14
	SBLT	14	11	12	12	21	16	17	14	13	13	15	17
	SBTH	86	89	88	88	79	84	83	86	87	87	85	83
	WBLT	76	83	74	83	77	81	83	83	78	85	84	83
	WBRT	24	17	26	17	23	19	17	17	22	15	16	17
JCT I-465 (NORTH)	NBTH	34	33	32	37	41	46	55	50	49	45	44	46
	NBRT	66	67	68	63	59	54	45	50	51	55	56	54
	SBLT	46	38	33	33	18	21	24	27	28	16	24	18
	SBTH	54	62	67	67	82	79	76	73	72	84	76	82
	WBLT	72	52	72	61	87	74	75	70	78	89	88	86
	WBRT	28	48	28	39	13	26	25	30	22	11	12	14

Table 9-6: Turning Movements per Period (Percentages)

SR 67 (KENTUCKY)		POCKET LENGTHS (FT)		STOP BAR DETECTOR LENGTHS (FT)			RACEWAY DETECTORS (FT)	
INT	MOVE	LEFT	RIGHT	LEFT	THRU	RIGHT	THRU	DIST
1	NB	300	300	36	--	--	6	300
1	SB	300	300	36	--	--	6	300
1	EB	--	--	--	36	--	--	--
1	WB	--	--	--	36	--	--	--
2	NB	280	397	36	--	--	6	300
2	SB	580	350	36	--	--	6	300
2	EB	--	--	--	36	--	--	--
2	WB	--	--	--	36	--	--	--
3	NB	365	365	36	--	--	6	300
3	SB	715	415	36	--	--	6	300
3	EB	--	--	--	36	--	--	--
3	WB	--	275	--	36	36	--	--
4	NB	--	PREV	--	--	--	6	300
4	SB	PREV	--	36	--	--	6	300
4	WB	--	--	36	--	36	--	--
5	NB	--	380	--	--	--	6	300
5	SB	465	--	36	36	--	6	300
5	WB	--	--	36	--	36	--	--

NOTE: "PREV" DENOTES THAT THE TURNING BAY BEGINS AT THE PREVIOUS INTERSECTION.

Table 9-7: Intersection Pocket Lengths and Detector Locations

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
1	NBLT	5	105	PRS
1	NBTH	2	102	PRS
1	SBLT	1	101	PRS
1	SBTH	6	106	PRS
1	EBTH	4	104	PRS
1	WBTH	8	108	PRS

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
2	NBLT	5	205	PRS
2	NBTH	2	202	PRS
2	SBLT	1	201	PRS
2	SBTH	6	206	PRS
2	EBTH	4	204	PRS
2	WBTH	8	208	PRS

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
3	NBLT	5	305	PRS
3	NBTH	2	302	PRS
3	SBLT	1	301	PRS
3	SBTH	6	306	PRS
3	EBTH	4	304	PRS
3	WBTH	8	308	PRS
3	WBRT	16	316	PRS

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
4	NBTH	2	402	PRS
4	SBLT	1	401	PRS
4	SBTH	6	406	PRS
4	SBTH	14	414	PRS
4	WBLT	4	404	PRS
4	WBLT	8	408	PRS
4	WBRT	16	416	PRS

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
5	NBTH	2	502	PRS
5	SBLT	1	501	PRS
5	SBTH	6	506	PRS
5	WBLT	4	504	PRS
5	WBLT	8	508	PRS
5	WBRT	16	516	PRS

Table 9-8: Intersection Detector Configuration (CID Logic Only)

INT	MOVE- MENT	DET NUM	LOCK / N-LCK	DELAY (SEC)	CALL PHASE	DETECTOR TYPE
1	NBLT	5	N-LCK	--	5	STANDARD (NORMAL)
1	NBTH	2	LOCK	--	2	STANDARD (NORMAL)
1	SBLT	1	N-LCK	--	1	STANDARD (NORMAL)
1	SBTH	6	LOCK	--	6	STANDARD (NORMAL)
1	EBTH	4	N-LCK	10	4	EXTEND / DELAY (T-1)
1	WBTH	8	N-LCK	10	8	EXTEND / DELAY (T-1)
2	NBLT	5	N-LCK	--	2	STOP BAR (CALLING)
2	NBTH	2	LOCK	--	2	STANDARD (NORMAL)
2	SBLT	1	N-LCK	--	6	STOP BAR (CALLING)
2	SBTH	6	LOCK	--	6	STANDARD (NORMAL)
2	EBTH	4	N-LCK	10	4	EXTEND / DELAY (T-1)
2	WBTH	8	N-LCK	10	8	EXTEND / DELAY (T-1)
3	NBLT	5	N-LCK	--	5	STANDARD (NORMAL)
3	NBTH	2	LOCK	--	2	STANDARD (NORMAL)
3	SBLT	1	N-LCK	--	1	STANDARD (NORMAL)
3	SBTH	6	LOCK	--	6	STANDARD (NORMAL)
3	EBTH	4	N-LCK	10	4	EXTEND / DELAY (T-1)
3	WBTH	8	N-LCK	--	8	STANDARD (NORMAL)
3	WBRT	16	N-LCK	20	8	EXTEND / DELAY (T-1)
4	NBTH	2	LOCK	--	2	STANDARD (NORMAL)
4	SBLT	1	N-LCK	--	1	STANDARD (NORMAL)
4	SBTH	6	LOCK	--	6	STANDARD (NORMAL)
4	SBTH	14	LOCK	--	6	STANDARD (NORMAL)
4	WBLT	4	N-LCK	--	8	STANDARD (NORMAL)
4	WBLT	8	N-LCK	--	8	STANDARD (NORMAL)
4	WBRT	16	N-LCK	20	8	EXTEND / DELAY (T-1)
5	NBTH	2	LOCK	--	2	STANDARD (NORMAL)
5	SBLT	1	N-LCK	--	1	STANDARD (NORMAL)
5	SBTH	6	LOCK	--	6	STANDARD (NORMAL)
5	WBLT	4	N-LCK	--	8	STANDARD (NORMAL)
5	WBLT	8	N-LCK	--	8	STANDARD (NORMAL)
5	WBRT	16	N-LCK	20	8	EXTEND / DELAY (T-1)

NOTE: RACEWAY DETECTORS MUST BE IN LOCK MODE IF THEY ARE NOT IN VEHICLE RECALL.

Table 9-9: Intersection Detector Configuration (Controller)

INT	MOVE- MENT	DETECTORS		DET NUM	STAT ID	LOC TLM	TLM ADD	SYS NUM	PUL PRS
		THRU	DIST						
2	SBTH	6	3546	13	213	2	SDA1	1	PUL
2	SBTH	6	3546	15	215	2	SDA2	2	PUL
2	NBTH	6	3531	9	209	2	SDB1	3	PUL
2	NBTH	6	3531	11	211	2	SDB2	4	PUL
3	NBTH	6	2863	9	309	3	SDA1	5	PRS
3	NBTH	6	2863	11	311	3	SDA2	6	PRS
3	NBTH	6	2863	13	313	3	SDB1	7	PRS
4	SBTH	6	2863	13	413	4	SDA1	8	PRS
4	SBTH	6	2863	15	415	4	SDA2	9	PRS
4	WBTH	6	-850	17	417	4	SDB1	10	PRS
4	WBTH	6	-850	19	419	4	SDB2	11	PRS
5	WBTH	6	-850	17	517	5	SDA1	12	PRS
5	WBTH	6	-850	19	519	5	SDA2	13	PRS

NOTE: A "*" REPRESENTS THAT AN ALTERNATE ADDRESS WAS USED DUE TO HARDWARE.

NOTE: ALL DISTANCES WITHOUT A "-" ARE MEASURED FROM THE UPSTREAM INTERSECTION.

Table 9-10: System Detector Configuration (CID Logic Only)

INT	DESCRIPTION (SEC)	1	2	3	4	5	6	7	8
1	MINIMUM GREEN	3	15	--	3	3	15	--	3
1	VEHICLE EXTENSION	2.5	5.0	--	3.0	2.5	5.0	--	3.0
1	MAXIMUM GREEN	35	80	--	35	35	80	--	35
1	YELLOW CLEARANCE	3.5	3.5	--	3.5	3.5	3.5	--	3.5
1	RED CLEARANCE	1.0	2.0	--	1.5	1.0	2.0	--	1.5
1	MINIMUM GAP TIME	2.5	3.0	--	3.0	2.5	3.0	--	3.0
2	MINIMUM GREEN	--	15	--	7	--	15	--	7
2	VEHICLE EXTENSION	--	5.0	--	3.0	--	5.0	--	3.0
2	MAXIMUM GREEN	--	80	--	35	--	80	--	35
2	YELLOW CLEARANCE	--	3.5	--	3.5	--	3.5	--	3.5
2	RED CLEARANCE	--	2.0	--	1.5	--	2.0	--	1.5
2	MINIMUM GAP TIME	--	3.0	--	3.0	--	3.0	--	3.0
3	MINIMUM GREEN	3	15	--	7	3	15	--	7
3	VEHICLE EXTENSION	2.5	5.0	--	3.0	2.5	5.0	--	3.0
3	MAXIMUM GREEN	35	80	--	45	35	80	--	45
3	YELLOW CLEARANCE	3.5	3.5	--	3.5	3.5	3.5	--	3.5
3	RED CLEARANCE	1.0	2.0	--	1.5	1.0	2.0	--	1.5
3	MINIMUM GAP TIME	2.5	3.0	--	3.0	2.5	3.0	--	3.0
4	MINIMUM GREEN	3	15	--	--	--	15	--	7
4	VEHICLE EXTENSION	2.5	5.0	--	--	--	5.0	--	3.0
4	MAXIMUM GREEN	35	80	--	--	--	80	--	45
4	YELLOW CLEARANCE	3.5	3.5	--	--	--	3.5	--	3.5
4	RED CLEARANCE	1.0	2.0	--	--	--	2.0	--	1.5
4	MINIMUM GAP TIME	2.5	3.0	--	--	--	3.0	--	3.0
5	MINIMUM GREEN	3	15	--	--	--	15	--	7
5	VEHICLE EXTENSION	2.5	5.0	--	--	--	5.0	--	3.0
5	MAXIMUM GREEN	35	80	--	--	--	80	--	45
5	YELLOW CLEARANCE	3.5	3.5	--	--	--	3.5	--	3.5
5	RED CLEARANCE	1.0	2.0	--	--	--	2.0	--	1.5
5	MINIMUM GAP TIME	2.5	3.0	--	--	--	3.0	--	3.0

NOTE: THE MAXIMUM GREEN TIMES SHOWN IN THIS TABLE ARE INHIBITED UNDER COORDINATION.

Table 9-11: General Phase Parameters (SR 67 – Kentucky)

INT	COS	CYC	OFF	1	2	3	4	5	6	7	8	LAG
1	111	100	0	12	64	--	12	12	64	--	12	--
1	211	140	0	12	104	--	12	12	104	--	12	--
1	311	140	0	12	101	--	15	12	101	--	12	--
1	411	150	0	12	114	--	12	19	107	--	12	--
1	412	150	0	13	109	--	16	13	109	--	12	--
2	111	100	30	--	88	--	12	--	88	--	12	--
2	211	140	34	--	128	--	12	--	128	--	12	--
2	311	140	120	--	128	--	12	--	128	--	12	--
2	411	150	36	--	128	--	22	--	128	--	22	--
2	412	150	87	--	138	--	12	--	138	--	12	--
3	111	100	92	18	64	--	18	12	70	--	18	--
3	211	140	71	27	65	--	48	15	80	--	48	5
3	311	140	57	45	63	--	32	12	96	--	32	1
3	411	150	68	23	100	--	27	23	100	--	27	5
3	412	150	26	50	68	--	32	12	106	--	32	1
4	111	100	26	12	65	--	--	--	77	--	23	1
4	211	140	18	12	102	--	--	--	114	--	26	1
4	311	140	81	21	52	--	--	--	73	--	67	--
4	411	150	132	12	88	--	--	--	100	--	50	--
4	412	150	75	22	43	--	--	--	63	--	85	1
5	111	100	44	13	75	--	--	--	88	--	12	--
5	211	140	119	25	97	--	--	--	122	--	18	--
5	311	140	83	28	92	--	--	--	120	--	20	--
5	411	150	134	13	93	--	--	--	106	--	44	--
5	412	150	60	30	85	--	--	--	115	--	35	--

NOTE: OFFSETS ARE REFERENCED FROM THE BEGINNING OF THE FIRST COORDINATED PHASE.

Table 9-12: SR 67 (Kentucky) Coordination Plans and Splits

STP	PRG	DAY	TIME	COS	SF1	SF2	SF3	SF4	TRP	OVR
1	1	M-F	0555	211	OFF	OFF	OFF	OFF	YES	NO
2	1	M-F	0900	111	OFF	OFF	OFF	OFF	YES	NO
3	1	M-F	1400	311	OFF	OFF	OFF	OFF	YES	NO
4	1	M-F	1900	111	OFF	OFF	OFF	OFF	YES	NO
5	1	M-F	2300	FREE	OFF	OFF	OFF	OFF	YES	NO
6	2	SAT	0730	111	OFF	OFF	OFF	OFF	YES	NO
7	2	SAT	2200	FREE	OFF	OFF	OFF	OFF	YES	NO
8	3	SUN	0900	111	OFF	OFF	OFF	OFF	YES	NO
9	3	SUN	2000	FREE	OFF	OFF	OFF	OFF	YES	NO

NOTE: TRP AS "YES" ENABLES THE TRAFFIC RESPONSIVE (TRP) PLAN AS "PLAN-IN-EFFECT".
NOTE: OVR AS "YES" ALLOWS TRP TO OVERRIDE TOD IF THE CYCLE COMMAND IS GREATER.

Table 9-13: Time of Day Programming Chart (SR 67 – Kentucky)

TLM ADD	CTR 1-24	SDA1 1-32	SDA2 1-32	SDB1 1-32	SDB2 1-32	SDC1 1-32	SDC2 1-32	SDD1 1-32	SDD2 1-32
1	1	0	0	0	0	0	0	0	0
2	2	1	2	3	4	0	0	0	0
3	3	5	6	7	0	0	0	0	0
4	4	8	9	10	11	0	0	0	0
5	5	12	13	0	0	0	0	0	0

NOTE: SYSTEM DETECTORS ARE WIRED TO THE NEAREST LOCAL CONTROLLER.

NOTE: THE NUMBERS ABOVE ARE THE ACTUAL MASTER SYSTEM DETECTOR NUMBERS.

Table 9-14: System Detector Mapping Table (Master Controller)

GROUP SETTINGS	1	2	3	4	5	6	7	8
ASSIGN SD TO LANE 1	1	5	8	10	7	0	0	0
ASSIGN SD TO LANE 2	2	6	9	11	0	0	0	0
ASSIGN SD TO LANE 3	3	3	1	12	0	0	0	0
ASSIGN SD TO LANE 4	4	4	2	13	0	0	0	0
DETECTORS REQUIRED	3	3	3	3	1	N/A	N/A	N/A
ASSIGN TO LEVEL	2	2	2	N/A	N/A	N/A	N/A	N/A
ASSIGN TO DIRECTION 1	N/A	AV	N/A	N/A	1	N/A	N/A	N/A
ASSIGN TO DIRECTION 2	N/A	N/A	AV	N/A	N/A	N/A	N/A	N/A
ASSIGN TO SPLIT A	AV	AV	AV	N/A	N/A	N/A	N/A	N/A
ASSIGN TO SPLIT B	N/A	N/A	N/A	AV	N/A	N/A	N/A	N/A
ASSIGN TO ARTERIAL	2	2	2	N/A	N/A	N/A	N/A	N/A
ASSIGN TO NON-ARTERIAL	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A

NOTE: SYSTEM DETECTORS ONLY FUNCTION DURING TRAFFIC RESPONSIVE (TRP) OPERATION.

Table 9-15: Traffic Responsive Programming (System Detectors)

FUNCTION COMPUTATIONS	LEV	DR1	DR2	SPA	SPB	ART	NRT
TRAFFIC PARAMETER	CON						
VALUE OF THE GROUPS	1	1	1	2	2	AV	AV
SMOOTHING FACTOR (%)	30	30	30	30	30	30	30
UPDATE THRESHOLD (%)	20	20	20	20	20	20	20

NOTE: SAMPLE PERIODS FOR THIS STUDY WAS ONCE PER CYCLE (TRAFFIC RESPONSIVE).

NOTE: CON = CONCENTRATION WHICH INCLUDES BOTH VOLUME AND OCCUPANCY FUNCTIONS.

Table 9-16: System Detector Computations (SR 67 – Kentucky)

LEVEL (0-101%)		OFFSET (0-100%)		SPLIT (0-101%)		NRT-ART (0-100%)	
2>1	12	1>AV	5	2>1	10	NRT>ART	20
1>2	22	AV>1	10	1>2	20	ART>NRT	30
3>2	35	2>AV	5	3>2	20		
2>3	50	AV>2	10	2>3	30		
4>3	70			4>3	30		
3>4	85			3>4	40		
5>4	101						
4>5	101						

NOTE: LEVEL AND SPLITS ARE OMITTED BY ENTERING A PERCENTAGE GREATER THAN 100%.

Table 9-17: System Thresholds for Plan Selection (SR 67 – Kentucky)

LEVEL	DESCRIPTION	CLR	COS	SF1	SF2	SF3	SF4
LEVEL 1	DIRECTION 1 (DR1)	NO	FREE	OFF	OFF	OFF	OFF
LEVEL 1	DIRECTION 2 (DR2)	NO	FREE	OFF	OFF	OFF	OFF
LEVEL 1	AVERAGE (AV)	NO	FREE	OFF	OFF	OFF	OFF
LEVEL 1	NRT-ART (NRT/ART)	NO	FREE	OFF	OFF	OFF	OFF
LEVEL 2	DIRECTION 1 (DR1)	NO	111	OFF	OFF	OFF	OFF
LEVEL 2	DIRECTION 2 (DR2)	NO	111	OFF	OFF	OFF	OFF
LEVEL 2	AVERAGE (AV)	NO	111	OFF	OFF	OFF	OFF
LEVEL 2	NRT-ART (NRT/ART)	NO	311	OFF	OFF	OFF	OFF
LEVEL 3	DIRECTION 1 (DR1)	NO	211	OFF	OFF	OFF	OFF
LEVEL 3	DIRECTION 2 (DR2)	NO	311	OFF	OFF	OFF	OFF
LEVEL 3	AVERAGE (AV)	NO	311	OFF	OFF	OFF	OFF
LEVEL 3	NRT-ART (NRT/ART)	NO	311	OFF	OFF	OFF	OFF
LEVEL 4	DIRECTION 1 (DR1)	NO	411	OFF	OFF	OFF	OFF
LEVEL 4	DIRECTION 2 (DR2)	NO	412	OFF	OFF	OFF	OFF
LEVEL 4	AVERAGE (AV)	NO	412	OFF	OFF	OFF	OFF
LEVEL 4	NRT-ART (NRT/ART)	NO	412	OFF	OFF	OFF	OFF
LEVEL 5	DIRECTION 1 (DR1)	YES	CLR	OFF	OFF	OFF	OFF
LEVEL 5	DIRECTION 2 (DR2)	YES	CLR	OFF	OFF	OFF	OFF
LEVEL 5	AVERAGE (AV)	YES	CLR	OFF	OFF	OFF	OFF
LEVEL 5	NRT-ART (NRT/ART)	YES	CLR	OFF	OFF	OFF	OFF

NOTE: SYSTEM DETECTORS ONLY FUNCTION DURING TRAFFIC RESPONSIVE (TRP) OPERATION.

Table 9-18: Traffic Responsive Plan Selection Chart (SR 67 – Kentucky)

TIME	TOD / TRP - 1		TOD / TRP - 2		TOD / TRP - 3		TOD / TRP - 4		TOD / TRP - 5	
6:15	211	TRAN	211	111	211	TRAN	211	211	211	211
6:30	211	211	211	111	211	211	211	TRAN	211	211
6:45	211	211	211	111	211	211	211	211	211	211
7:00	211	211	211	111	211	211	211	211	211	211
7:15	211	211	211	111	211	211	211	211	211	211
7:30	211	211	211	111	211	211	211	211	211	211
7:45	211	211	211	111	211	211	211	211	211	211
8:00	211	211	211	111	211	211	211	211	211	211
8:15	211	211	211	111	211	211	211	211	211	211
8:30	211	211	211	211	211	211	211	211	211	211
8:45	211	211	211	211	211	211	211	211	211	111
9:00	211	211	TRAN	211	211	211	211	211	211	111
9:15	111	211	111	211	111	TRAN	111	211	111	111
9:30	111	TRAN	111	211	111	111	111	211	111	111
9:45	111	111	111	211	111	111	111	TRAN	111	111
10:00	111	111	111	211	111	111	111	111	111	111
10:15	111	111	111	211	111	111	111	111	111	111
10:30	111	111	111	TRAN	111	111	111	111	111	111
10:45	111	111	111	111	111	111	111	111	111	111
11:00	111	111	111	111	111	111	111	111	111	111
11:15	111	111	111	111	111	111	111	111	111	111
11:30	111	111	111	111	111	111	111	111	111	111
11:45	111	111	111	111	111	111	111	111	111	111
12:00	111	111	111	111	111	111	111	111	111	111
12:15	111	111	111	111	111	111	111	111	111	111
12:30	111	111	111	111	111	111	111	111	111	111
12:45	111	111	111	111	111	111	111	111	111	111
13:00	111	111	111	111	111	111	111	111	111	111
13:15	111	111	111	111	111	111	111	111	111	111
13:30	111	111	111	111	111	111	111	111	111	111
13:45	111	111	111	311	111	111	111	111	111	111
14:00	111	111	111	TRAN	111	111	111	111	111	111
14:15	111	111	311	111	311	311	311	111	311	111
14:30	111	311	311	TRAN	311	311	311	311	311	311
14:45	111	311	311	311	311	311	311	311	311	311
15:00	111	311	311	311	311	311	311	311	311	311
15:15	311	311	311	311	311	311	311	311	311	311
15:30	311	311	311	311	311	311	311	311	311	311
15:45	311	311	311	311	311	311	311	311	311	311
16:00	311	311	311	311	311	311	311	311	311	311
16:15	311	311	311	311	311	311	311	311	311	311
16:30	311	311	311	311	311	311	311	311	311	311
16:45	311	311	311	311	311	311	311	311	311	311
17:00	311	311	311	311	311	311	311	311	311	311
17:15	311	311	311	311	311	311	311	311	311	311
17:30	311	TRAN	311	311	311	311	311	311	311	311
17:45	311	311	311	311	311	311	311	311	311	311
SYNC	97%	96%	98%	94%	97%	96%	98%	96%	97%	96%

Table 9-19: SR 67 (Kentucky) Pattern Select Table – Node 3 (All Scenarios)

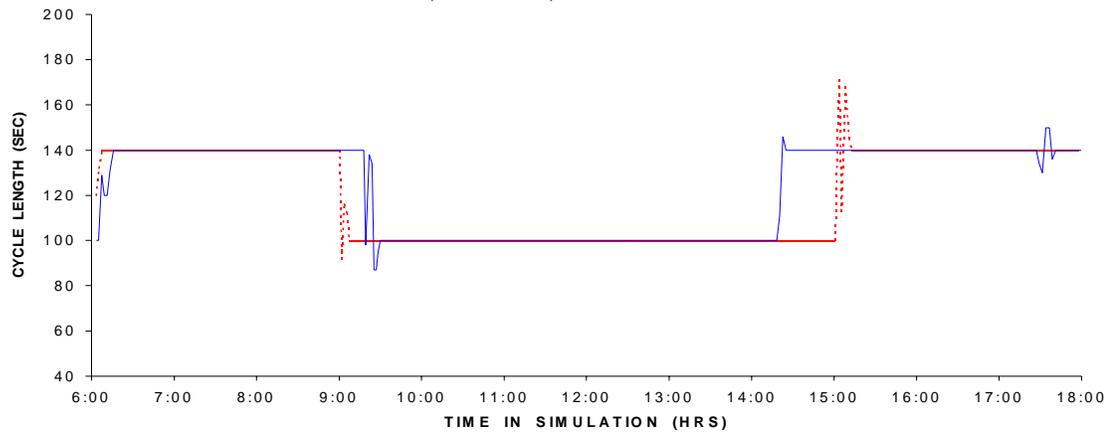
CASE	CASE_1		CASE_2		CASE_3		CASE_4		CASE_5	
NODE	TOD	TRP								
3	97	96	98	94	97	96	98	96	97	96
4	97	95	99	95	98	96	99	96	98	97
5	98	94	98	95	98	96	98	96	97	96

Table 9-20: SR 67 (Kentucky) Percent In-Sync (%) Table – All Scenarios

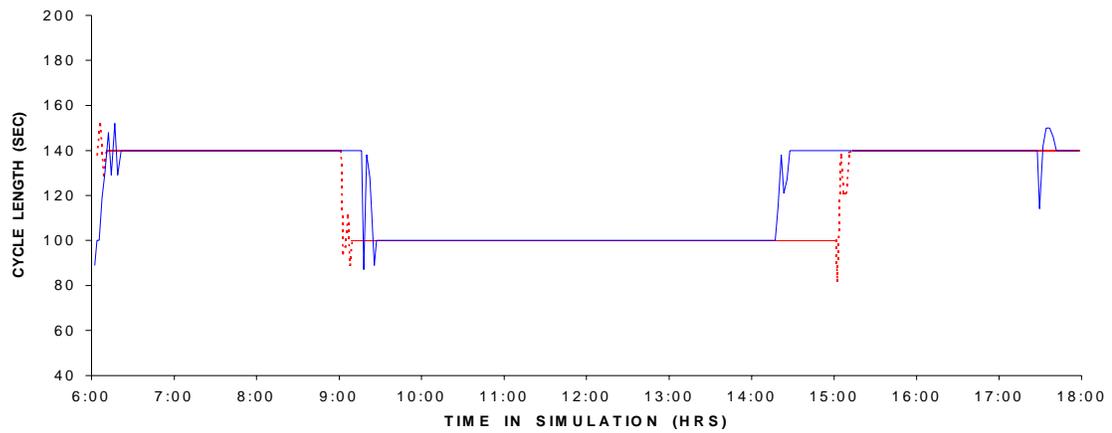
DELAY (V-M)	CASE_1	CASE_1A	CASE_2	CASE_3	CASE_4	CASE_5
TIME-OF-DAY	66,053	57,741	46,631	50,751	55,014	59,914
RESPONSIVE	59,995	59,995	56,701	51,365	55,949	59,431

Table 9-21: SR 67 (Kentucky) Cumulative Delay Time – All Scenarios (V-M)

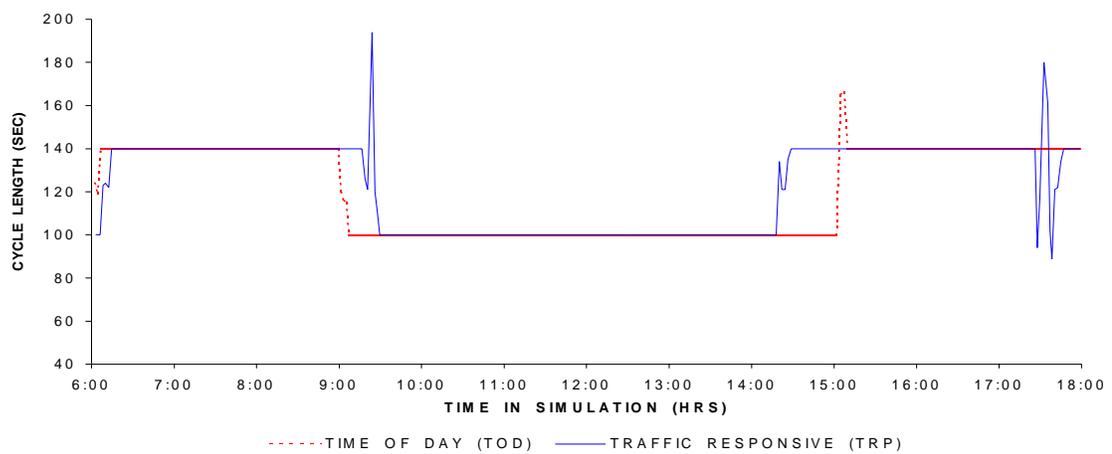
COMPARISON OF TRANSITIONING ALGORITHMS (CASE_1)
SR 67 (KENTUCKY) - CYCLE GRAPHS



a) Node 3: SR 67 & High School Road



b) Node 4: SR 67 & JCT I-465 (South)

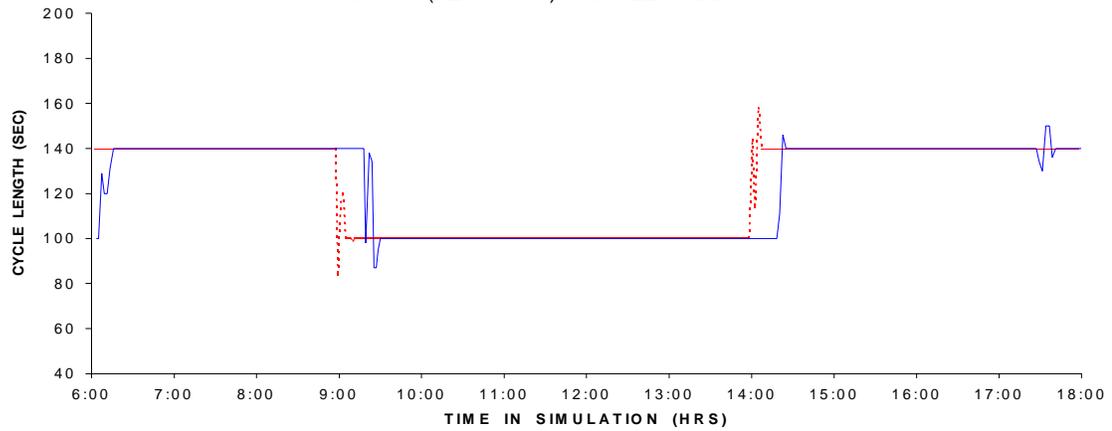


c) Node 5: SR 67 & JCT I-465 (North)

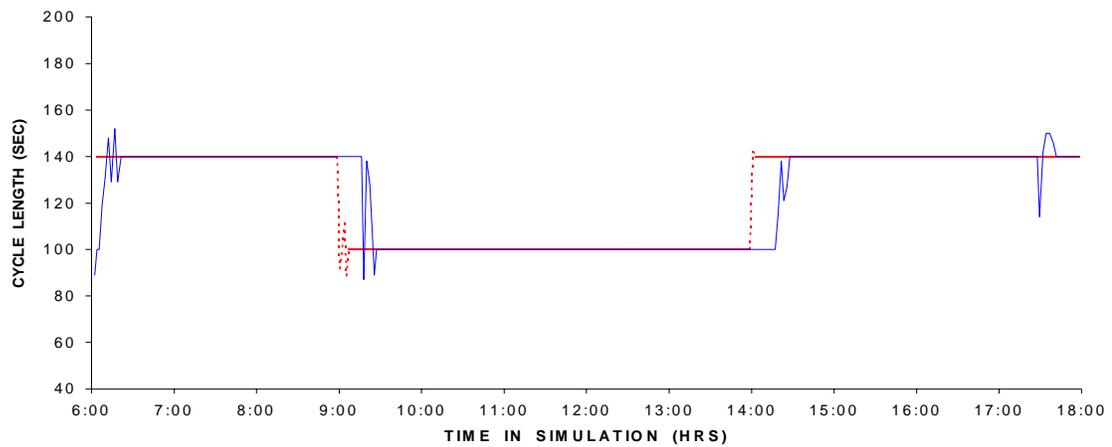
Figure 9-9: SR 67 (Kentucky) System Cycle Graphs – Case_1

--- TIME OF DAY (TOD) — TRAFFIC RESPONSIVE (TRP)

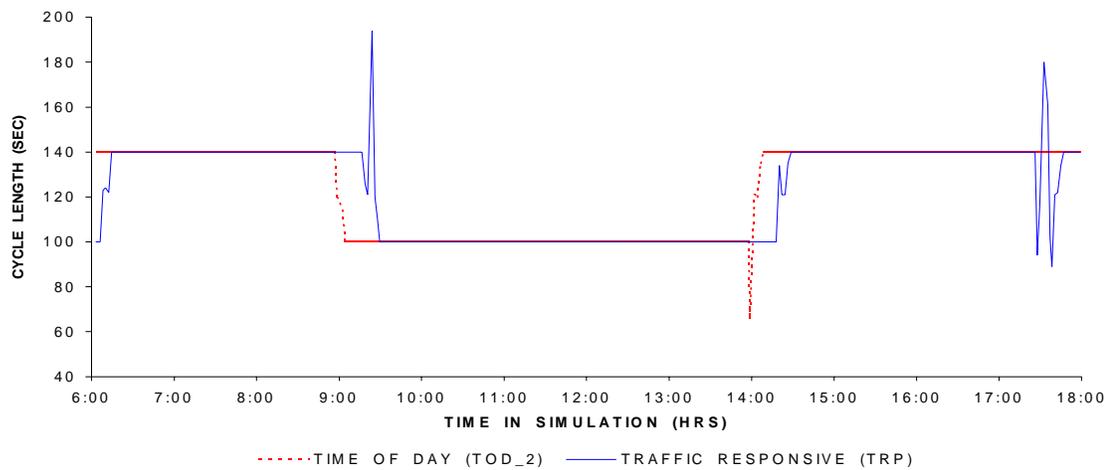
COMPARISON OF TRANSITIONING ALGORITHMS (CASE_1)
SR 67 (KENTUCKY) - CYCLE GRAPHS



a) Node 3: SR 67 & High School Road



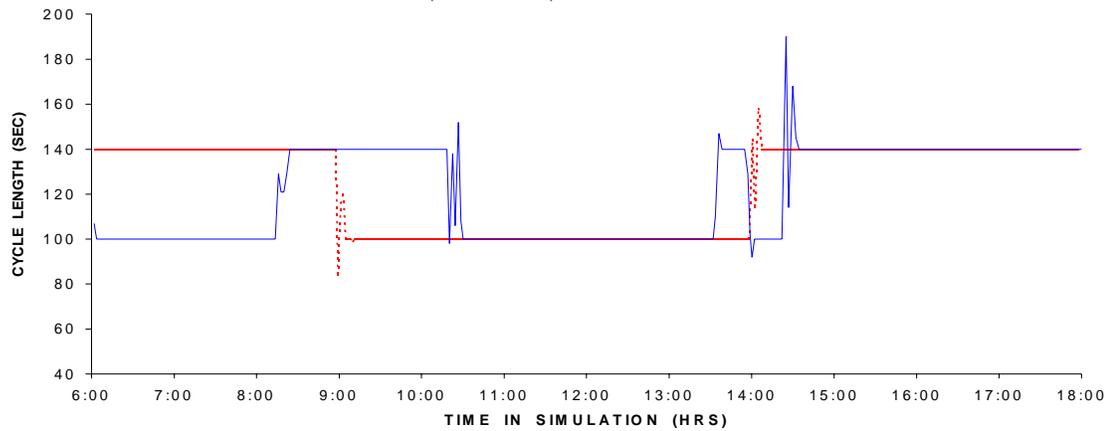
b) Node 4: SR 67 & JCT I-465 (South)



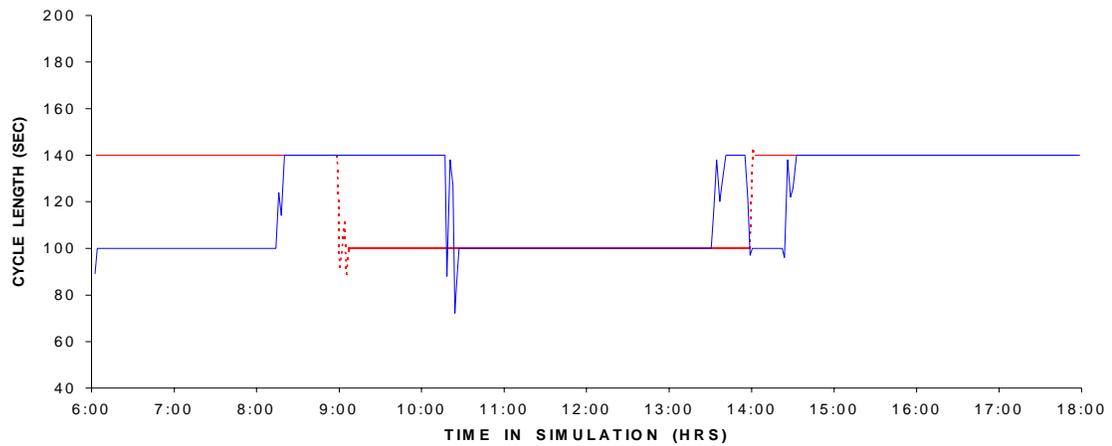
c) Node 5: SR 67 & JCT I-465 (North)

Figure 9-10: SR 67 (Kentucky) System Cycle Graphs – Case_1 (TOD_2)

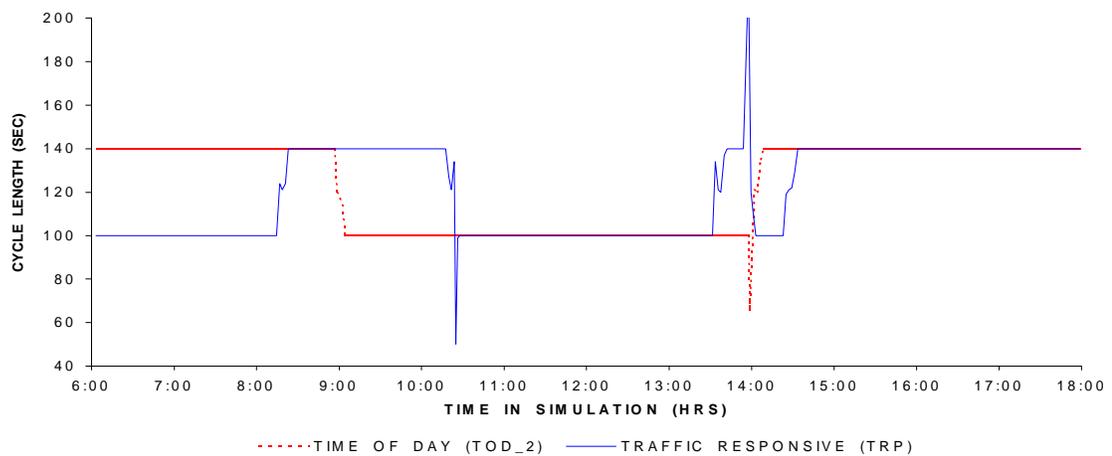
COMPARISON OF TRANSITIONING ALGORITHMS (CASE_2)
SR 67 (KENTUCKY) - CYCLE GRAPHS



a) Node 3: SR 67 & High School Road



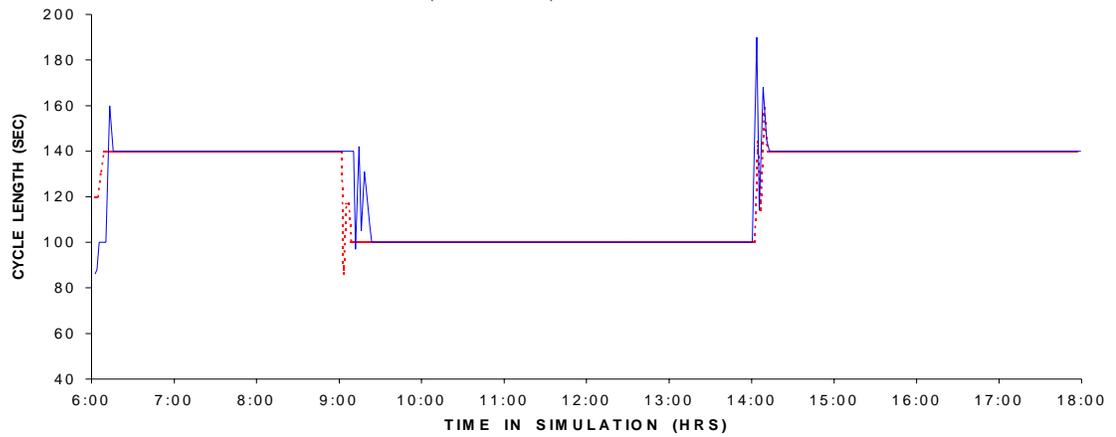
b) Node 4: SR 67 & JCT I-465 (South)



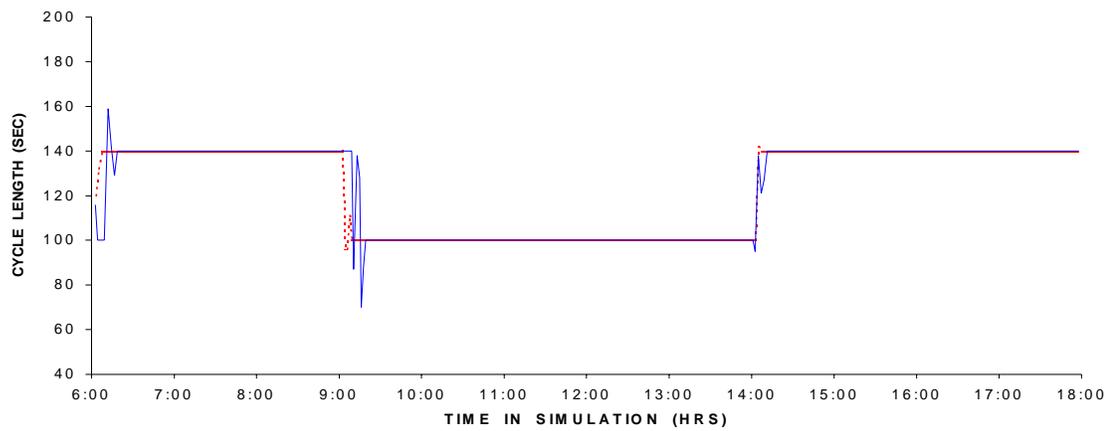
c) Node 5: SR 67 & JCT I-465 (North)

Figure 9-11: SR 67 (Kentucky) System Cycle Graphs – Case_2

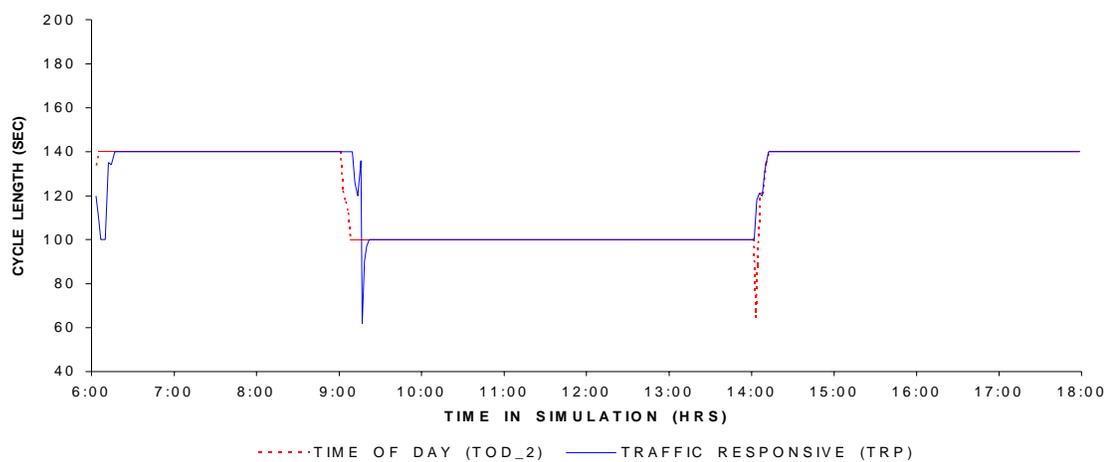
COMPARISON OF TRANSITIONING ALGORITHMS (CASE_3)
SR 67 (KENTUCKY) - CYCLE GRAPHS



a) Node 3: SR 67 & High School Road



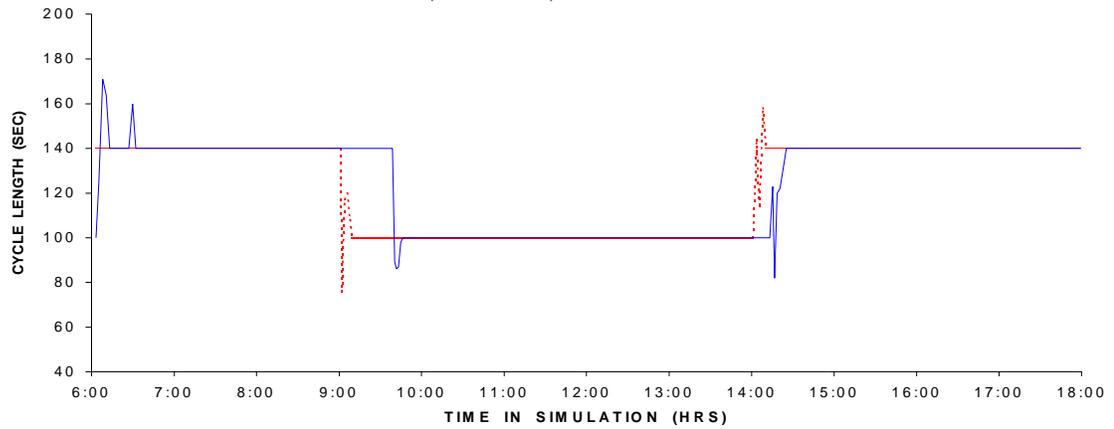
b) Node 4: SR 67 & JCT I-465 (South)



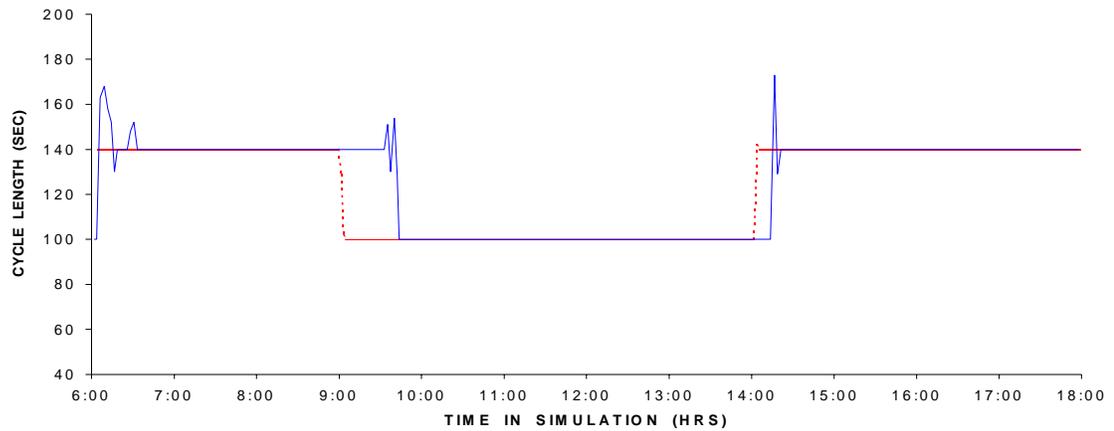
c) Node 5: SR 67 & JCT I-465 (North)

Figure 9-12: SR 67 (Kentucky) System Cycle Graphs – Case_3

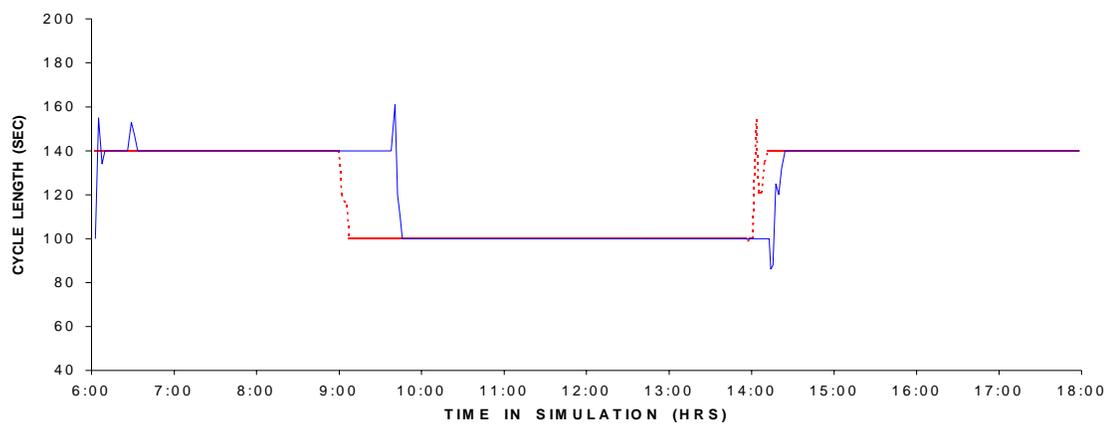
COMPARISON OF TRANSITIONING ALGORITHMS (CASE_4)
SR 67 (KENTUCKY) - CYCLE GRAPHS



a) Node 3: SR 67 & High School Road



b) Node 4: SR 67 & JCT I-465 (South)

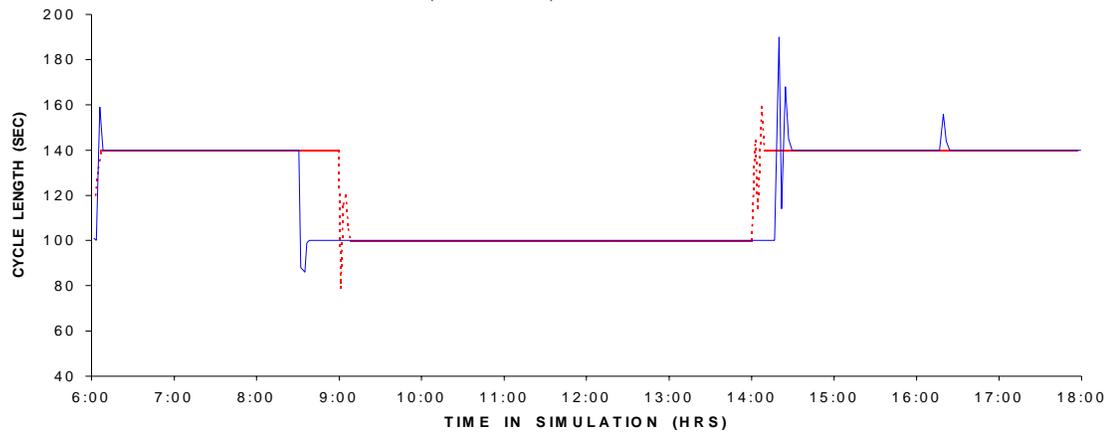


--- TIME OF DAY (TOD_2) — TRAFFIC RESPONSIVE (TRP)

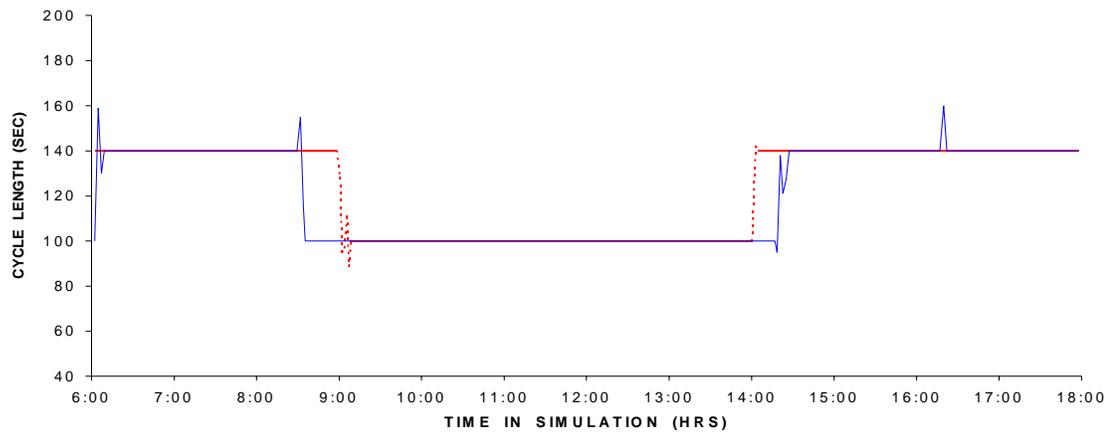
c) Node 5: SR 67 & JCT I-465 (North)

Figure 9-13: SR 67 (Kentucky) System Cycle Graphs – Case_4

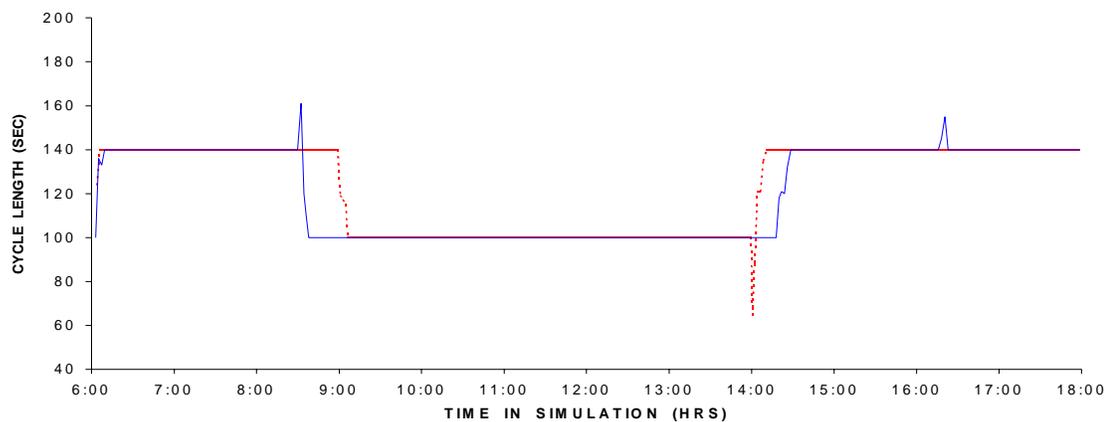
COMPARISON OF TRANSITIONING ALGORITHMS (CASE_5)
 SR 67 (KENTUCKY) - CYCLE GRAPHS



a) Node 3: SR 67 & High School Road



b) Node 4: SR 67 & JCT I-465 (South)



--- TIME OF DAY (TOD_2) — TRAFFIC RESPONSIVE (TRP)

c) Node 5: SR 67 & JCT I-465 (North)

Figure 9-14: SR 67 (Kentucky) System Cycle Graphs – Case_5

CUMULATIVE TRAVEL TIME (6:00AM TO 6:00PM)
 NORTHBOUND SR 67 - KENTUCKY - (HEATHROW DRIVE TO JCT I-465) - THRU VEHICLES

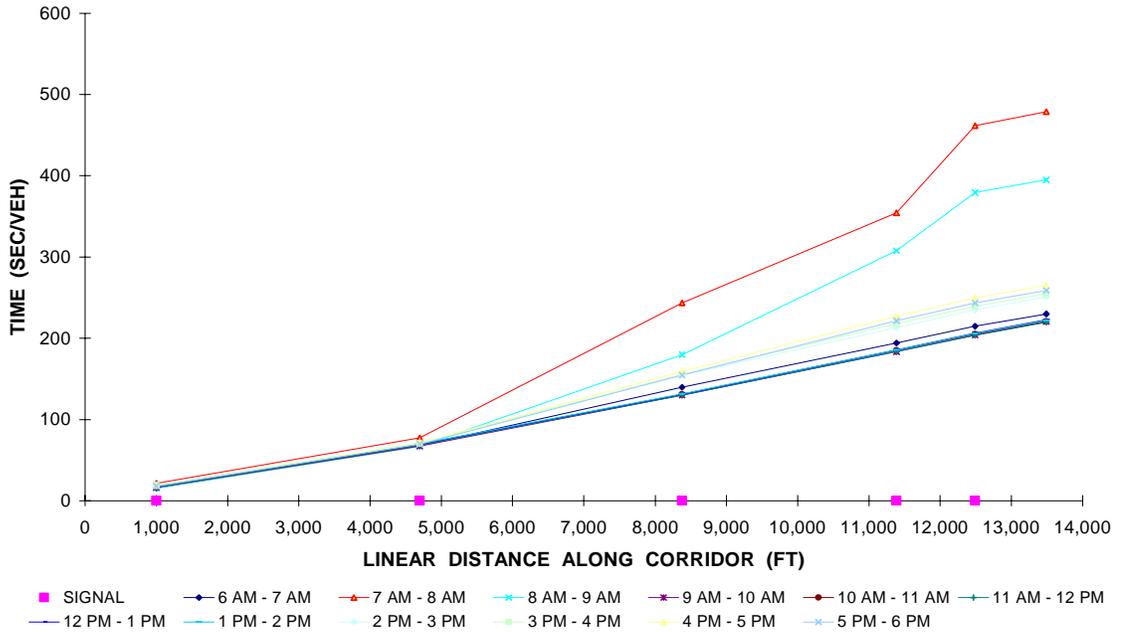


Figure 9-15: Cumulative NB Travel Time (S/V) Per Period (TRP) – Case_1

CUMULATIVE TRAVEL TIME (6:00AM TO 6:00PM)
 SOUTHBOUND SR 67 - KENTUCKY - (HEATHROW DRIVE TO JCT I-465) - THRU VEHICLES

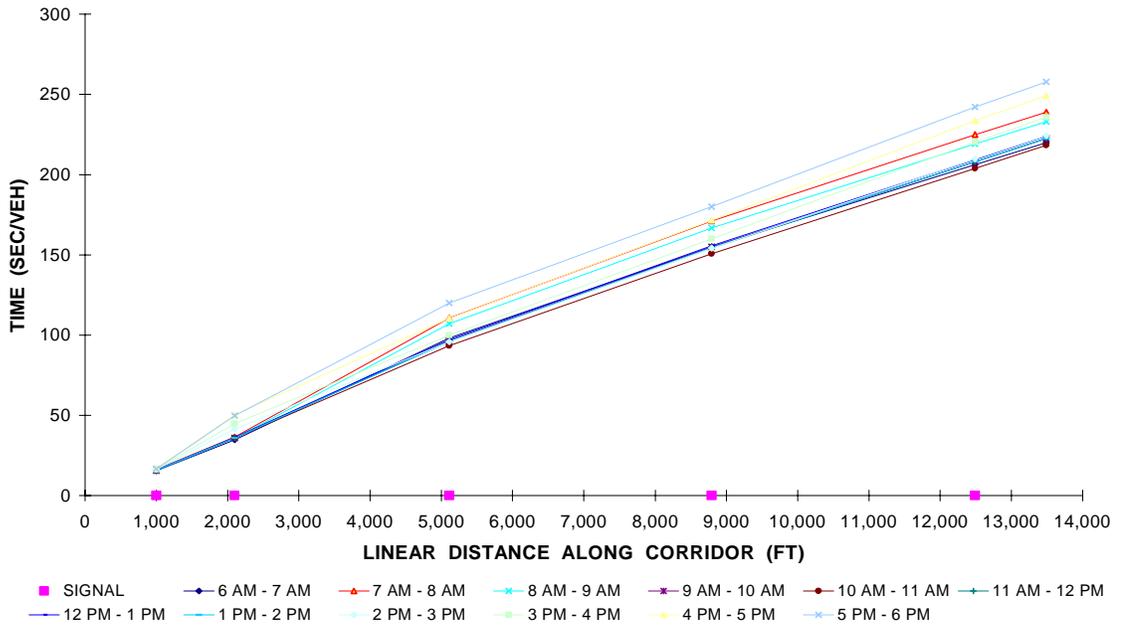


Figure 9-16: Cumulative SB Travel Time (S/V) Per Period (TRP) – Case_1

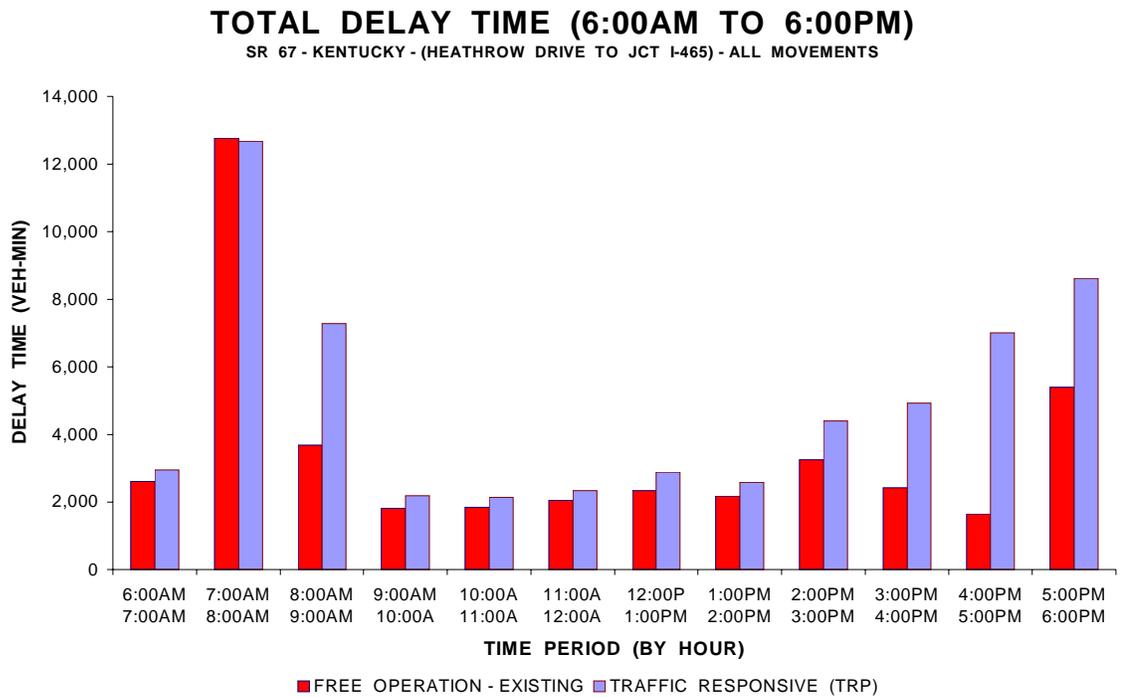


Figure 9-17: Total Delay Time (V-M) Per Period (Free Vs TRP) – Case_1

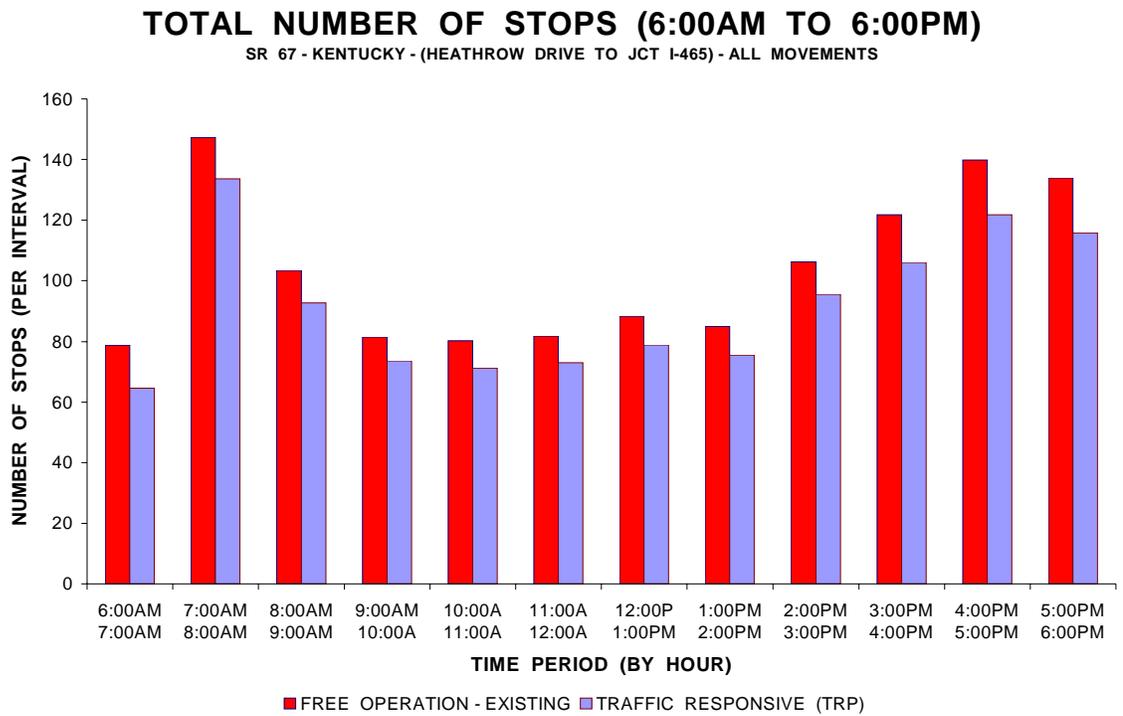


Figure 9-18: Total Number of Stops Per Period (Free Vs TRP) – Case_1

CUMULATIVE DELAY TIME (6:00AM TO 6:00PM)

SR 67 - KENTUCKY - (HEATHROW DRIVE TO JCT I-465) - ALL MOVEMENTS

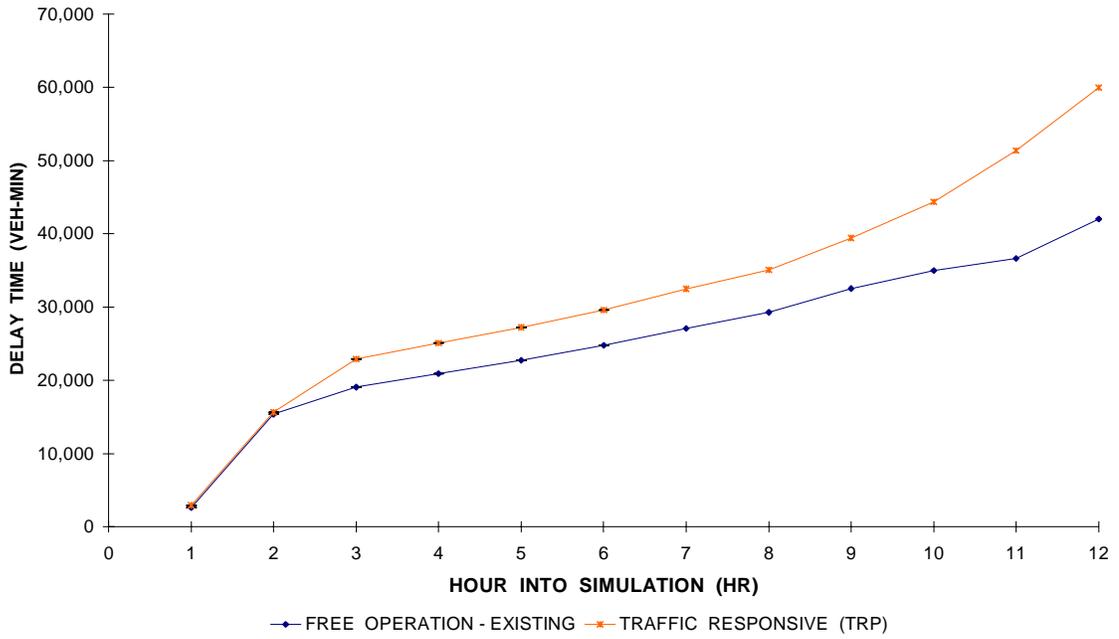


Figure 9-19: Cumulative Delay Time (V-M) – (Free Vs TRP) – Case_1

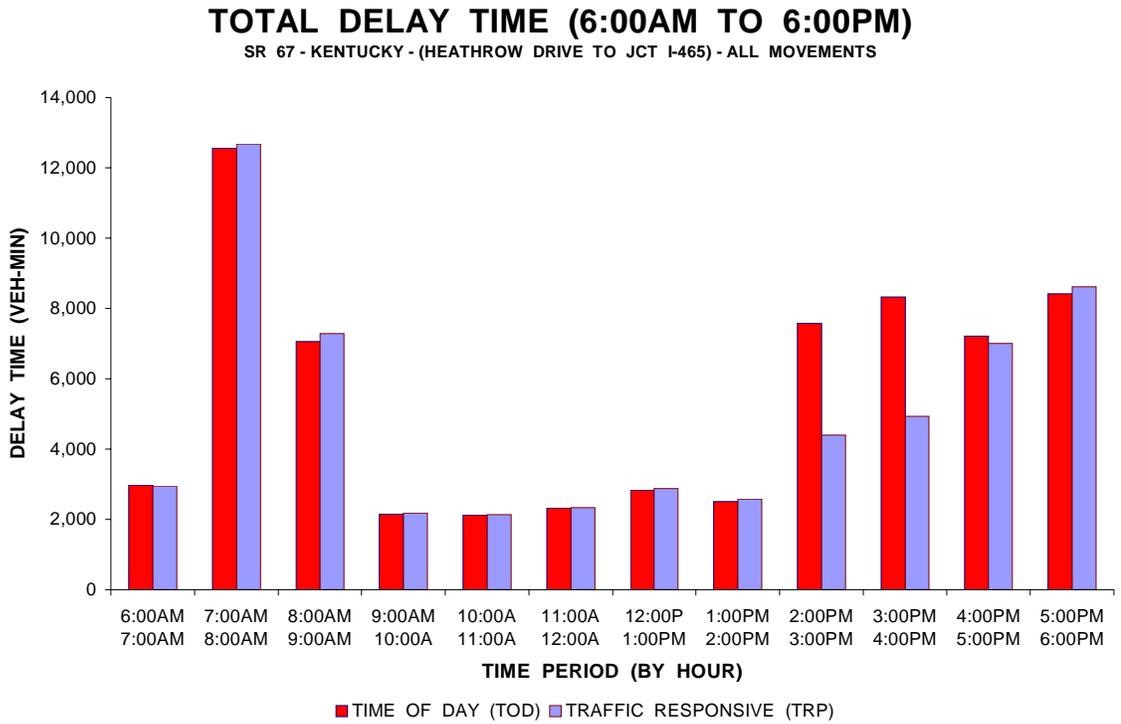


Figure 9-20: Total Delay Time (V-M) Per Period (TOD Vs TRP) – Case_1

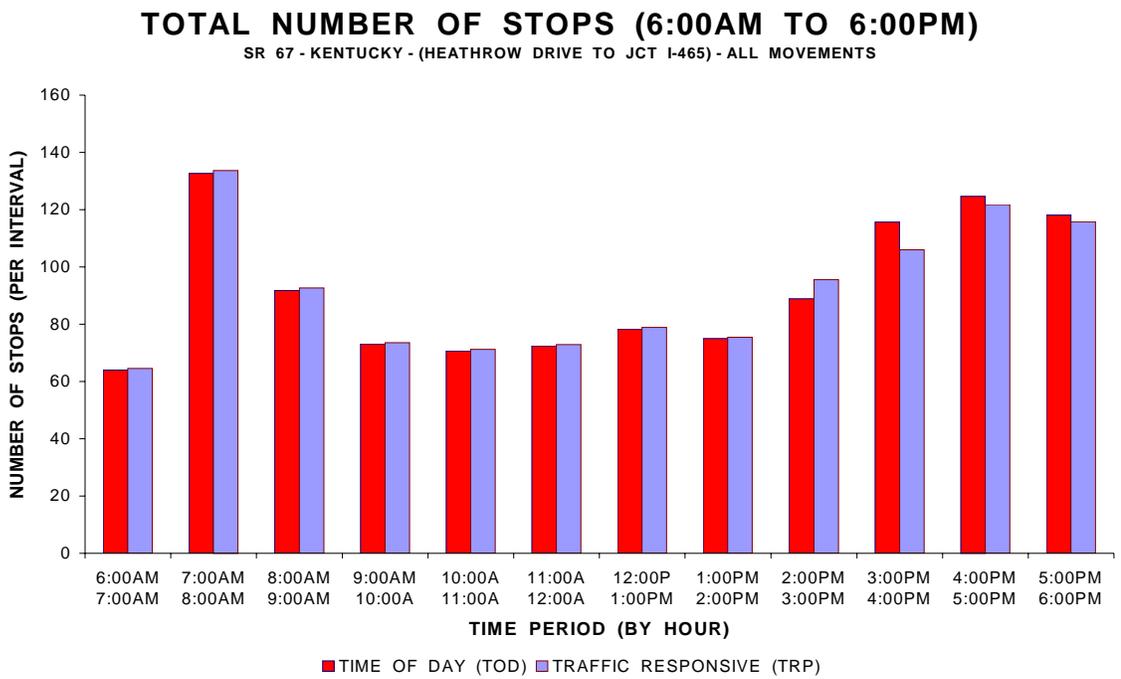


Figure 9-21: Total Number of Stops Per Period (TOD Vs TRP) – Case_1

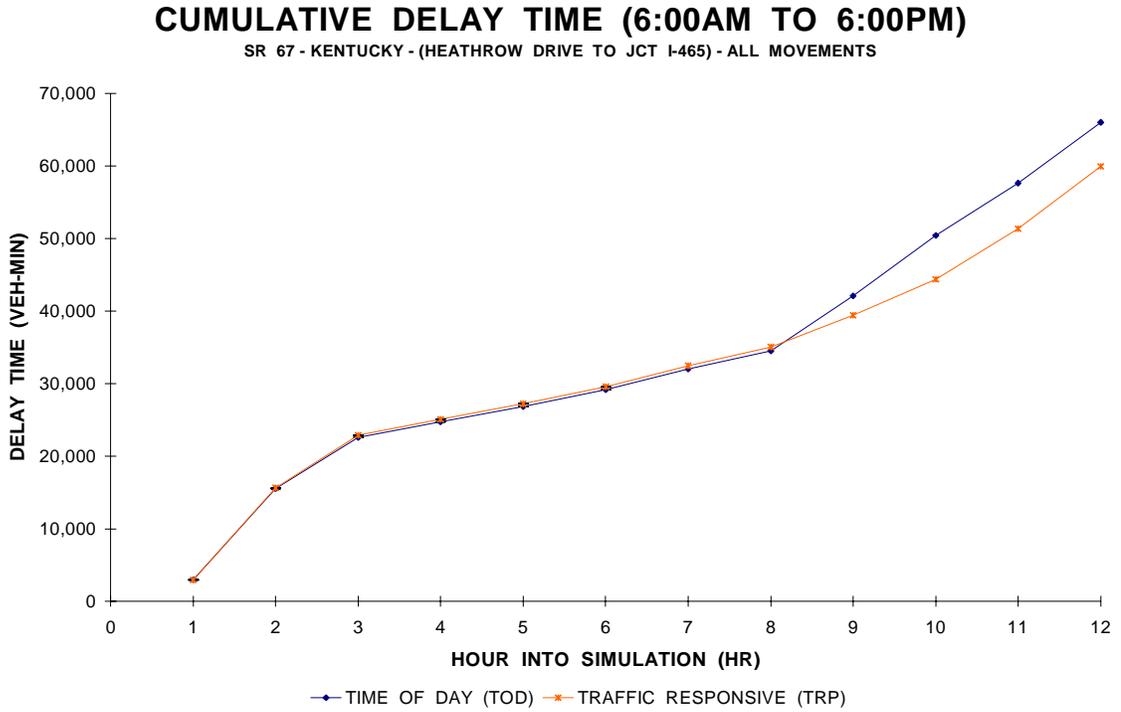


Figure 9-22: Cumulative Delay Time (V-M) – (TOD Vs TRP) – Case_1

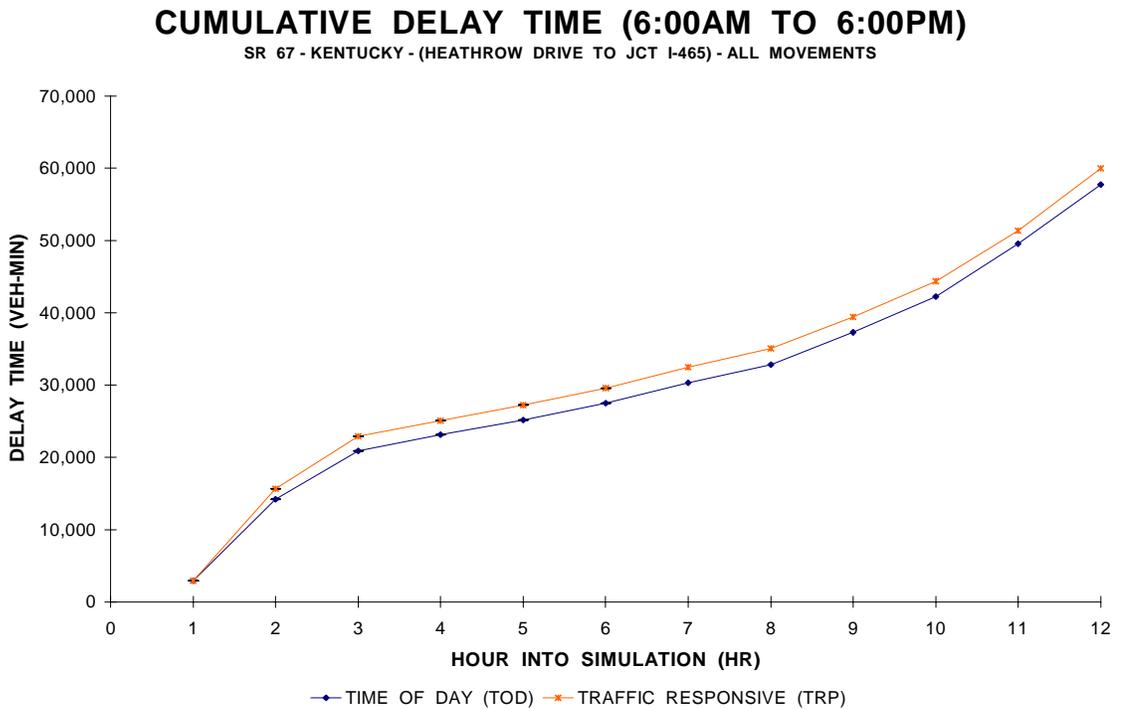


Figure 9-23: Cumulative Delay Time (V-M) – (TOD (2) Vs TRP) – Case_1

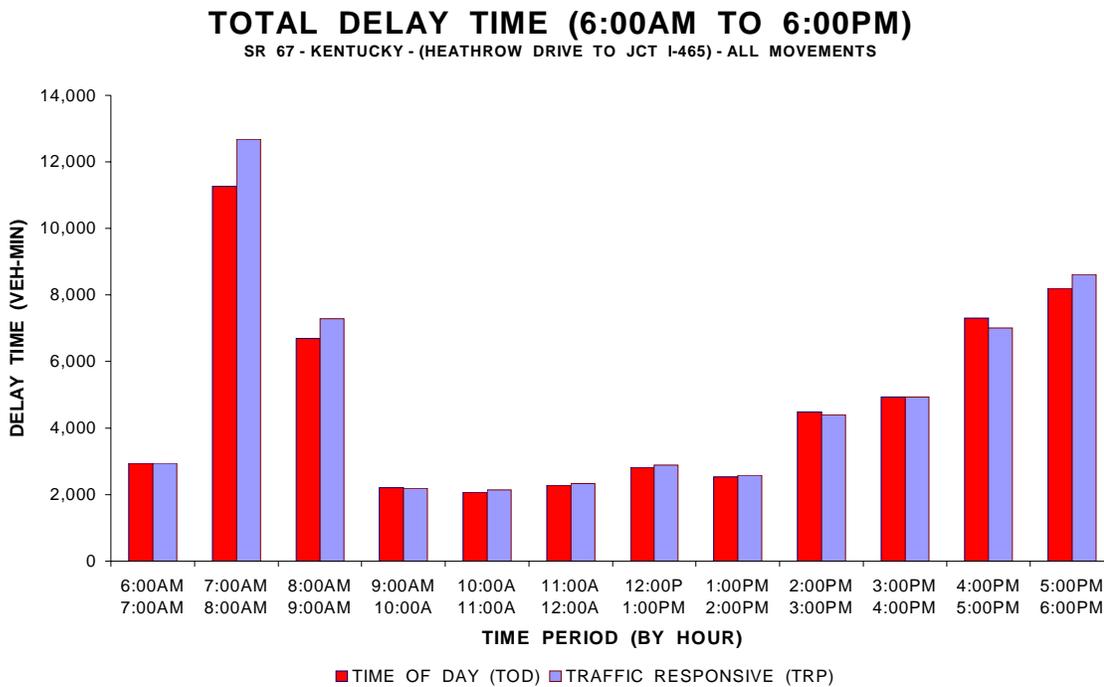


Figure 9-24: Total Delay Time (V-M) Per Period (TOD (2) Vs TRP) – Case_1

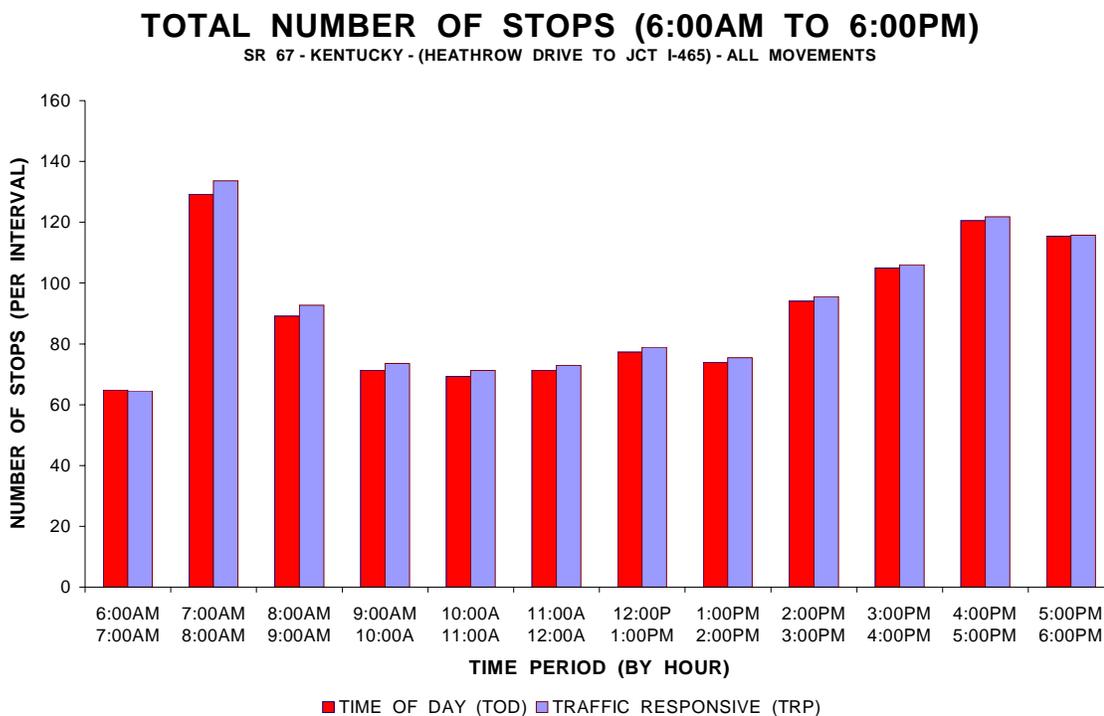


Figure 9-25: Total Number of Stops Per Period (TOD (2) Vs TRP) – Case_1

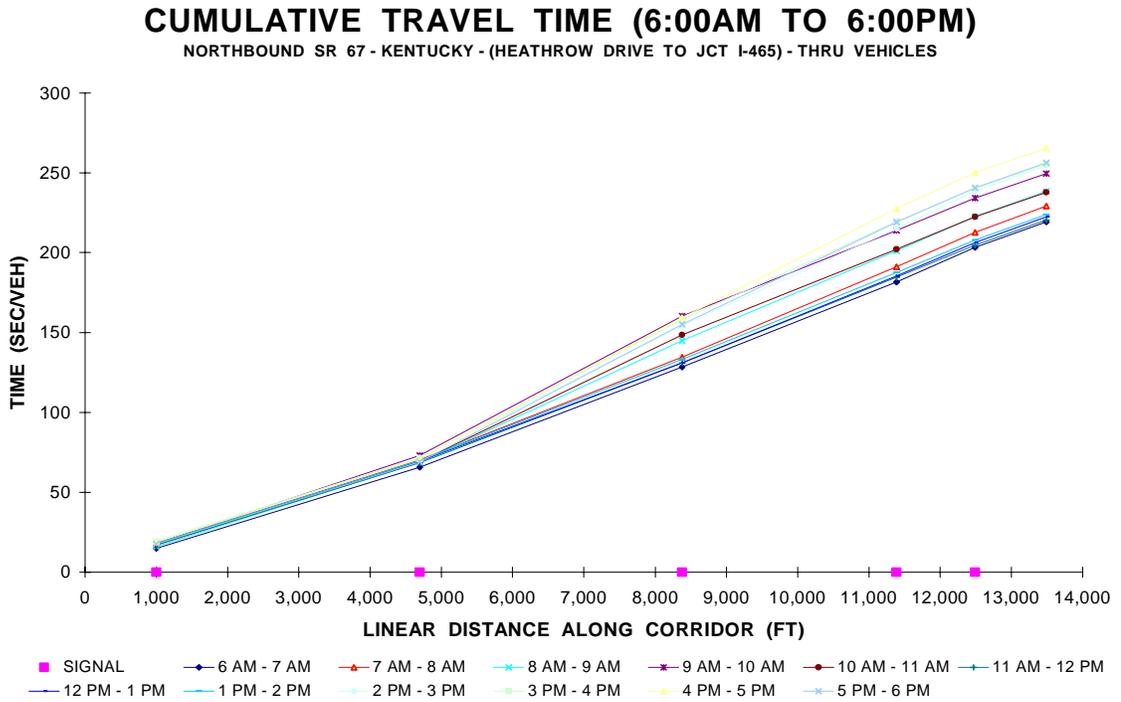


Figure 9-26: Cumulative NB Travel Time (S/V) Per Period (TRP) – Case_2

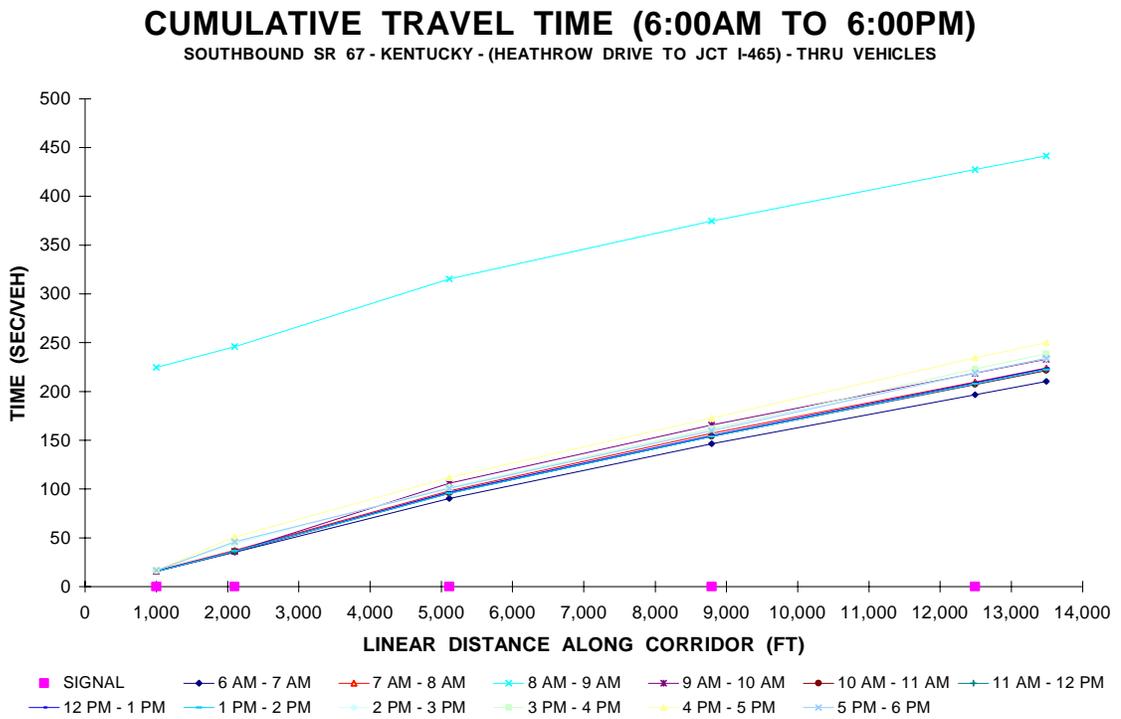


Figure 9-27: Cumulative SB Travel Time (S/V) Per Period (TRP) – Case_2

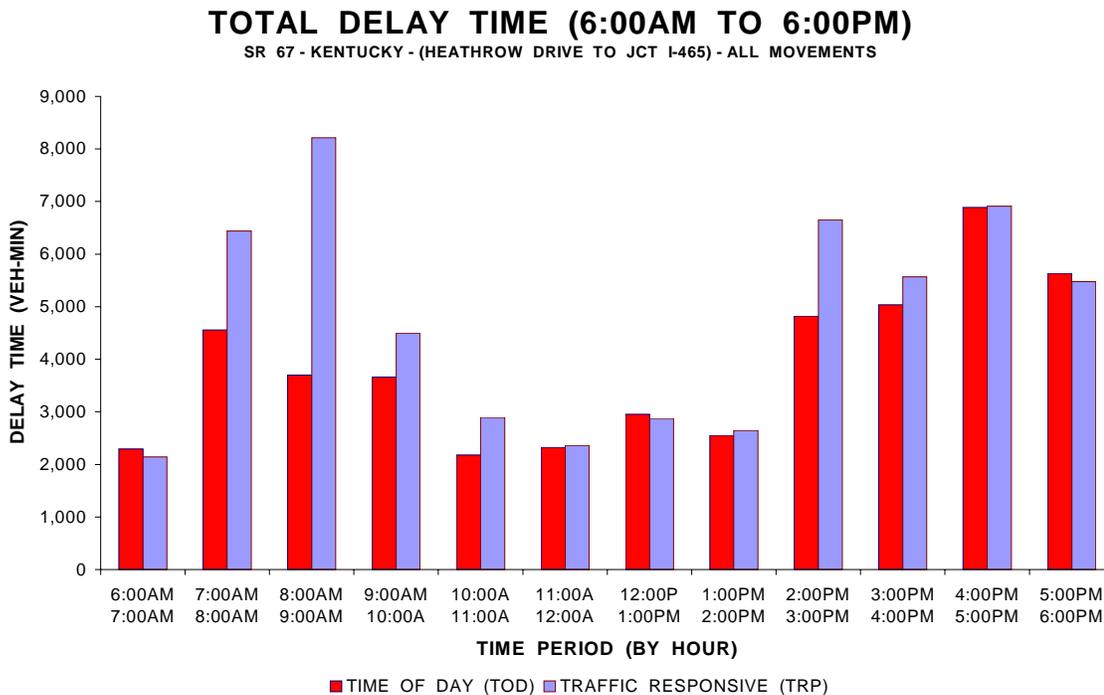


Figure 9-28: Total Delay Time (V-M) Per Period (TOD (2) Vs TRP) – Case_2

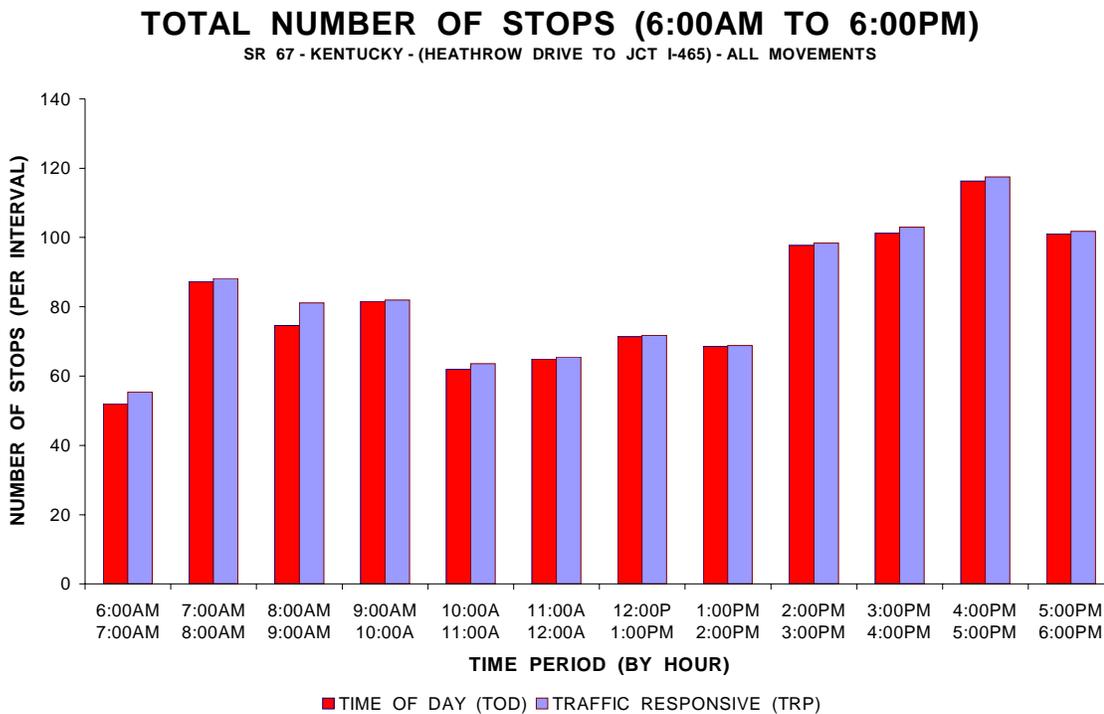


Figure 9-29: Total Number of Stops Per Period (TOD (2) Vs TRP) – Case_2

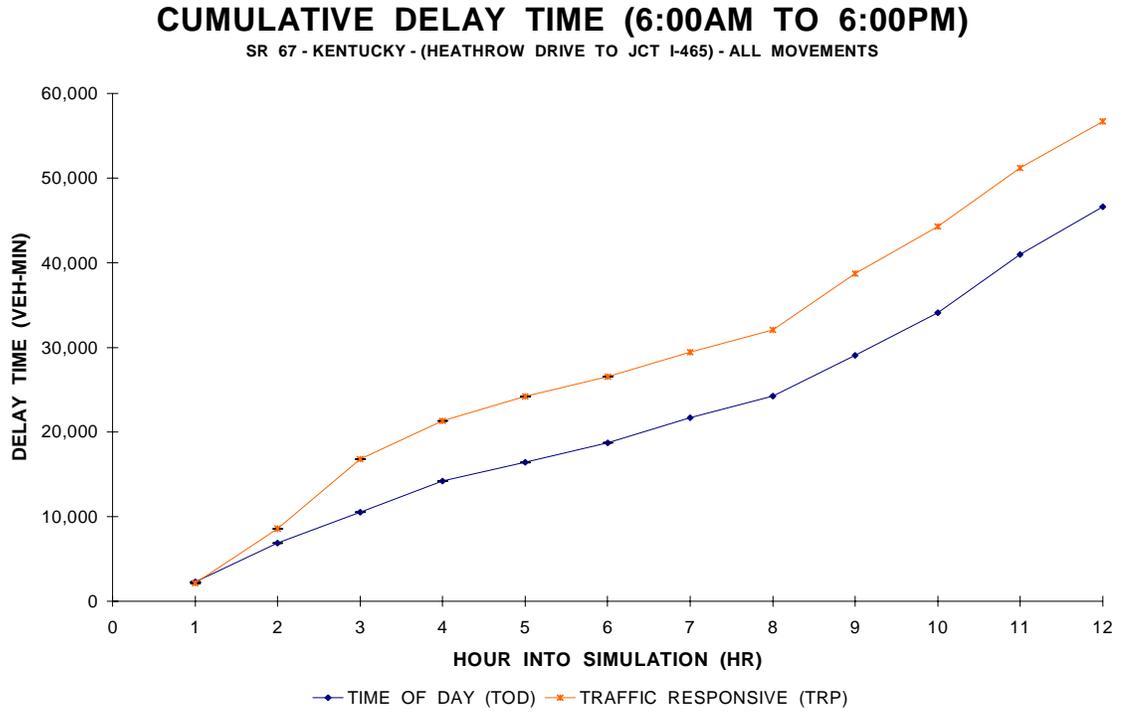


Figure 9-30: Cumulative Delay Time (V-M) – (TOD (2) Vs TRP) – Case_2

CUMULATIVE TRAVEL TIME (6:00AM TO 6:00PM)

NORTHBOUND SR 67 - KENTUCKY - (HEATHROW DRIVE TO JCT I-465) - THRU VEHICLES

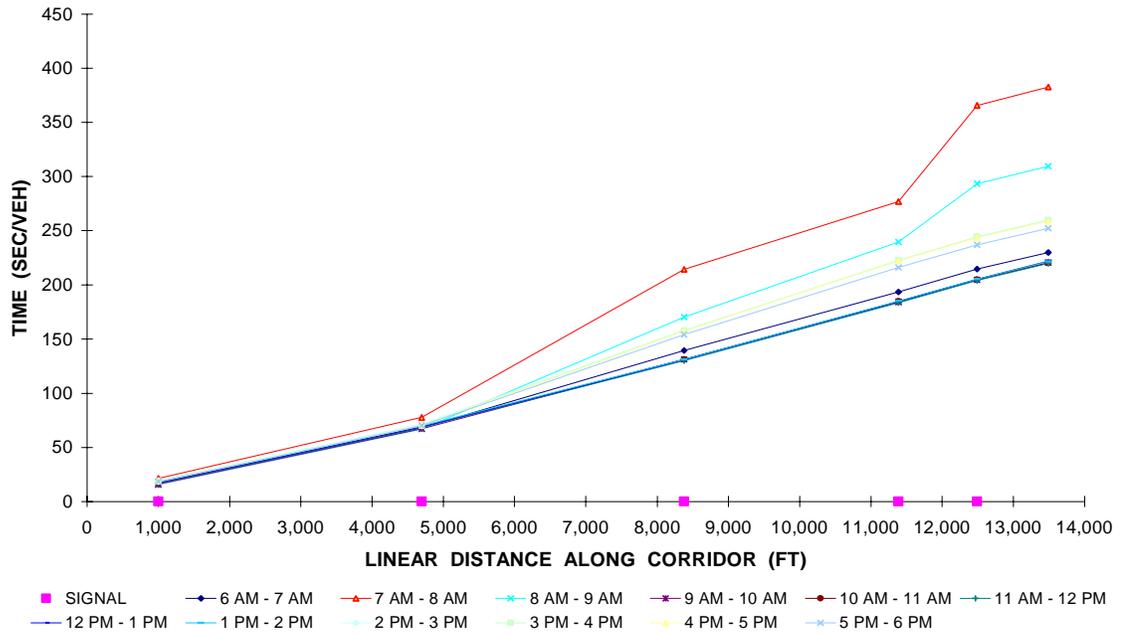


Figure 9-31: Cumulative NB Travel Time (S/V) Per Period (TRP) – Case_3

CUMULATIVE TRAVEL TIME (6:00AM TO 6:00PM)

SOUTHBOUND SR 67 - KENTUCKY - (HEATHROW DRIVE TO JCT I-465) - THRU VEHICLES

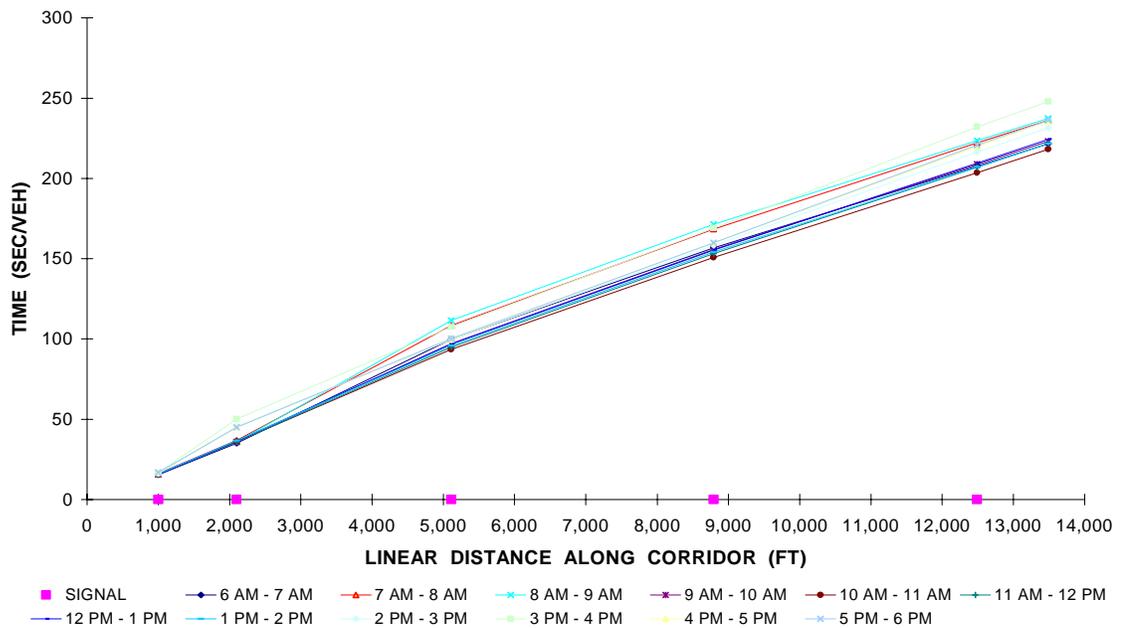


Figure 9-32: Cumulative SB Travel Time (S/V) Per Period (TRP) – Case_3

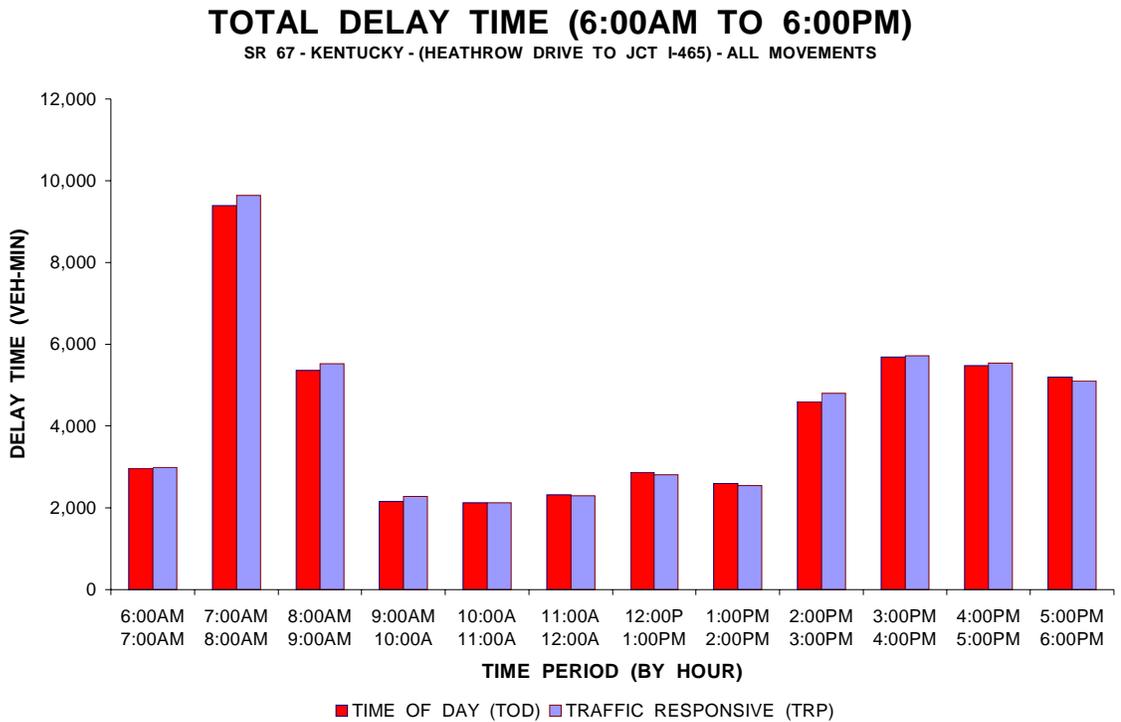


Figure 9-33: Total Delay Time (V-M) Per Period (TOD (2) Vs TRP) – Case_3

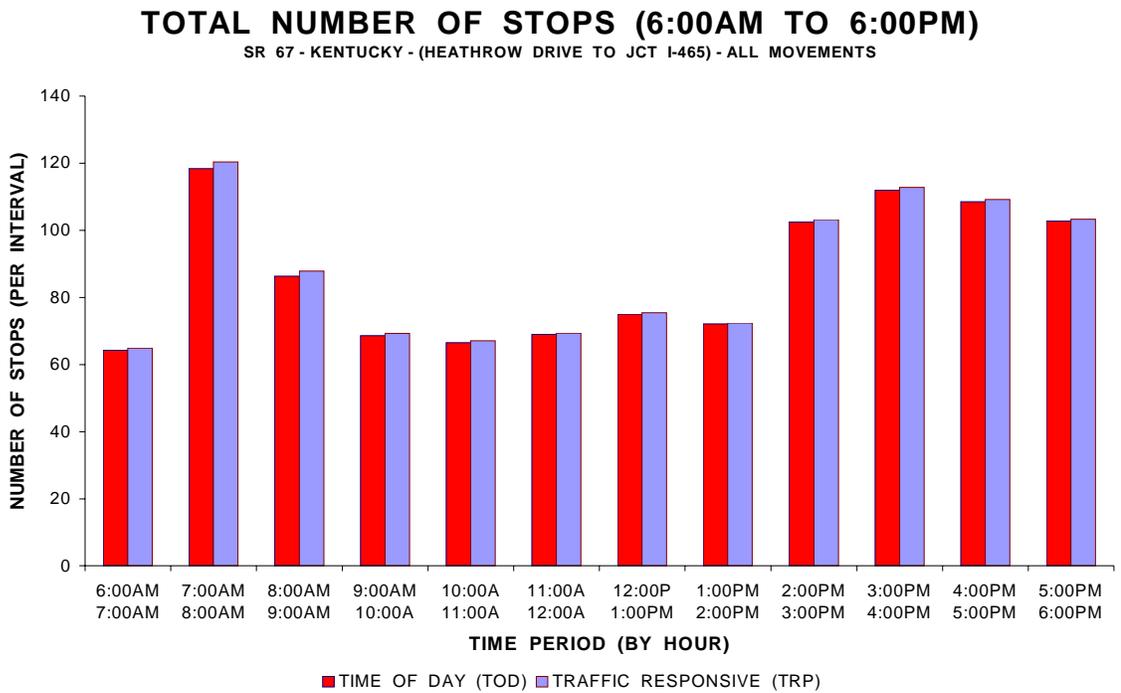


Figure 9-34: Total Number of Stops Per Period (TOD (2) Vs TRP) – Case_3

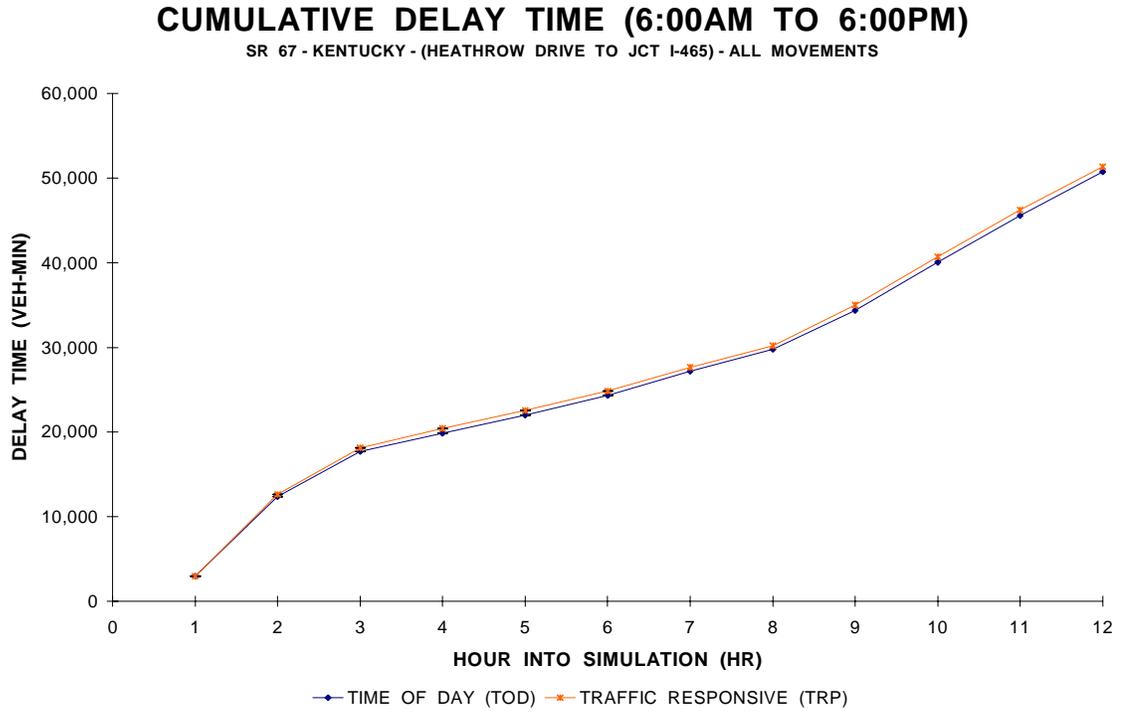


Figure 9-35: Cumulative Delay Time (V-M) – (TOD (2) Vs TRP) – Case_3

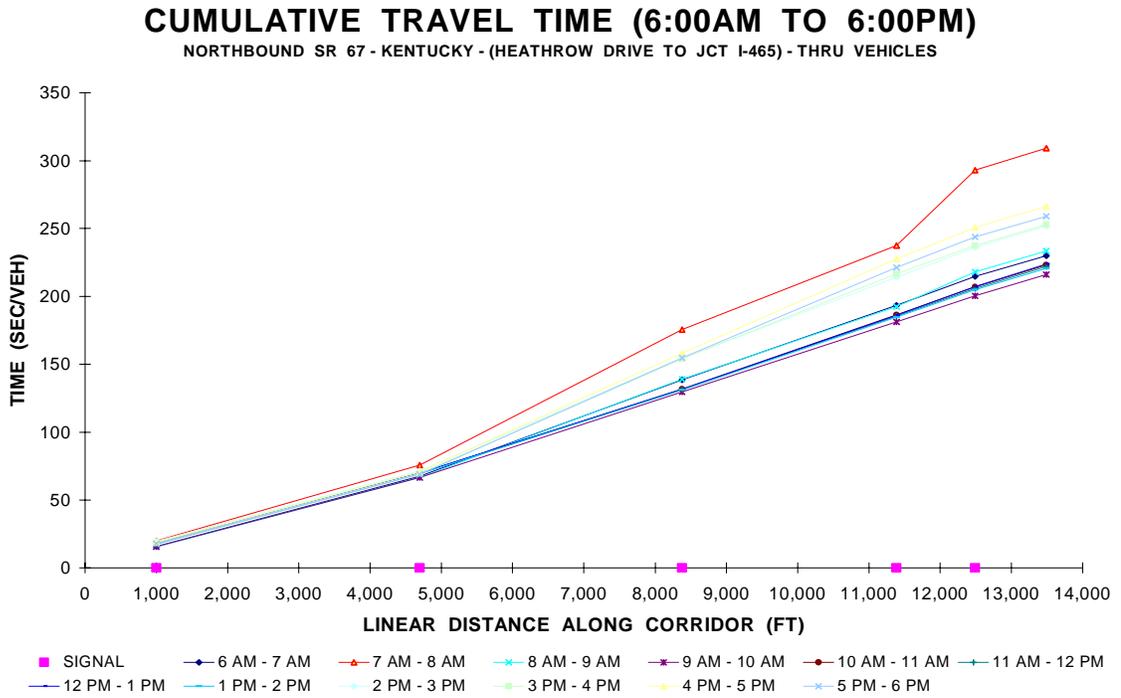


Figure 9-36: Cumulative NB Travel Time (S/V) Per Period (TRP) – Case_4

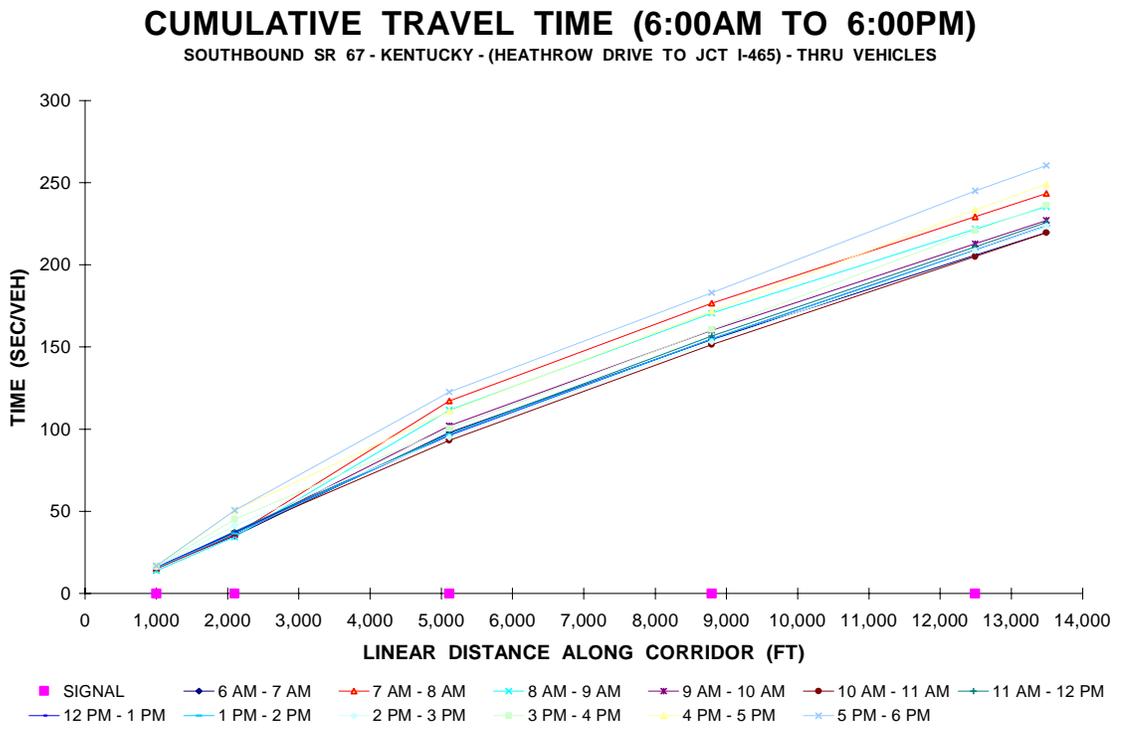


Figure 9-37: Cumulative SB Travel Time (S/V) Per Period (TRP) – Case_4

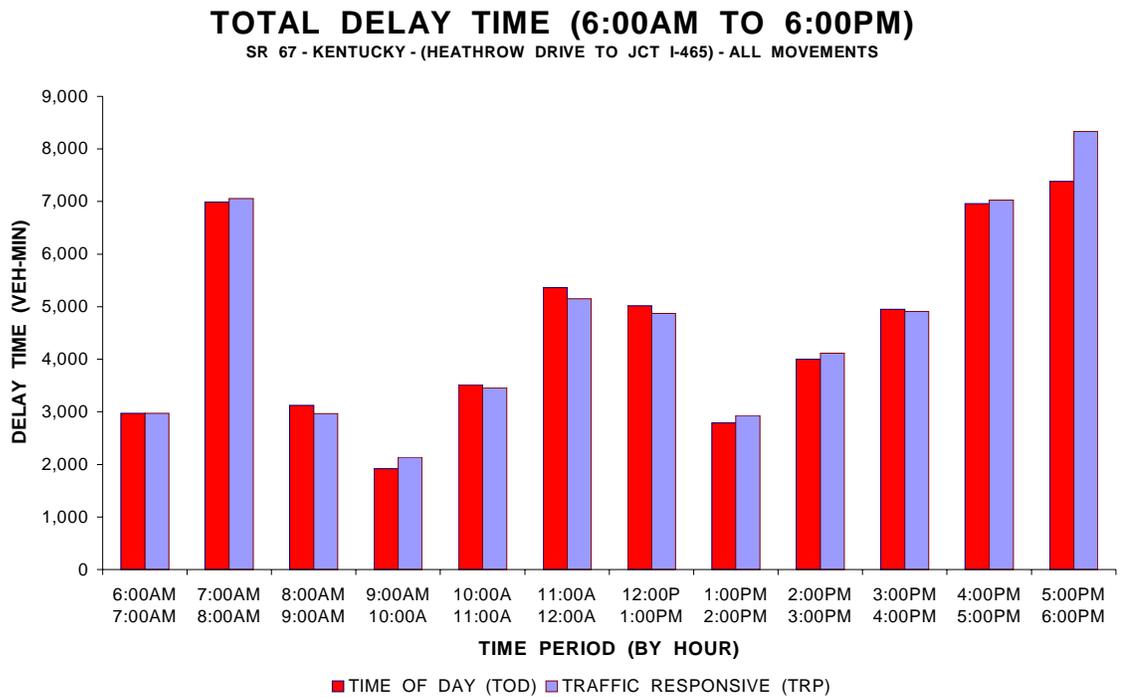


Figure 9-38: Total Delay Time (V-M) Per Period (TOD (2) Vs TRP) – Case_4

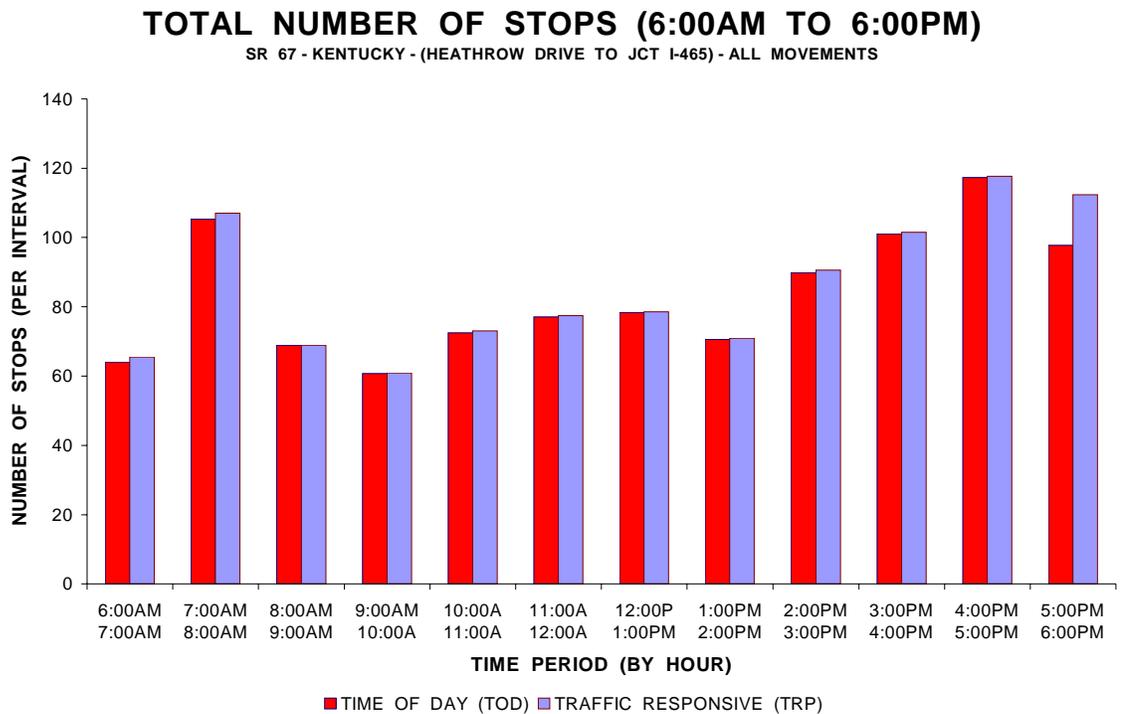


Figure 9-39: Total Number of Stops Per Period (TOD (2) Vs TRP) – Case_4

CUMULATIVE DELAY TIME (6:00AM TO 6:00PM)

SR 67 - KENTUCKY - (HEATHROW DRIVE TO JCT I-465) - ALL MOVEMENTS

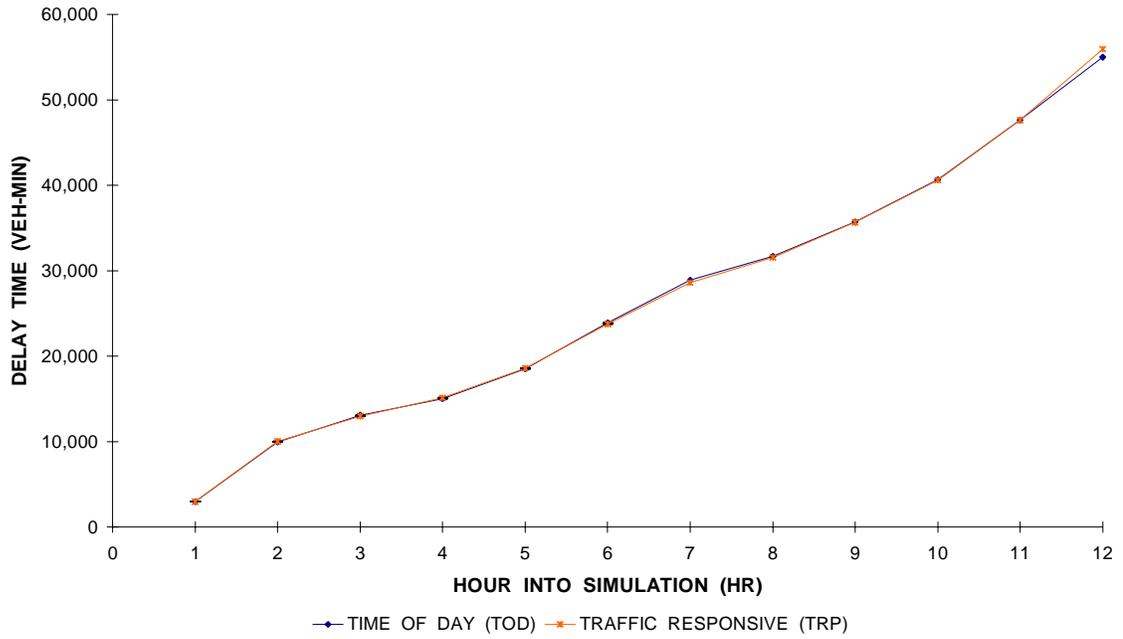


Figure 9-40: Cumulative Delay Time (V-M) – (TOD (2) Vs TRP) – Case_4

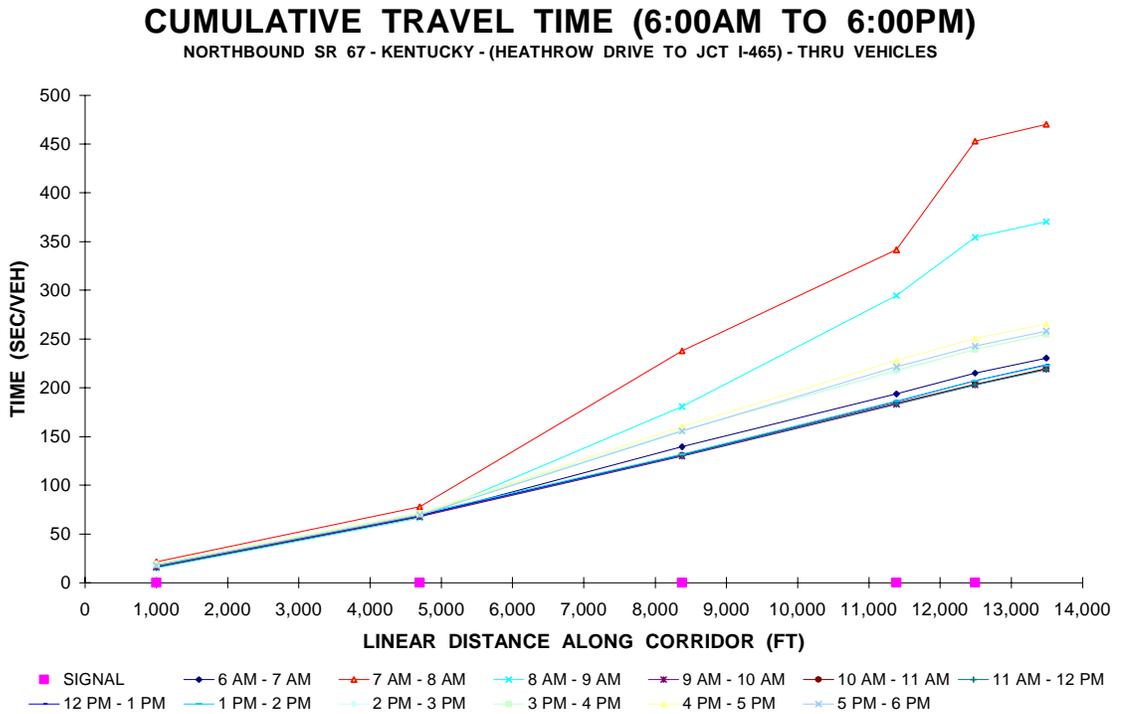


Figure 9-41: Cumulative NB Travel Time (S/V) Per Period (TRP) – Case_5

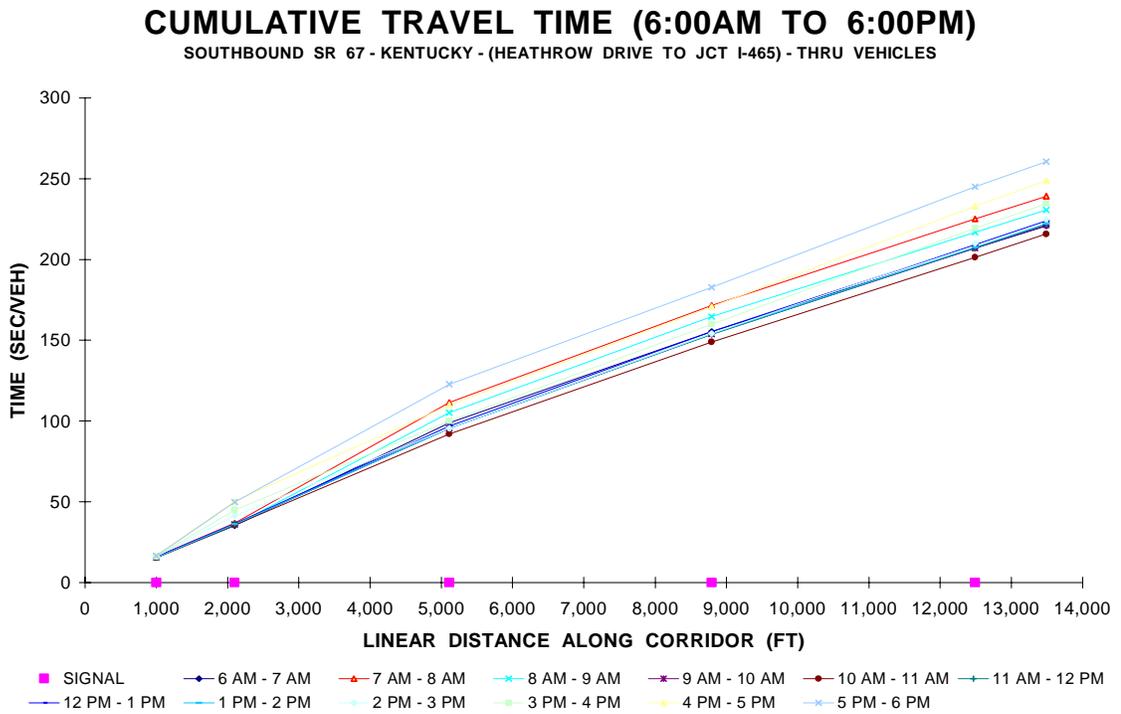


Figure 9-42: Cumulative SB Travel Time (S/V) Per Period (TRP) – Case_5

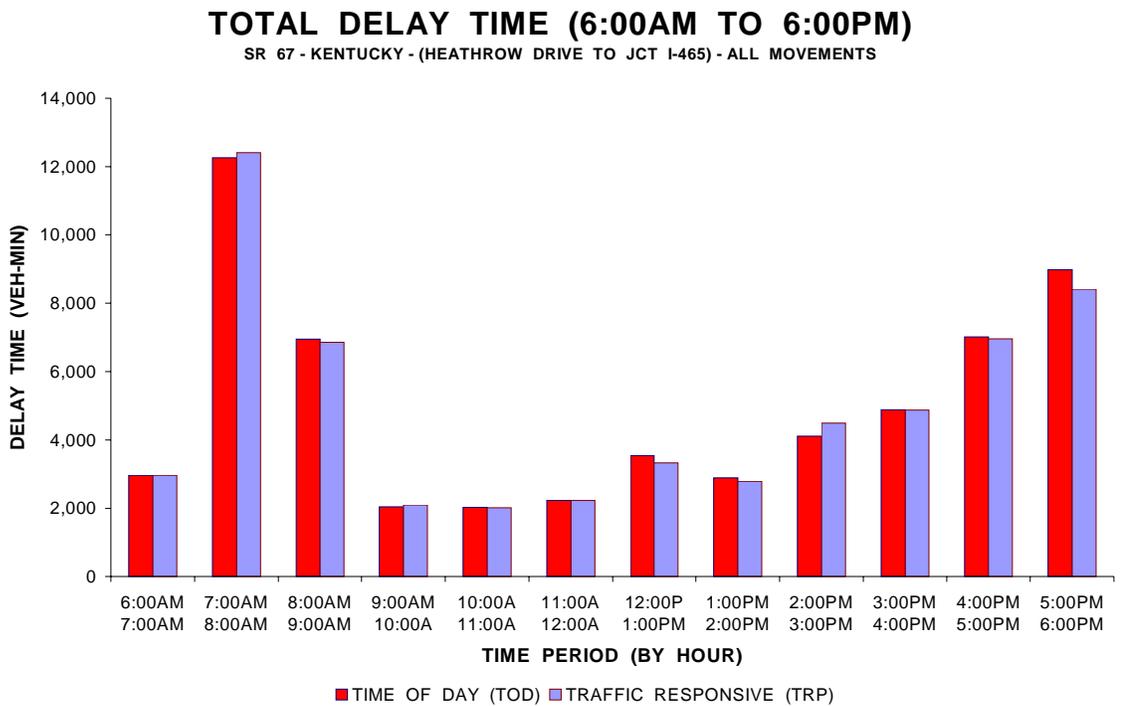


Figure 9-43: Total Delay Time (V-M) Per Period (TOD (2) Vs TRP) – Case_5

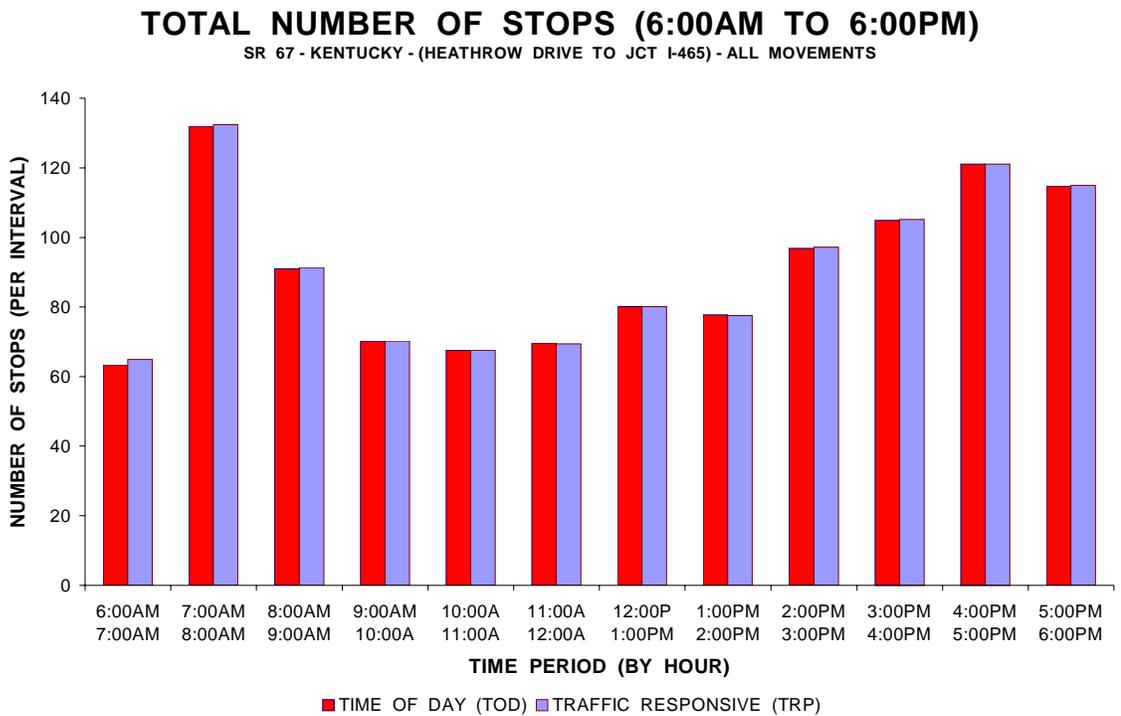


Figure 9-44: Total Number of Stops Per Period (TOD (2) Vs TRP) – Case_5

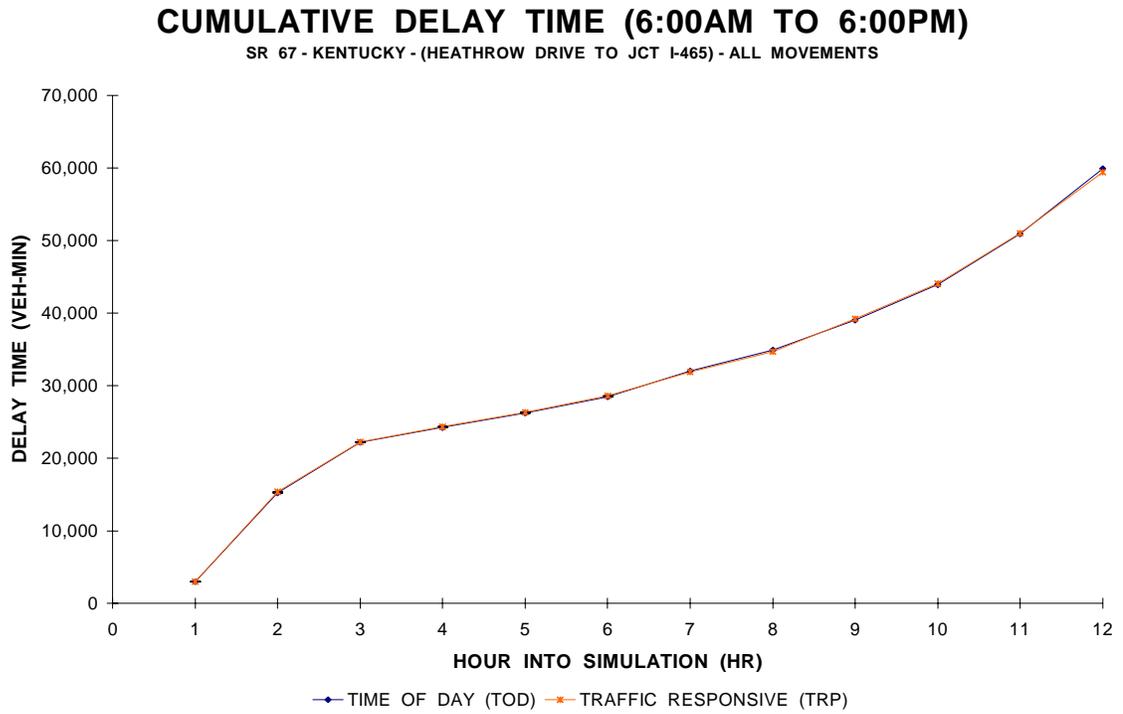


Figure 9-45: Cumulative Delay Time (V-M) – (TOD (2) Vs TRP) – Case_5

CHAPTER 10 – CONCLUSIONS AND FUTURE RESEARCH

Summary of Evaluation Procedures

Based on the analysis performed in this research, it should be apparent that the configuration and evaluation of modern closed-loop signal systems is not a trivial task. Modern actuated control parameters, which help reduce total delay, also make the design of a traffic signal system more complex, since the green intervals are no longer fixed. Therefore, the Highway Capacity Manual (HCM) procedures should not be the final word for analyzing the overall performance of an arterial network, since such methodologies do not account for spillback and other occurrences that can severely degrade the overall performance of the signal system. Hence, it is important that simulation based procedures, which consider actuated control parameters, be used in order to help better validate a timing plan that corresponds to particular volume scenario.

Summary of Analysis Procedures

It should also be apparent that the three areas examined as part of this research (preemption, diamond interchanges, and traffic responsive) all required the use of the Controller Interface Device (CID), so that the simulation can communicate with the actual control equipment. This was because each of these areas examined features that were vendor specific, and not included in the internal simulation model. Recall that the preemption study examined the effect that an emergency vehicle would have on the performance of the arterial, because of transitioning, while the diamond interchange study examined some advanced ring structures and phasing changes, which could not be attained

directly with the internal model. Lastly, the Traffic Responsive (TRP) analysis used a vendor specific computation that could only be performed in the actual control equipment, and so the CID's were necessary, in order to bring the count data from the simulation into the master controller for processing.

Although the simulation software is commercially available, the Controller Interface Device (CID) and actual control equipment are not as readily available. Hence, it should be mentioned that it is still better to use the internal model that accompanies the simulation package, rather than not use simulation at all.

General Findings and Results

When examining the three areas that were part of this research, it can be determined that there are a variety of issues and factors which should be considered in the design of an arterial signal system. One of the big picture concepts is that coordination generally helps reduce the total number of stops, but often at the expense of total overall delay. This should be apparent from the last chapter, where the coordinated operations were compared with the independent (Free) operation. Actuated control parameters help greatly reduce total delay, even for coordinated systems, which is why the efforts of setting up a coordinated-actuated system are worth the additional effort. It is known that the delay for a fixed-time suburban network often performs significantly worse because of the unused green time that often remains on the minor side streets. Considering that the arterial traffic is typically much heavier, there are benefits to reverting back to the arterial, even with the penalty associated with an early return to green that could potentially lead to more stops downstream.

The next concept, which is apparent for all the studies (particularly preemption), is that it is not necessarily the transitioning that degrades the overall performance of an arterial network during unsaturated conditions, but rather

inadequate split timings, which results in spillback that often impedes the through movements. This was of a concern for the majority of these studies, particularly at instances where there were protected only left-turn arrows that only permitted vehicles to turn left during the green interval. Recall from the preemption study that this occurrence was related to the preemption event, which stole green time from such movements, while in the Traffic Responsive (TRP) study, it was the result of the wrong pattern being selected, thereby shorting those movements that require the additional time the most.

Given these instances, where the potential for spillback is evident during certain periods of the day, it can be beneficial to provide extra slack time for these movements, and designing the offset around the expected gap-out times, in order to avoid potential wasted time. This was tried with some of the latter networks that were examined as part of this research and the results appeared to be encouraging. Recall that left-turn spillback is of particular concern at diamond interchanges, where the limited interior left-turn storage often requires special phasing that forces such movements to stay active for longer periods of time (4-Phase).

It should be apparent from that last couple of chapters, that Traffic Responsive (TRP) procedures can reduce the total system delay, if the appropriate parameters are properly configured and are able to respond to a scenario that is not part of the traditional time-based (TOD) schedule. Recall that traffic responsive does best when the volume scenarios best match that of a pre-configured plan. Deviations from such plans can increase the likelihood of an incorrect plan being selected. However if the engineer did a good job designing the system heuristics, and considered the appropriate scenarios, then it is likely that the procedure would select the most suitable plan, for the given traffic pattern.

Recall that it is not necessarily the rapid plan selections that degrade the overall system performance, but rather one or more of the major approaches having inadequate split time. With proper configuration of the Traffic Responsive (TRP) parameters, these occurrences can usually be detected and responded to, while the time-based (TOD) procedures are fixed to a particular schedule and thereby can not respond. Although transitioning has only a slight impact on overall delay, the total number of stops encountered in the system generally increase with the more transitioning that occurs, provided that the system was optimally timed to begin with. Note that if the Traffic Responsive (TRP) selection chart contains the same traditional patterns (morning, midday, and afternoon) as the time-based (TOD) procedure, then the likelihood of relieving abnormally heavy congestion (events) is typically reduced, since such plans do not exist.

In cases where the appropriate Traffic Responsive (TRP) plans do not exist, it is likely such procedures may then perform close to, if not slightly worse than the time-based (TOD) operation had the same plans been justified. This is generally associated with the additional transitioning and response time required with the TRP procedure. Therefore, there may be little benefit for setting up such parameters in order to respond to typical traffic conditions. Hence, additional event plans which can not be included in the time-based schedule because of unpredictability in the occurrence is where TRP operation can be particularly helpful. Many vendors have a feature that allow the time-based (TOD) schedule remain active until heavier demands are detected by the TRP computations, at which time the time-based (TOD) plan can be temporarily overridden.

Future Research

This report provided a set of rational evaluation procedures that could be used to help better understand the operation of coordinated-actuated signal systems. The cycle analysis graphs and transitioning tables, which were

generated for all studies, as part of this research, were particularly helpful for determining how the actual control equipment responded to a variety of stimuli, ranging from emergency vehicle preemption to the advanced detector logic associated with diamond interchanges, and Traffic Responsive (TRP) strategies. These cycle graphs helps one examine the various transitioning algorithms inside the actual control equipment, only to realize that there is more research and possible improvements to be made in this area.

As evident from the cycle graphs for all cases examined as part of this research, it can be determined that the cycle lengths varied significantly during the transitioning intervals. This appeared to be most prevalent with those intersections that had lighter side street demand. During the analysis it was observed that some controllers would often reach their coordination cycle only to temporarily bounce out of coordination a cycle later, in order to make up for a permissive period that was serviced late during a prior cycle. Such findings indicate that more scrutiny into these transitioning algorithms may be advantageous, in order to possibly reduce the amount of time spent in transition.

LIST OF REFERENCES

LIST OF REFERENCES

- Bretherton, R.D., "Scoot Urban Traffic Control System: Philosophy and Evaluation," Control, Computers, Communications in Transportation, 1990, pp. 237-239.
- Bullock, D. and A. Catarella, "A Real-Time Simulation Environment for Evaluating Traffic Signal Systems," Transportation Research Record, #1634, TRB, National Research Council, Washington, DC, 1998, pp. 130-135.
- Bullock, D., G. Daigle, and J. Clark, "ATMS Evaluation Procedures," Proceedings of the Fifth ITS World Congress, October 12-16, 1998.
- Bullock, D., J.M. Morales, B. Sanderson, "Impact of Signal Preemption on the Operation of the Virginia Route 7 Corridor," Proceedings of the 1999 ITS America Conference, April 19-22, 1999.
- Bullock, D., T. Urbanik, and A. Catarella, "Traffic Signal System Progression Recovery from Railroad Preemption," Proceedings of the Fifth International Symposium on Railroad-Highway Grade Crossing Research and Safety, October 20-22, 1998, pp. 355-365.
- Capelle, D.G., and C. Pinell, "Design and Operation of Diamond Interchanges," Report E-45-61, Texas Transportation Institute, Texas A&M University, College Station, Texas, August 1961.
- Chang, E. C. P. "Guidelines for Actuated Controllers in Coordinated Systems." Transportation Research Record, #1554, TRB, National Research Council, Washington D.C., 1996, pp. 61-73.
- DeCamp, G.B., "A Primer on Diamond Interchanges," In TexITE News, Texas Section of Institute of Transportation Engineers, Houston, Texas, Spring 1993, pp. 3-4, 11.
- Dobinson, K.W., and A.G., Sim, "Sydney Coordinated Adaptive Traffic (SCAT) System Philosophy and Benefits," IEEE Transactions on Vehicular Technology, 1980, pp. 130-137.

- Econolite Control Products, Advanced System Controller ASC/2 Programming Manual. Anaheim, CA, 1996.
- Engelbrecht, R., C. Poe, and K. Balke, "Development of a Distributed Hardware-In-The-Loop Simulation System for Transportation Networks," Transportation Research Board Annual Meeting, National Research Council, Washington, DC, 1999, Preprint #990599.
- Fambro, D.B., and J.A. Bonneson, "Optimization and Evaluation of Diamond Interchange Signal Timing," In 1988 Compendium of Technical Papers, Institute of Transportation Engineers, Washington, DC, 1988, pp. 125.
- Gartner, N.H., "OPAC: A Demand-Responsive Strategy for Traffic Signal Control," Transportation Research Record, #906, TRB, National Research Council, Washington, DC, 1983, pp. 75-81.
- Kim, Y. and C.J. Messer, "Traffic Signal Timing Models for Oversaturated Signalized Interchanges," Research Report 1148-2, Texas Transportation Institute, Texas A&M University, College Station, Texas, January 1992.
- Head, L., P. Mirchandani and D. Sheppard. "Hierarchical Framework for Real-Time Traffic Control." Transportation Research Record, #1360, TRB, National Research Council, Washington, DC, 1992, pp. 82-88.
- Head, L., P. Mirchandani and S. Shelby. "The RHODES Prototype: A Description and Some Results." Proceedings from the 77th Annual Meeting of the Transportation Research Board. TRB, Washington, DC, 1998.
- Herrick, G.C., and C.J. Messer, "Strategies for Improving Traffic Operations at Oversaturated Signalized Interchanges," Research Report 1148-4F, Texas Transportation Institute, Texas A&M University, College Station, Texas, March 1992.
- Husch, D., 1999, "SimTraffic CI Supplemental Guide," Trafficware, Berkely, CA.
- Jovanis, P.P., and J.A. Gregor. "Coordination of Actuated Arterial Traffic Signal Systems." Journal of Transportation Engineering, Volume 112, Number 4. American Society of Civil Engineers, New York, NY, July 1986.
- Koonce, P.T. Urbanik, and D. Bullock, "Evaluation of Diamond Interchange Settings using Hardware-In-The-Loop-Simulation," Transportation Research Board, National Research Council, Washington, DC, 1999, Preprint #990715.

- Lin, Pei-Sung and Kenneth G. Courage. "Phase Time Prediction for Traffic-Actuated Intersections." Transportation Research Record, #1555, TRB, National Research Council, Washington, DC, 1996, pp. 17-22.
- Lom, K. M. and C. E. Lee, "Actuated Traffic Signal Control at Diamond Interchanges," ASCE Journal of Transportation Engineering, v 118 n 3, May-June 1992, p. 410-429.
- Messer, C.J., and M. S. Chang, "Traffic Operations of Basic Traffic-Actuated Control Systems at Diamond Interchanges," Transportation Research Record, #1114, TRB, National Research Council, Washington, DC, 1987, pp. 54-62.
- Messer, C.J. and R. Nageswara. "Improved Traffic Signal Coordination Strategies for Actuated Control." Texas Transportation Institute, Texas A&M University, College Station, Texas, August 1996.
- Munjal, P.K., "An Analysis of Diamond Interchanges," Transportation Research Record, #349, TRB, National Research Council, Washington, DC, 1971, pp. 47-64.
- National Electrical Manufacturers Association, National Transportation Communications for ITS Protocol Object Definitions for Actuated Traffic Signal Controller Units, Standards Publication No. TS 3.5-1996, Washington, DC, 1996.
- National Electrical Manufacturers Association. Traffic Controller Assemblies. Standards Publication No. TS 2, Washington, DC, 1992.
- National Research Council, Transportation Research Board Special Report 209, Highway Capacity Manual. 3rd Edition. Washington DC, 1997.
- Nelson, E and D. Bullock, "Impact Evaluation of Emergency Vehicle Preemption on Signalized Corridor Operation," Transportation Research Board, National Research Council, Washington, DC, 2000, Preprint #00847.
- "Passer III-98 Users Manual," Texas Transportation Institute, 1998.
- Shoup, G. and D. Bullock, "A Dynamic Offset Tuning Procedure Using Real-Time Travel Data," Transportation Research Record, #1683, TRB, National Research Council, Washington, DC, 1999, pp. 84-94.
- Shoup, G. and D. Bullock, "Performance Evaluation of Coordinated-Actuated Traffic Signal Systems," Proceedings of the 1999 Institute of Transportation Engineers Annual Meeting, August 1-4, 1999.

- Skabardonis, A. "Determination of Timings in Signal Systems with Traffic-Actuated Controllers." Transportation Research Record, #1554, TRB, National Research Council, Washington, DC, 1996, pp. 18-26.
- Wallace, C. E. and K. G. Courage. "Arterial Progression - New Design Approach." Transportation Research Record, #881, TRB, National Research Council, Washington, DC, 1982, pp. 53-59.
- Yamada, K. and T. Yokota. "Realization of Offset Optimization which Takes Crossroad Traffic Demand into Account." ITS Fifth World Congress, Seoul, Korea, 1998.

APPENDICIES

APPENDIX A – EMERGENCY VEHICLE PREEMPTION CYCLE ANALYSIS
AND TRANSITIONING RESULTS

INT_1	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
	TIME	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD
8:00	311	311	311	311	311	311	311	311	311
8:02	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:06	311	TRAN	TRAN	TRAN	311	311	TRAN	TRAN	TRAN
8:08	311	TRAN	311	TRAN	311	311	TRAN	TRAN	311
8:10	311	TRAN	311	311	311	311	TRAN	TRAN	311
8:12	311	TRAN	311	311	311	311	TRAN	311	TRAN
8:14	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	311	311	TRAN
8:18	311	311	311	311	311	311	311	311	TRAN
8:20	311	311	311	311	311	311	311	311	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	82%	46%	73%	64%	85%	83%	36%	45%	36%

DMD	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
	TIME	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD
8:00	311	311	311	311	311	311	311	311	311
8:02	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:06	TRAN	TRAN	TRAN	TRAN	TRAN	311	TRAN	TRAN	TRAN
8:08	311	TRAN	TRAN	311	TRAN	311	TRAN	TRAN	TRAN
8:10	311	TRAN	311	311	TRAN	311	TRAN	TRAN	311
8:12	311	311	311	311	TRAN	311	TRAN	TRAN	TRAN
8:14	311	311	311	311	TRAN	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	311	311	TRAN
8:18	311	311	311	311	311	311	311	311	TRAN
8:20	311	311	311	311	311	311	311	311	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	73%	55%	64%	73%	36%	81%	36%	36%	27%

INT_4	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
	TIME	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD
8:00	311	311	311	311	311	311	311	311	311
8:02	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	311
8:06	311	TRAN	TRAN	311	TRAN	TRAN	311	TRAN	311
8:08	311	TRAN	311	311	TRAN	TRAN	311	311	311
8:10	311	TRAN	311	311	311	311	311	311	311
8:12	311	TRAN	311	311	311	311	TRAN	TRAN	TRAN
8:14	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	311	311	TRAN
8:18	311	311	311	311	311	311	311	311	311
8:20	311	311	311	311	311	311	311	311	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	82%	45%	73%	82%	63%	64%	64%	55%	48%

Table A-1: SR 26 (South) Pattern Select Table – Path_1 (All Scenarios)

INT_1	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
TIME	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	TRAN	311	311	311	TRAN	TRAN	TRAN	311	311
8:02	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:06	TRAN	TRAN	311	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:08	311	311	311	TRAN	TRAN	311	TRAN	TRAN	TRAN
8:10	311	311	311	TRAN	TRAN	311	311	TRAN	311
8:12	311	311	311	311	TRAN	311	TRAN	TRAN	TRAN
8:14	311	311	311	311	TRAN	311	TRAN	TRAN	311
8:16	311	311	311	311	TRAN	311	TRAN	311	311
8:18	311	311	311	311	311	311	311	311	311
8:20	311	311	311	311	311	311	311	311	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	73%	73%	82%	54%	27%	72%	36%	36%	54%

DMD	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
TIME	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	TRAN	311	311	311	TRAN	311	311	311	311
8:02	TRAN	TRAN	311	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:06	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:08	TRAN	TRAN	TRAN	TRAN	TRAN	311	TRAN	TRAN	TRAN
8:10	311	TRAN	311	311	TRAN	311	311	TRAN	311
8:12	311	311	311	311	311	311	TRAN	TRAN	311
8:14	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	311	TRAN	311
8:18	311	311	311	311	311	311	311	TRAN	311
8:20	311	311	311	311	311	311	311	TRAN	311
8:22	311	311	311	311	311	311	311	TRAN	311
SYNC	64%	54%	64%	63%	55%	73%	55%	9%	45%

INT_4	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
TIME	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	311	311	311	311	TRAN	311	311	TRAN	311
8:02	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	311	311	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:06	311	311	311	TRAN	TRAN	311	311	TRAN	311
8:08	311	311	311	311	TRAN	311	311	TRAN	311
8:10	311	311	311	311	TRAN	311	311	TRAN	311
8:12	311	311	311	311	TRAN	311	TRAN	TRAN	TRAN
8:14	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:18	311	311	311	311	311	311	TRAN	TRAN	311
8:20	311	311	311	311	311	311	311	TRAN	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	84%	90%	91%	72%	45%	83%	46%	8%	45%

Table A-2: SR 26 (South) Pattern Select Table – Path_2 (All Scenarios)

INT_1	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
TIME	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	311	311	311	311	311	311	311	TRAN	311
8:02	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:06	TRAN	TRAN	TRAN	TRAN	TRAN	311	TRAN	TRAN	TRAN
8:08	TRAN	TRAN	311	TRAN	TRAN	311	TRAN	TRAN	TRAN
8:10	311	TRAN	311	TRAN	TRAN	311	311	TRAN	311
8:12	311	TRAN	311	311	TRAN	311	TRAN	311	TRAN
8:14	311	311	311	311	TRAN	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	311	311	311
8:18	311	311	311	311	311	311	311	311	311
8:20	311	311	311	311	311	311	311	311	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	64%	46%	76%	55%	38%	83%	45%	36%	45%

DMD	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
TIME	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	311	311	311	311	311	311	311	311	311
8:02	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:06	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:08	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:10	311	TRAN	311	TRAN	TRAN	311	311	TRAN	311
8:12	311	TRAN	311	311	TRAN	311	TRAN	TRAN	TRAN
8:14	311	311	311	311	TRAN	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	311	311	311
8:18	311	311	311	311	311	311	311	311	311
8:20	311	311	311	311	311	311	311	311	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	64%	46%	64%	55%	36%	65%	45%	36%	45%

INT_4	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
TIME	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	311	311	311	311	311	311	311	311	311
8:02	311	311	311	311	311	311	311	311	311
8:04	311	311	311	311	311	311	311	311	311
8:06	311	311	311	311	311	311	311	311	311
8:08	311	311	311	311	311	311	311	311	311
8:10	311	311	311	311	311	311	311	311	311
8:12	311	311	311	311	311	311	311	311	311
8:14	311	311	311	311	311	311	311	311	311
8:16	311	311	311	311	311	311	311	311	311
8:18	311	311	311	311	311	311	311	311	311
8:20	311	311	311	311	311	311	311	311	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table A-3: SR 26 (South) Pattern Select Table – Path_3 (All Scenarios)

INT_1	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
TIME	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	311	311	311	311	311	311	311	311	311
8:02	311	311	311	311	311	311	311	311	311
8:04	311	311	311	311	311	311	311	311	311
8:06	311	311	311	311	311	311	311	311	311
8:08	311	311	311	311	311	311	311	311	311
8:10	311	311	311	311	311	311	311	311	311
8:12	311	311	311	311	311	311	311	311	311
8:14	311	311	311	311	311	311	311	311	311
8:16	311	311	311	311	311	311	311	311	311
8:18	311	311	311	311	311	311	311	311	311
8:20	311	311	311	311	311	311	311	311	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	100%	100%	100%	100%	100%	100%	100%	100%	100%

DMD	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
TIME	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	311	311	TRAN	311	311	311	TRAN	311	311
8:02	311	311	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:06	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:08	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:10	311	311	311	311	TRAN	311	TRAN	TRAN	311
8:12	311	311	311	311	TRAN	311	TRAN	TRAN	TRAN
8:14	311	311	311	311	TRAN	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	311	TRAN	311
8:18	311	311	311	311	311	311	311	311	311
8:20	311	311	311	311	311	311	311	311	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	63%	64%	64%	64%	36%	63%	36%	27%	45%

INT_4	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
TIME	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	TRAN	311	311	311	311	TRAN	TRAN	311	311
8:02	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	311	TRAN	TRAN
8:06	311	TRAN	TRAN	TRAN	TRAN	TRAN	311	311	311
8:08	311	TRAN	311	311	311	311	311	311	311
8:10	311	TRAN	311	311	311	311	311	311	311
8:12	311	TRAN	311	311	311	311	TRAN	TRAN	TRAN
8:14	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:18	311	311	311	311	311	311	TRAN	TRAN	311
8:20	311	311	311	311	311	311	311	311	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	82%	46%	74%	73%	72%	73%	45%	28%	54%

Table A-4: SR 26 (South) Pattern Select Table – Path_4 (All Scenarios)

INT_1	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	TRAN	TRAN	311	311	TRAN	311	311	311	311
8:02	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:06	311	TRAN	311	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:08	311	TRAN	311	TRAN	311	311	TRAN	TRAN	TRAN
8:10	311	TRAN	311	311	311	311	TRAN	311	311
8:12	311	TRAN	311	311	311	311	TRAN	TRAN	TRAN
8:14	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	311	TRAN	311
8:18	311	311	311	311	311	311	311	TRAN	311
8:20	311	311	311	311	311	311	311	TRAN	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	82%	45%	81%	64%	73%	72%	36%	19%	45%

DMD	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	TRAN	TRAN	311	311	TRAN	311	311	311	311
8:02	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:06	TRAN	TRAN	311	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:08	311	TRAN	311	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:10	311	TRAN	311	311	TRAN	311	TRAN	TRAN	TRAN
8:12	311	TRAN	311	311	311	311	TRAN	TRAN	TRAN
8:14	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	TRAN	TRAN	311
8:18	311	311	311	311	311	311	311	TRAN	311
8:20	311	311	311	311	311	311	311	TRAN	311
8:22	311	311	311	311	311	311	311	TRAN	311
SYNC	73%	45%	81%	64%	55%	63%	27%	9%	30%

INT_4	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	311	311	311	311	311	311	311	311	311
8:02	311	311	311	311	311	311	311	311	311
8:04	311	311	311	311	311	311	311	311	311
8:06	311	311	311	311	311	311	311	311	311
8:08	311	311	311	311	311	311	311	311	311
8:10	311	311	311	311	311	311	311	311	311
8:12	311	311	311	311	311	311	311	311	311
8:14	311	311	311	311	311	311	311	311	311
8:16	311	311	311	311	311	311	311	311	311
8:18	311	311	311	311	311	311	311	311	311
8:20	311	311	311	311	311	311	311	311	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table A-5: SR 26 (South) Pattern Select Table – Path_5 (All Scenarios)

INT_1	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	311	311	311	311	311	311	311	311	311
8:02	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:06	311	TRAN	311	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:08	311	311	311	TRAN	TRAN	311	TRAN	TRAN	TRAN
8:10	311	311	311	TRAN	311	311	311	TRAN	311
8:12	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:14	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	TRAN	311	311
8:18	311	311	311	311	311	311	311	311	311
8:20	311	311	311	311	311	311	311	311	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	82%	72%	82%	50%	64%	73%	36%	36%	45%

DMD	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	TRAN	311	311	311	311	311	311	311	311
8:02	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:06	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:08	311	TRAN	311	311	TRAN	TRAN	TRAN	TRAN	TRAN
8:10	311	TRAN	311	311	TRAN	311	TRAN	311	TRAN
8:12	311	311	311	311	TRAN	311	TRAN	311	TRAN
8:14	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	TRAN	TRAN	311
8:18	311	311	311	311	311	311	311	TRAN	311
8:20	311	311	311	311	311	311	311	TRAN	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	73%	54%	73%	73%	45%	64%	27%	18%	36%

INT_4	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	311	311	311	311	311	311	311	311	311
8:02	311	311	311	311	311	311	311	311	311
8:04	311	311	311	311	311	311	311	311	311
8:06	311	311	311	311	311	311	311	311	311
8:08	311	311	311	311	311	311	311	311	311
8:10	311	311	311	311	311	311	311	311	311
8:12	311	311	311	311	311	311	311	311	311
8:14	311	311	311	311	311	311	311	311	311
8:16	311	311	311	311	311	311	311	311	311
8:18	311	311	311	311	311	311	311	311	311
8:20	311	311	311	311	311	311	311	311	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table A-6: SR 26 (South) Pattern Select Table – Path_6 (All Scenarios)

INT_1	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
TIME	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	311	311	311	311	311	311	311	311	311
8:02	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:06	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:08	311	TRAN	311	TRAN	311	311	TRAN	TRAN	311
8:10	311	TRAN	311	TRAN	311	311	TRAN	TRAN	311
8:12	311	TRAN	311	311	311	311	TRAN	TRAN	TRAN
8:14	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:18	311	311	311	311	311	311	311	TRAN	TRAN
8:20	311	311	311	311	311	311	311	TRAN	311
8:22	311	311	311	311	311	311	311	311	311
SYNC	72%	45%	63%	55%	73%	73%	20%	9%	36%

DMD	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
TIME	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	311	TRAN	311	311	311	311	311	311	TRAN
8:02	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:06	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:08	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:10	311	311	311	TRAN	311	311	311	TRAN	311
8:12	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:14	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:18	311	311	311	311	311	311	311	TRAN	TRAN
8:20	111	311	311	311	311	311	311	TRAN	311
8:22	311	311	311	311	311	311	311	TRAN	311
SYNC	63%	64%	63%	55%	64%	64%	36%	9%	27%

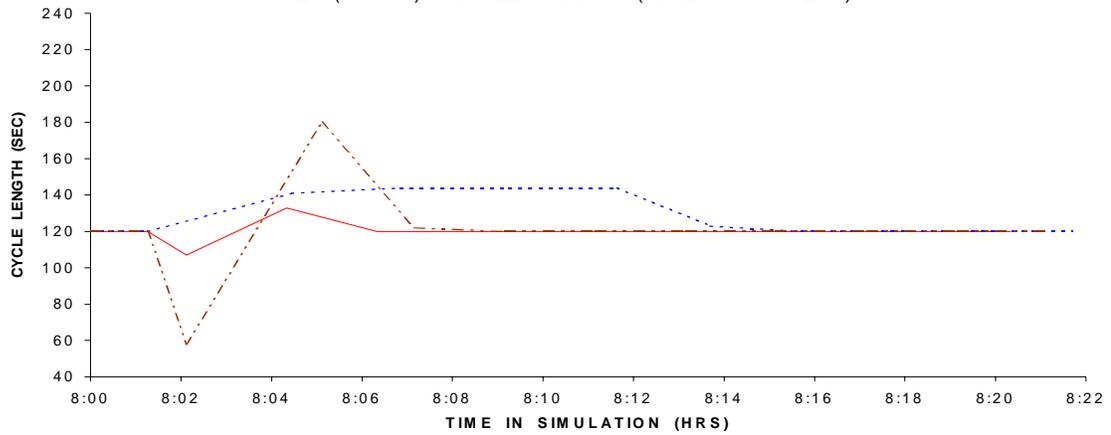
INT_4	1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
TIME	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
8:00	TRAN	311	TRAN	311	311	311	TRAN	311	311
8:02	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:04	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN	TRAN
8:06	TRAN	TRAN	311	TRAN	TRAN	311	TRAN	TRAN	TRAN
8:08	311	TRAN	311	311	311	311	TRAN	TRAN	TRAN
8:10	311	TRAN	311	311	311	311	TRAN	TRAN	311
8:12	311	TRAN	311	311	311	311	TRAN	TRAN	TRAN
8:14	311	311	311	311	311	311	TRAN	TRAN	TRAN
8:16	311	311	311	311	311	311	311	TRAN	311
8:18	311	311	311	311	311	311	311	TRAN	311
8:20	311	311	311	311	311	311	311	TRAN	311
8:22	311	311	311	311	311	311	311	TRAN	311
SYNC	73%	45%	73%	72%	72%	81%	36%	9%	45%

Table A-7: SR 26 (South) Pattern Select Table – Path_7 (All Scenarios)

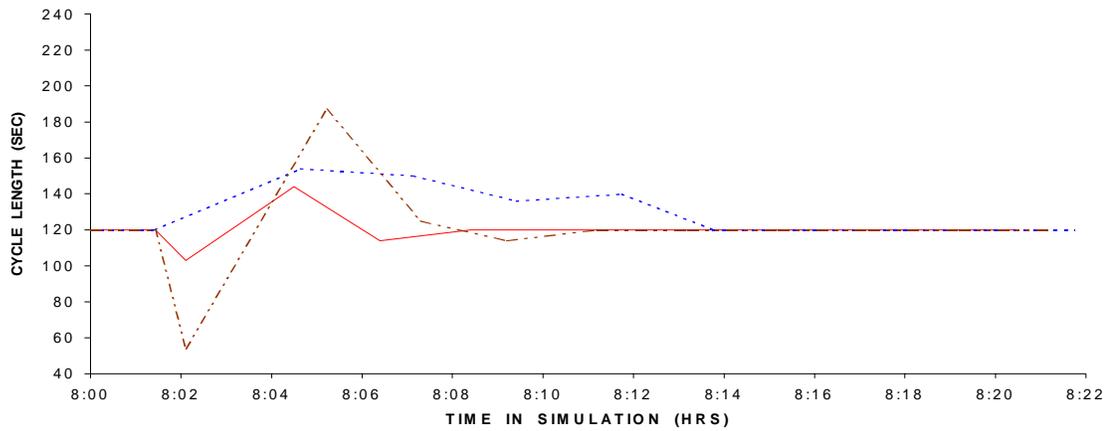
PREEMPTION		1_PREEMPT			2_PREEMPTS			3_PREEMPTS		
PATH	NODE	SMT	ADD	DWL	SMT	ADD	DWL	SMT	ADD	DWL
1	1	82	46	73	64	85	83	36	45	36
1	2-3	73	55	64	73	36	81	36	36	27
1	4	82	45	73	82	63	64	64	55	48
2	1	73	73	82	54	27	72	36	36	54
2	2-3	64	54	64	63	55	73	55	9	45
2	4	84	90	91	72	45	83	46	8	45
3	1	64	46	76	55	38	83	45	36	45
3	2-3	64	46	64	55	36	65	45	36	45
3	4	100	100	100	100	100	100	100	100	100
4	1	100	100	100	100	100	100	100	100	100
4	2-3	63	64	64	64	36	63	36	27	45
4	4	82	46	74	73	72	73	45	28	54
5	1	82	45	81	64	73	72	36	19	45
5	2-3	73	45	81	64	55	63	27	9	30
5	4	100	100	100	100	100	100	100	100	100
6	1	82	72	82	50	64	73	36	36	45
6	2-3	73	54	73	73	45	64	27	18	36
6	4	100	100	100	100	100	100	100	100	100
7	1	72	45	63	55	73	73	20	9	36
7	2-3	63	64	63	55	64	64	36	9	27
7	4	73	45	73	72	72	81	36	9	45

Table A-8: SR 26 (South) Percent In-Sync (%) Table – All Scenarios

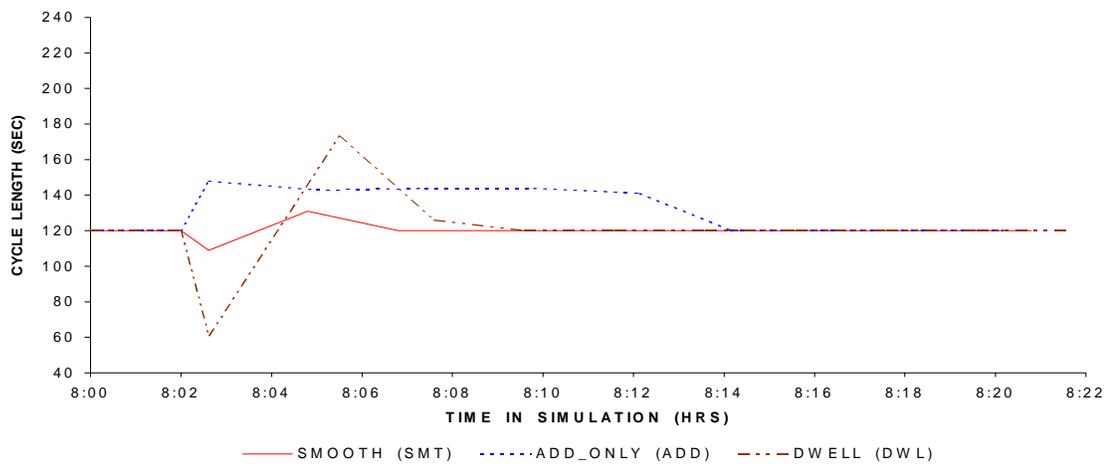
ANALYSIS OF TRANSITIONING ALGORITHMS (1_PREEMPT)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



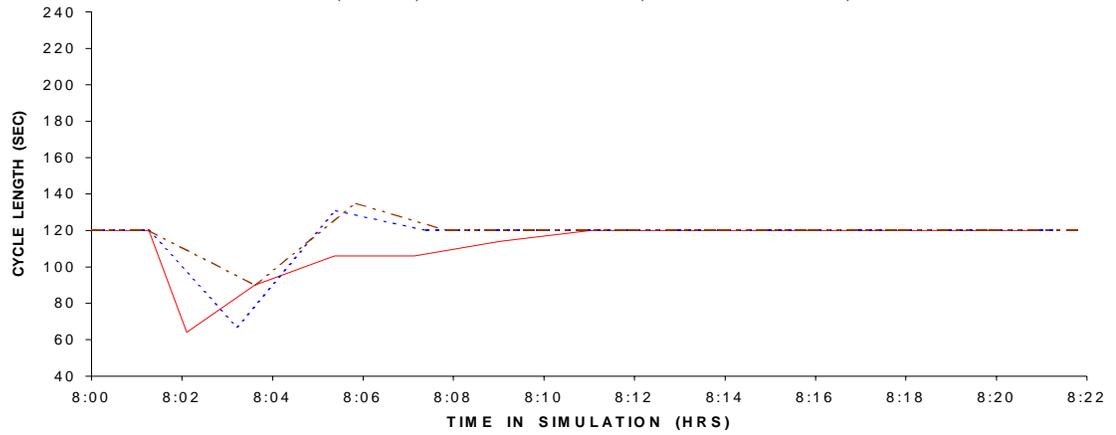
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



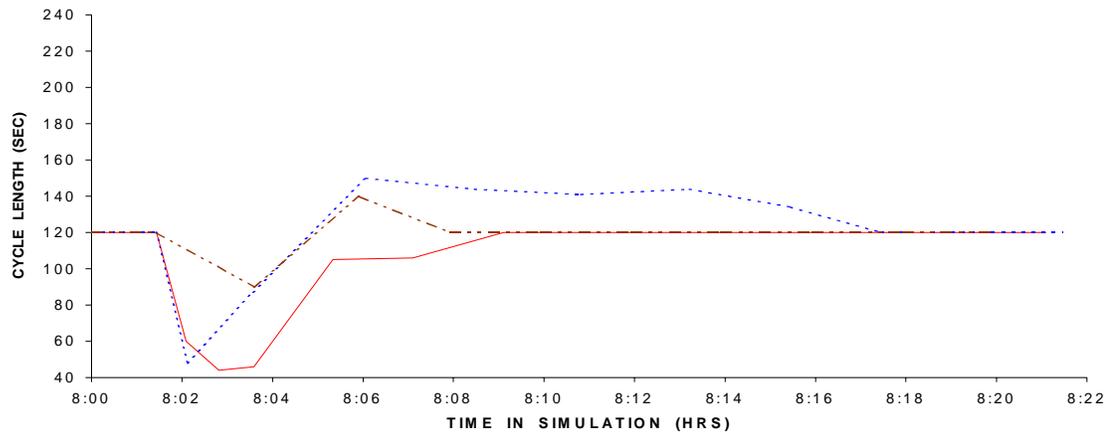
c) Node 4: SR 26 & Meijer Entrance

Figure A-1: SR 26 (South) System Cycle Graphs – 1_Preempt (Path_1)

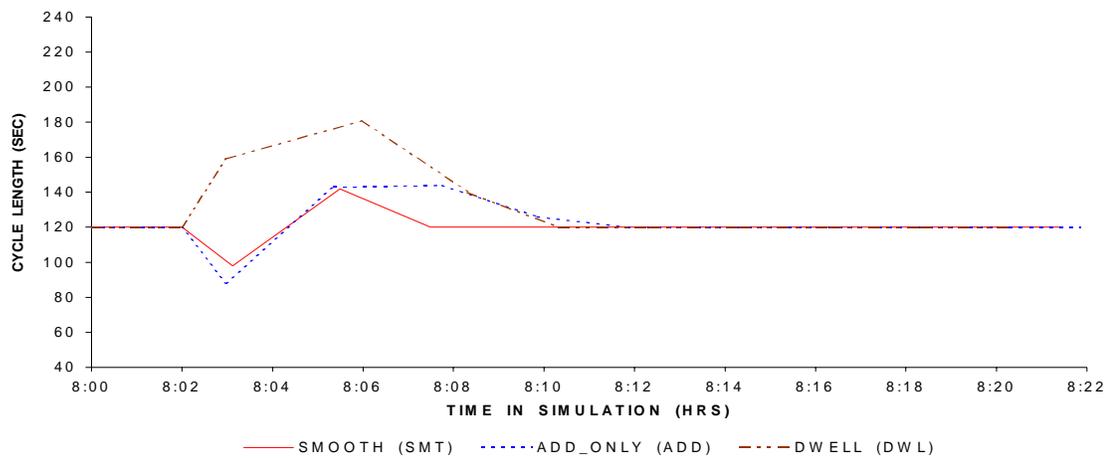
ANALYSIS OF TRANSITIONING ALGORITHMS (2_PREEMPTS)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



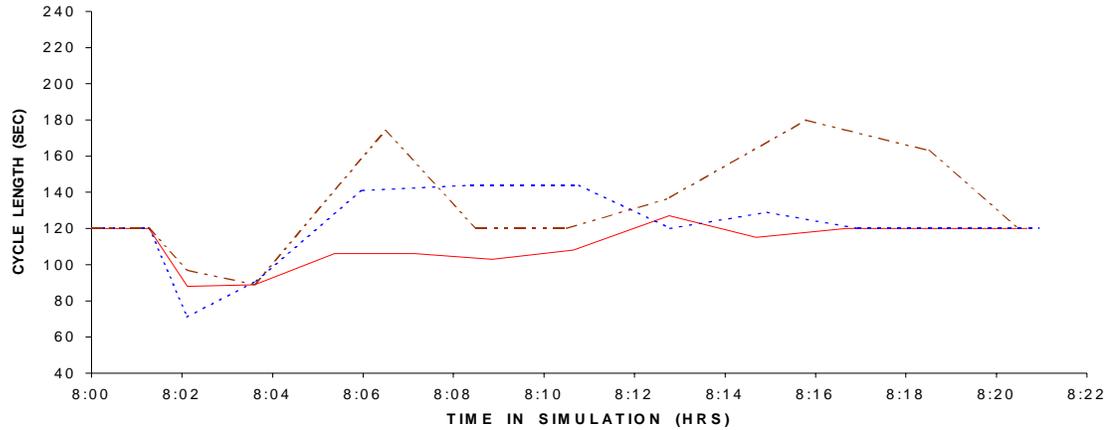
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



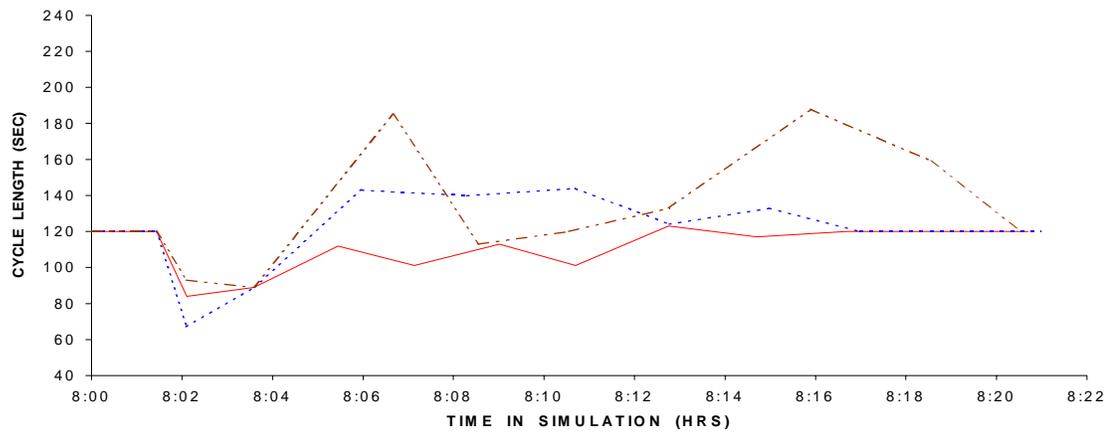
c) Node 4: SR 26 & Meijer Entrance

Figure A-2: SR 26 (South) System Cycle Graphs – 2_Preempts (Path_1)

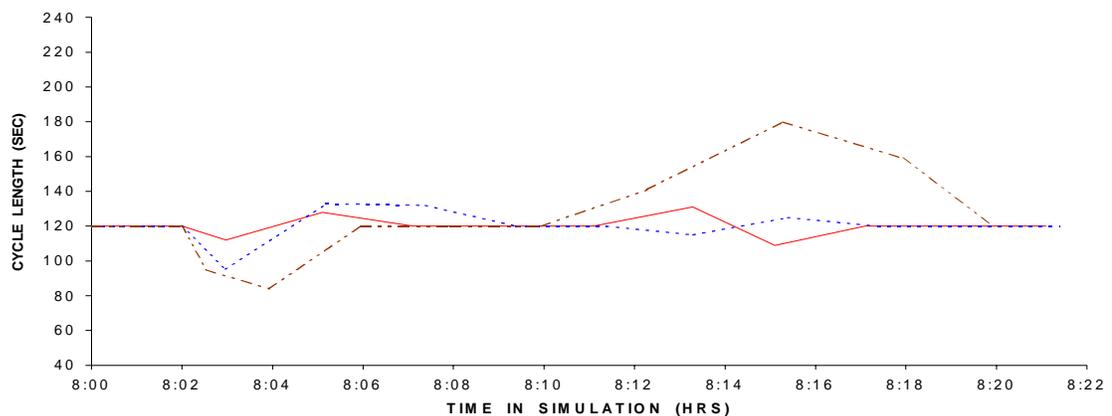
ANALYSIS OF TRANSITIONING ALGORITHMS (3_PREENPTS)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)

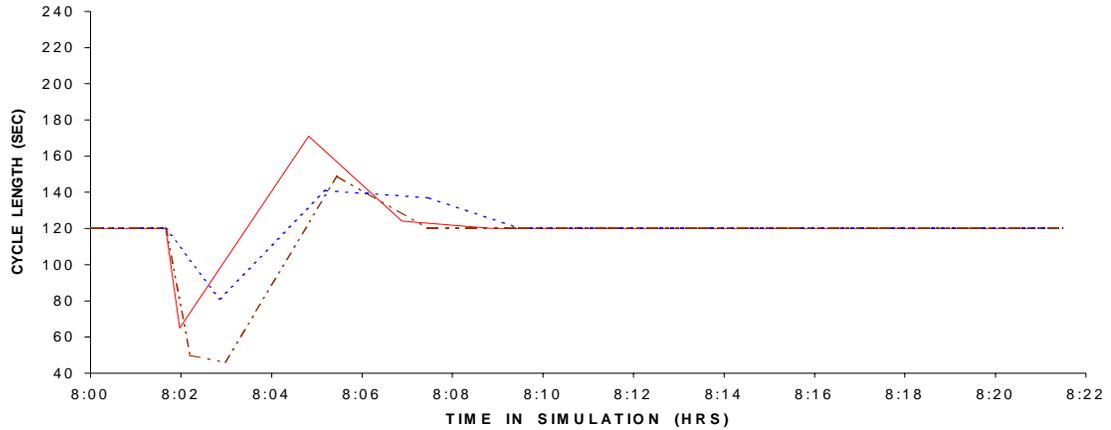


— SMOOTH (SMT) - - - - ADD_ONLY (ADD) - - - - DWELL (DWL)

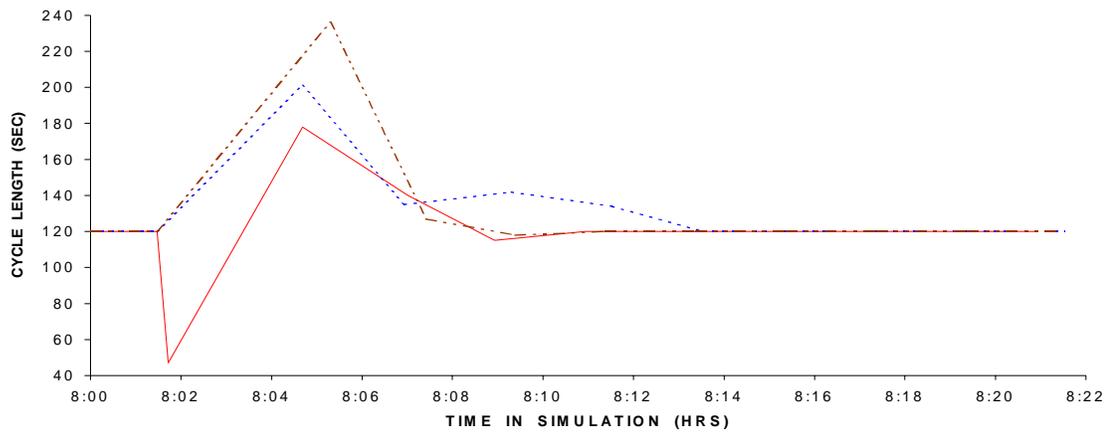
c) Node 4: SR 26 & Meijer Entrance

Figure A-3: SR 26 (South) System Cycle Graphs – 3_Preempts (Path_1)

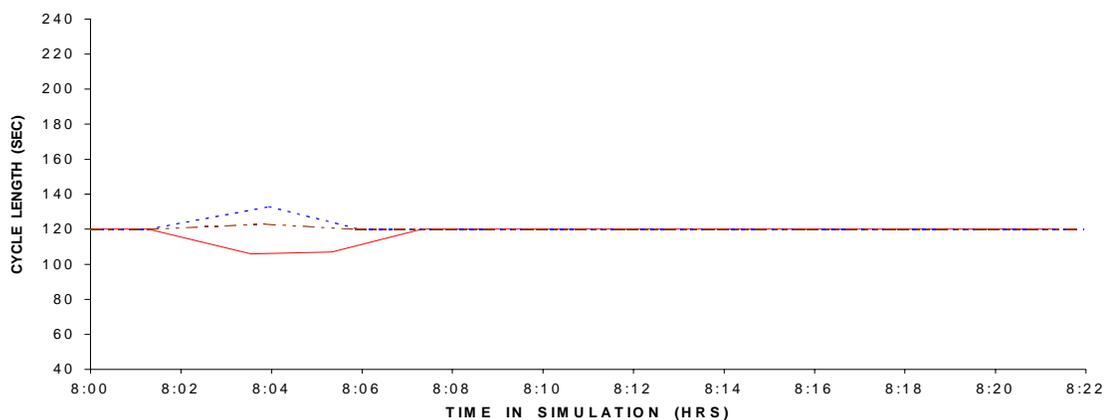
ANALYSIS OF TRANSITIONING ALGORITHMS (1_PREEMPT)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



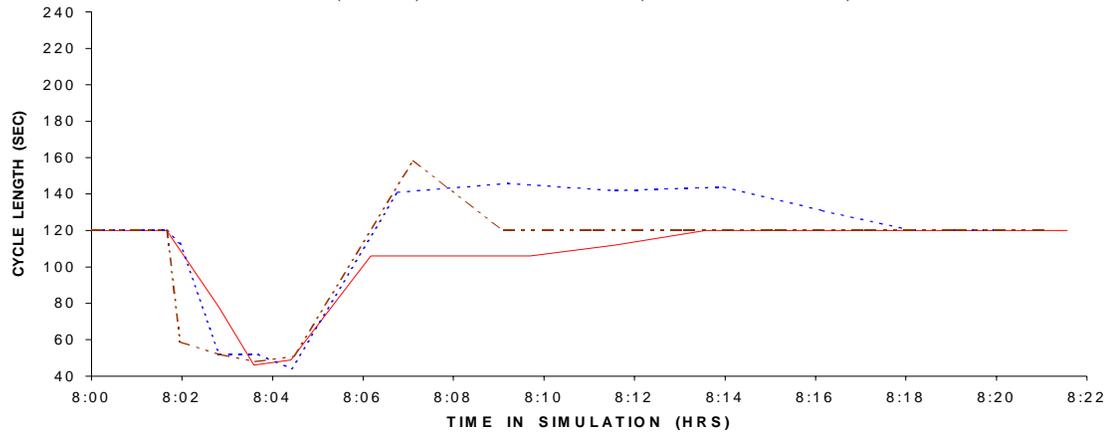
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



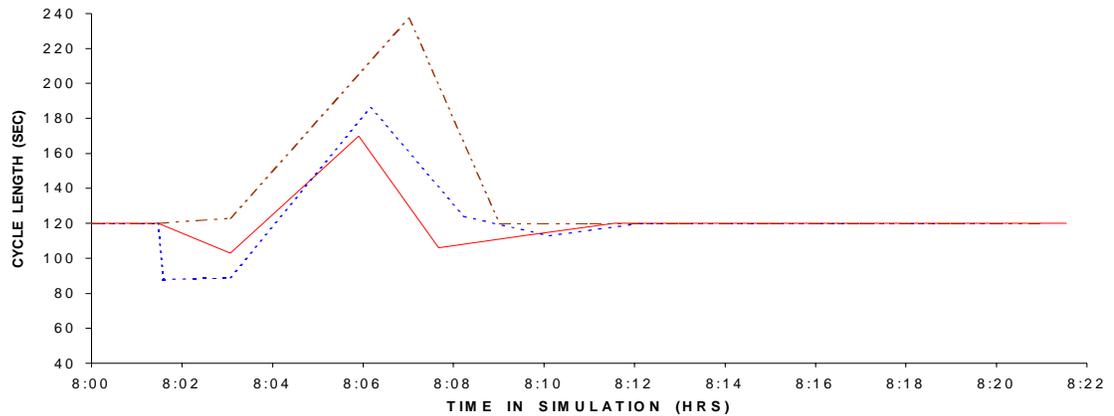
c) Node 4: SR 26 & Meijer Entrance

Figure A-4: SR 26 (South) System Cycle Graphs – 1_Preempt (Path_2)

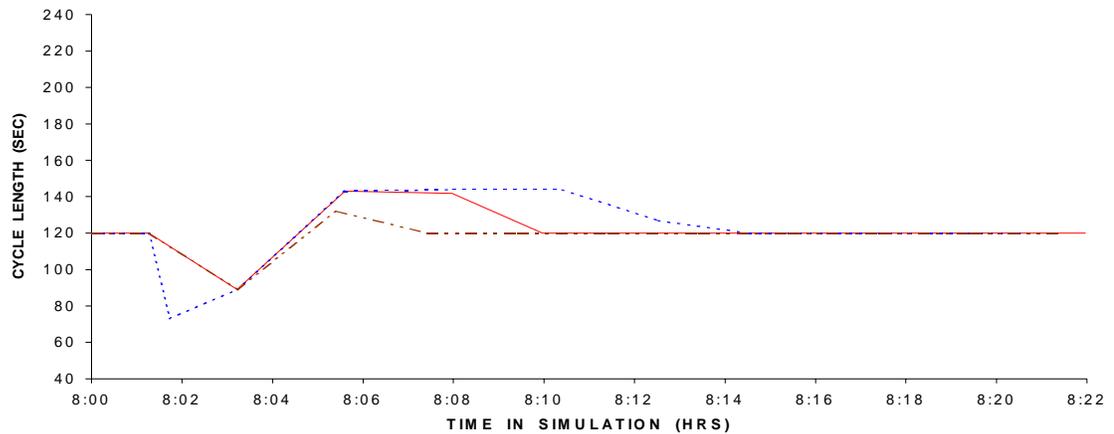
ANALYSIS OF TRANSITIONING ALGORITHMS (2_PREEMPTS)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



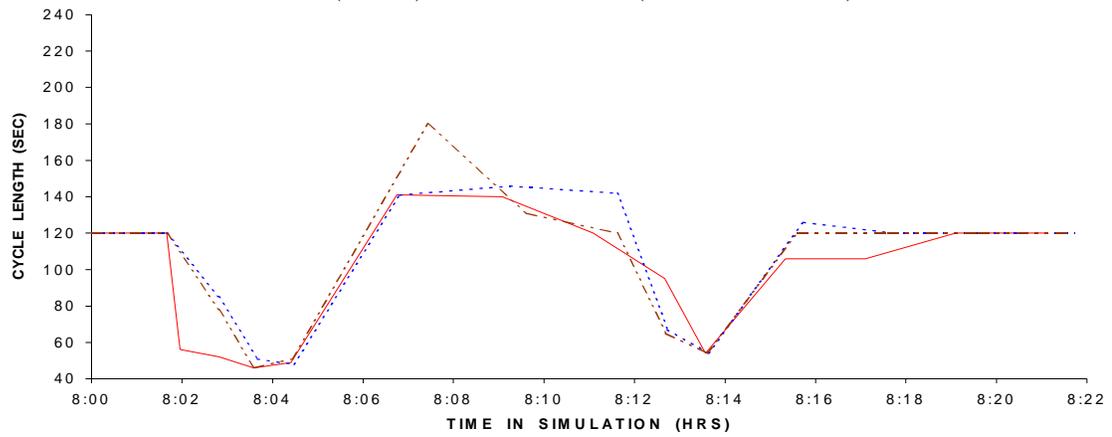
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



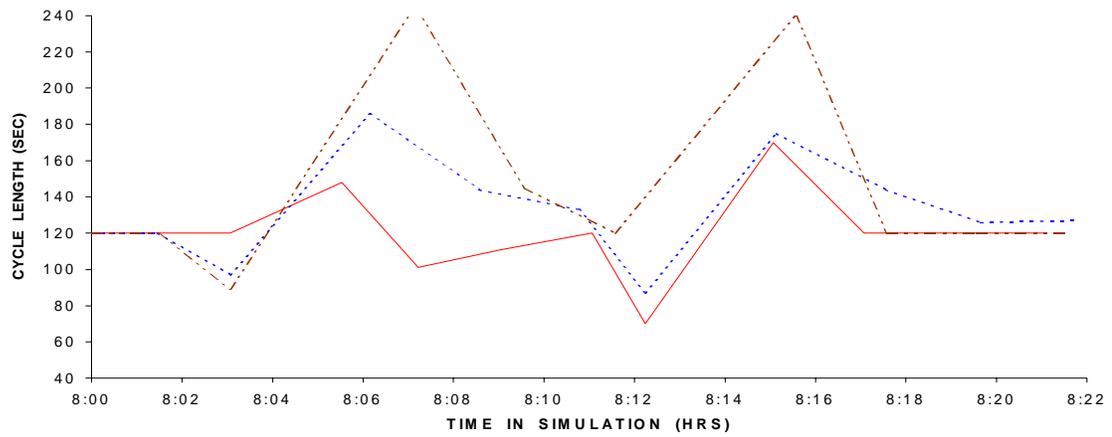
c) Node 4: SR 26 & Meijer Entrance

Figure A-5: SR 26 (South) System Cycle Graphs – 2_Preempts (Path_2)

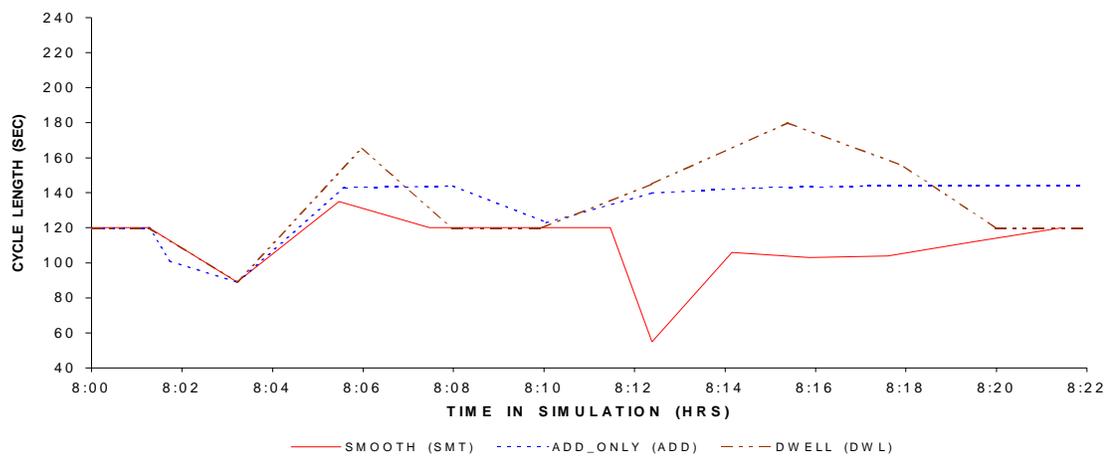
ANALYSIS OF TRANSITIONING ALGORITHMS (3_PREEMPTS)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



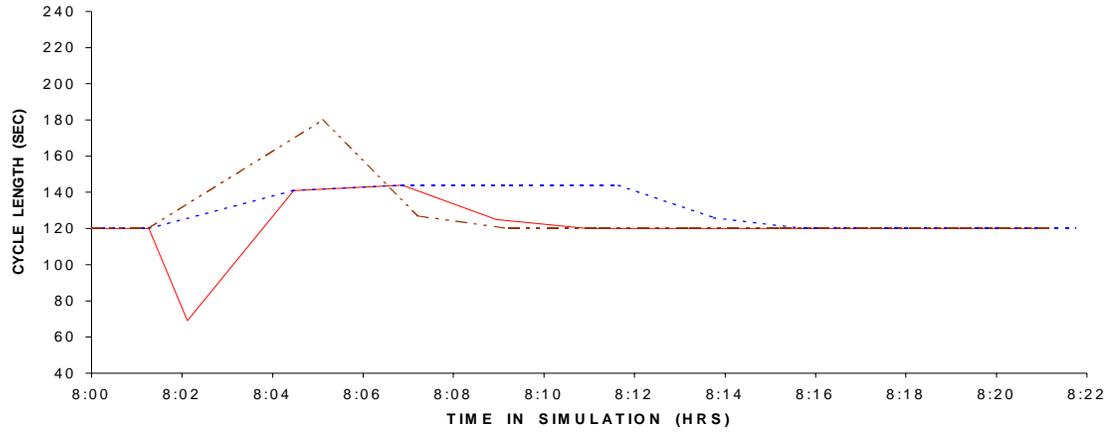
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



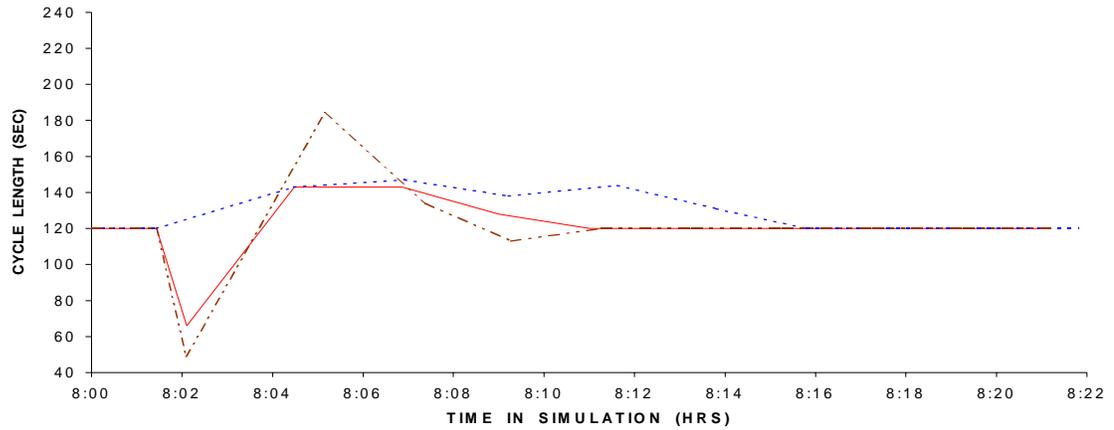
c) Node 4: SR 26 & Meijer Entrance

Figure A-6: SR 26 (South) System Cycle Graphs – 3_Preempts (Path_2)

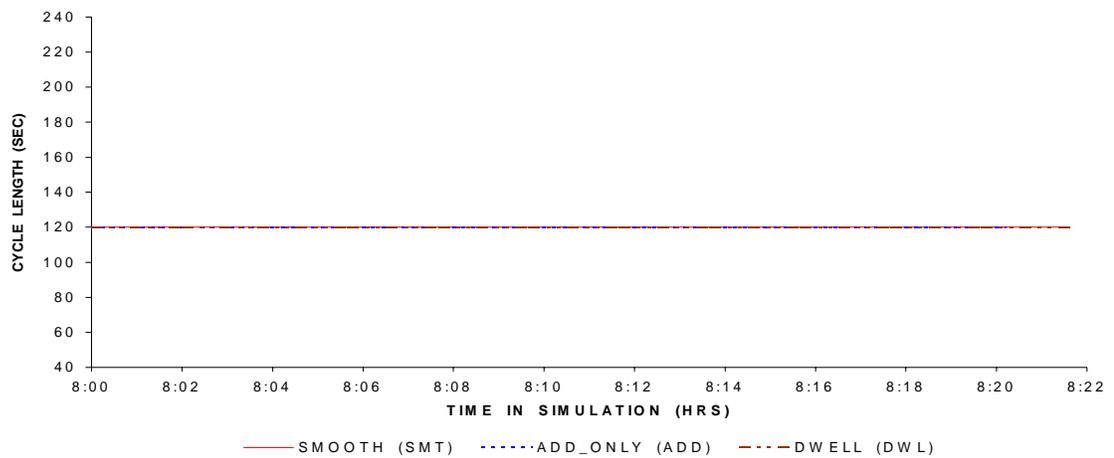
ANALYSIS OF TRANSITIONING ALGORITHMS (1_PREEMPT)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



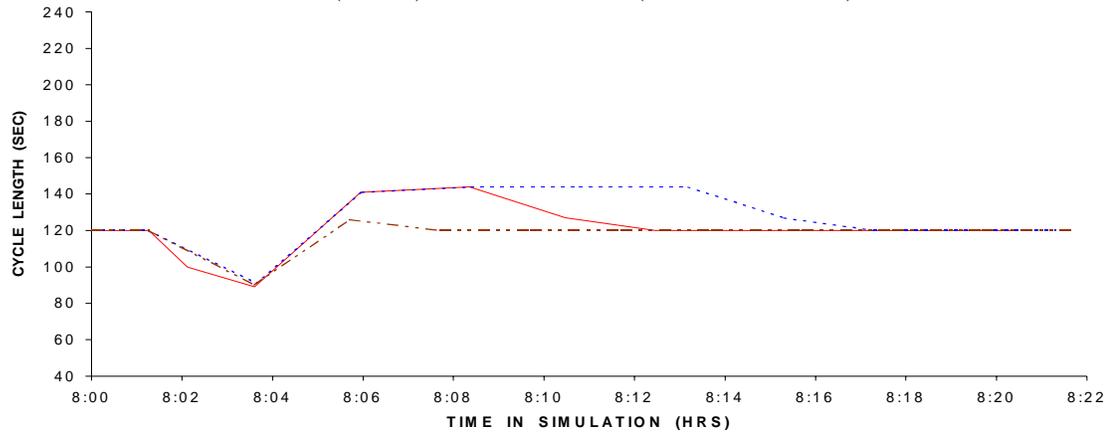
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



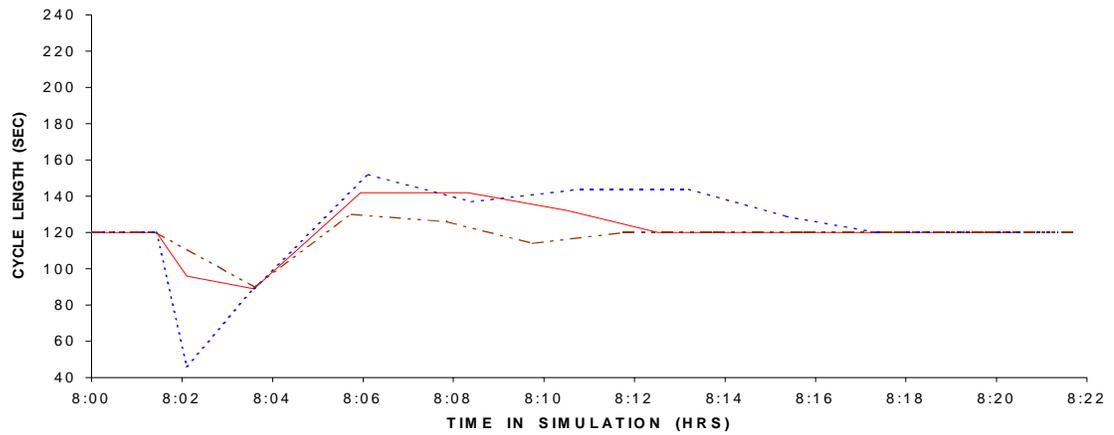
c) Node 4: SR 26 & Meijer Entrance

Figure A-7: SR 26 (South) System Cycle Graphs – 1_Preempt (Path_3)

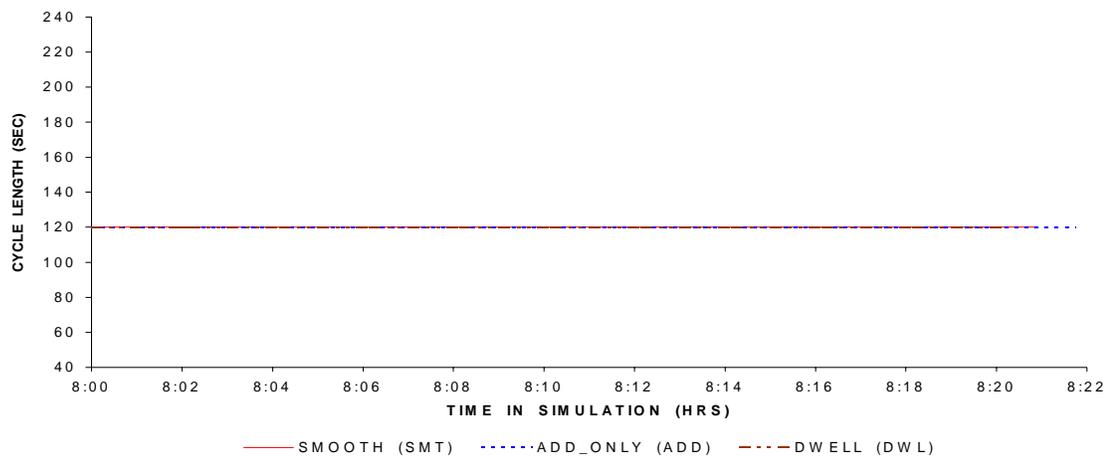
ANALYSIS OF TRANSITIONING ALGORITHMS (2_PREEMPTS)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



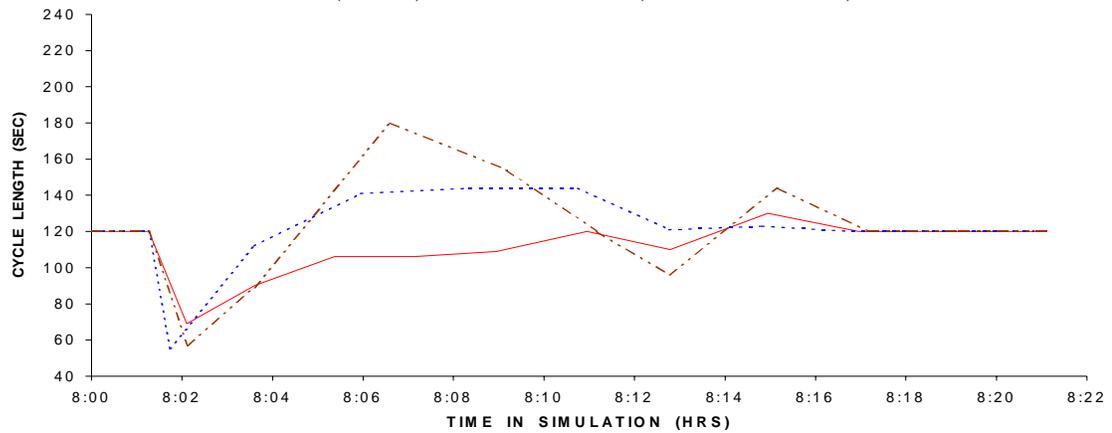
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



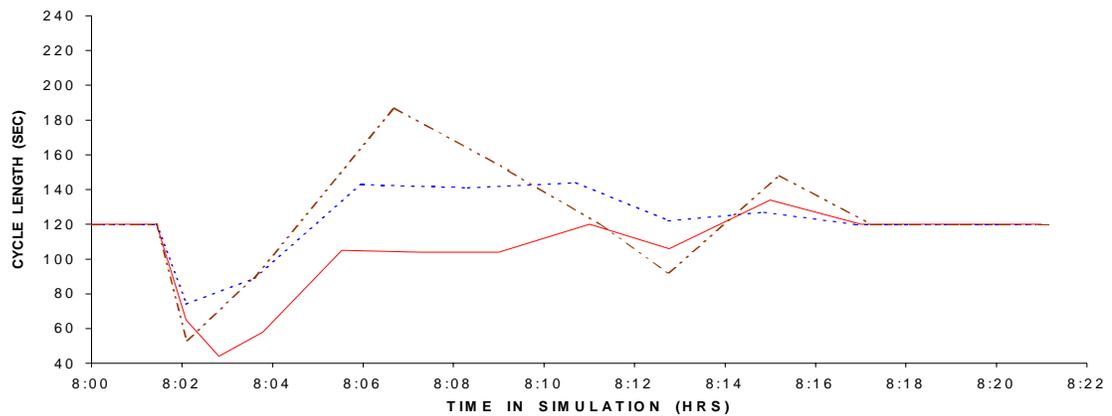
c) Node 4: SR 26 & Meijer Entrance

Figure A-8: SR 26 (South) System Cycle Graphs – 2_Preempts (Path_3)

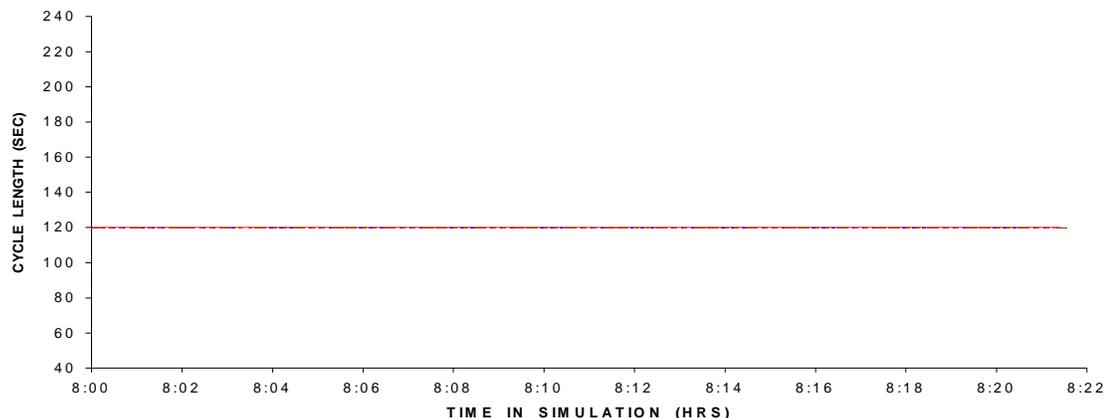
ANALYSIS OF TRANSITIONING ALGORITHMS (3_PREEMPTS)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)

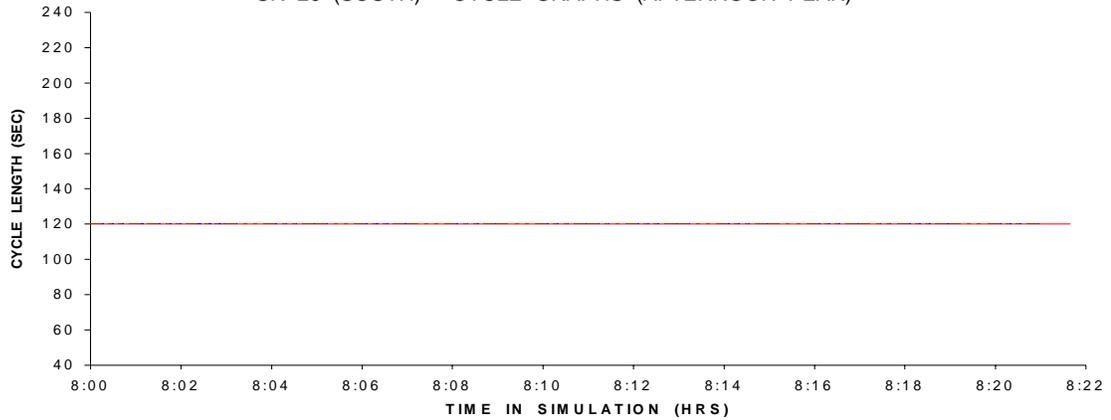


c) Node 4: SR 26 & Meijer Entrance

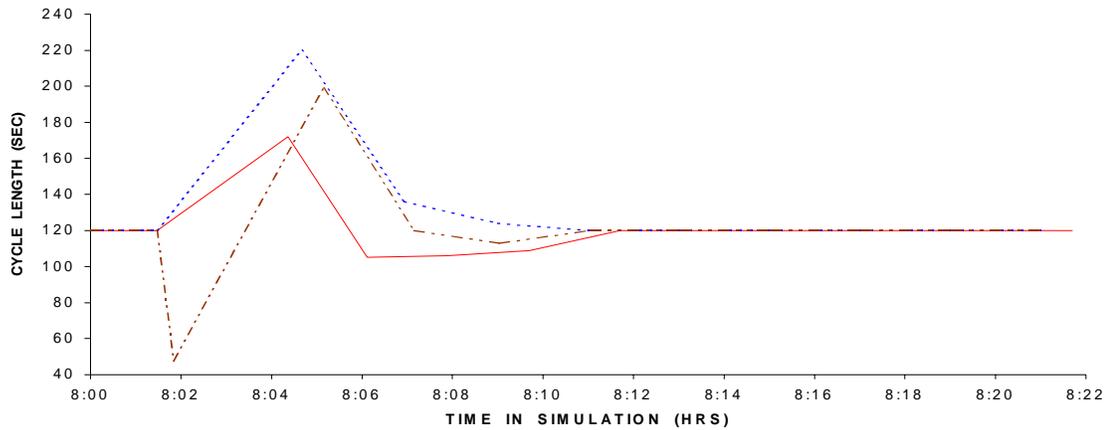
— SMOOTH (SMT) - - - - ADD_ONLY (ADD) - . - . DWELL (DWL)

Figure A-9: SR 26 (South) System Cycle Graphs – 3_Preempts (Path_3)

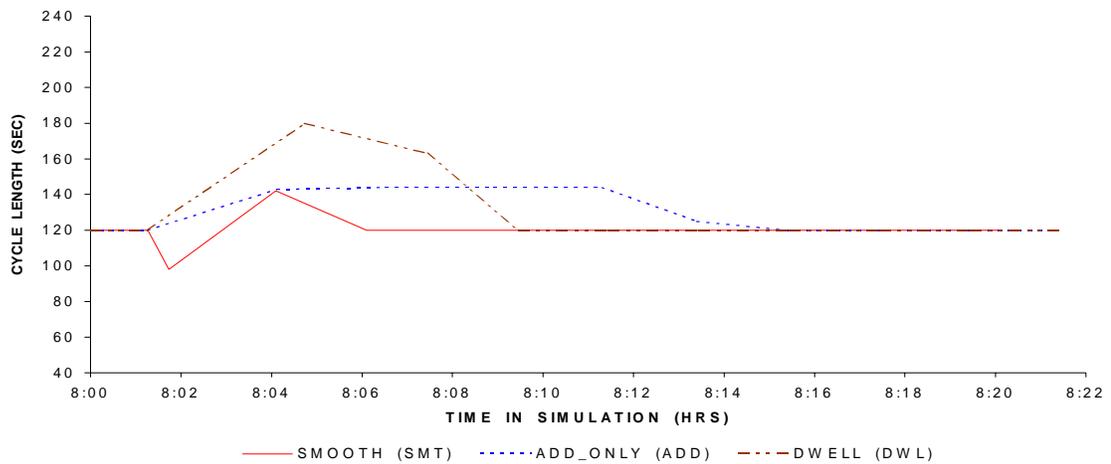
ANALYSIS OF TRANSITIONING ALGORITHMS (1_PREEMPT)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



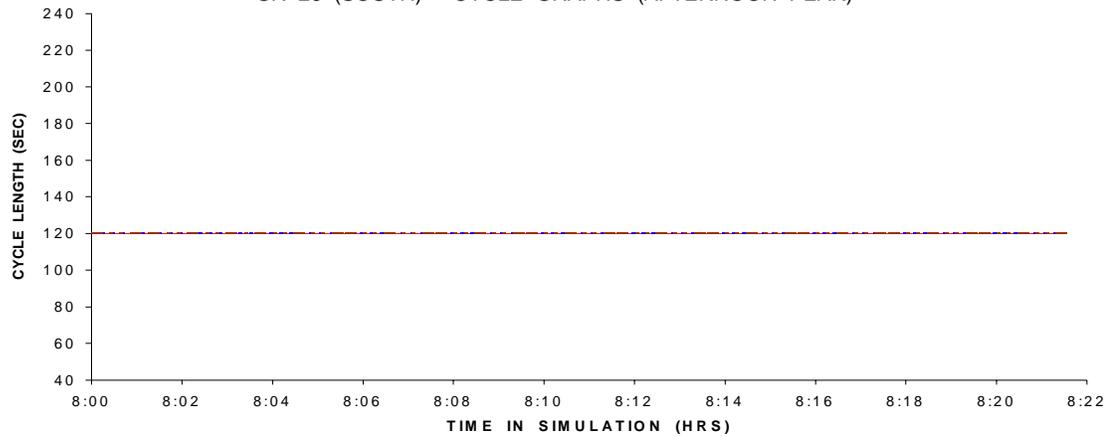
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



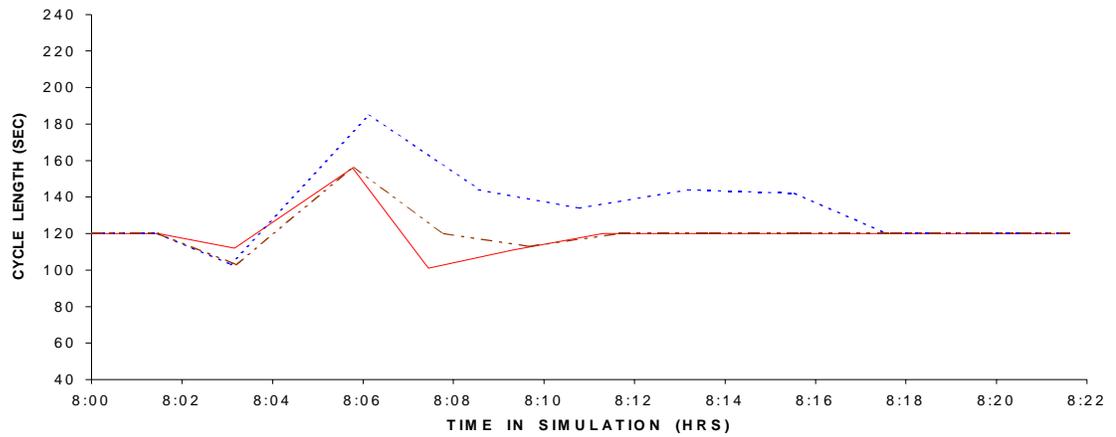
c) Node 4: SR 26 & Meijer Entrance

Figure A-10: SR 26 (South) System Cycle Graphs – 1_Preempt (Path_4)

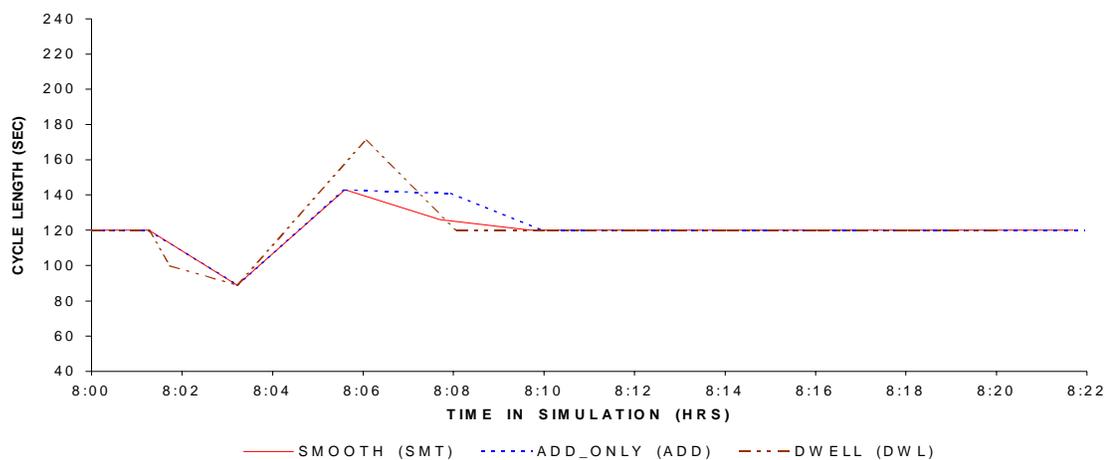
ANALYSIS OF TRANSITIONING ALGORITHMS (2_PREEMPTS)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



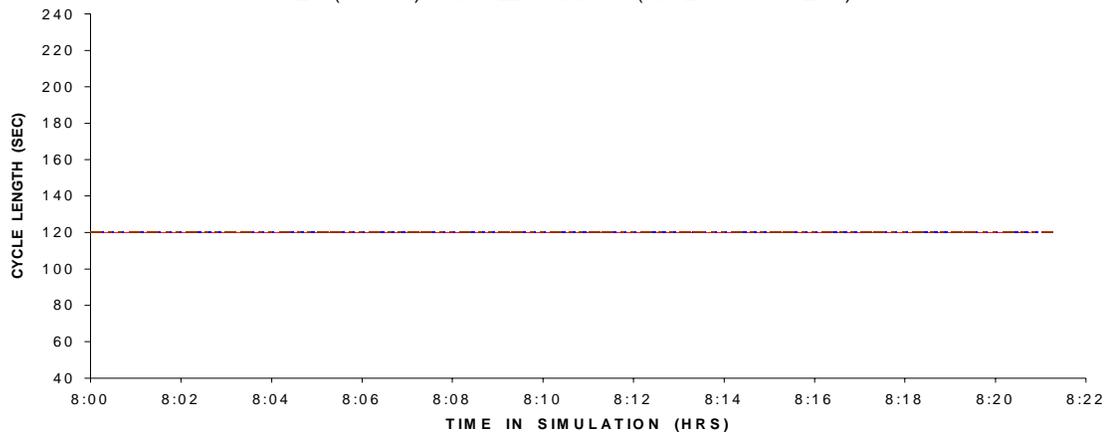
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



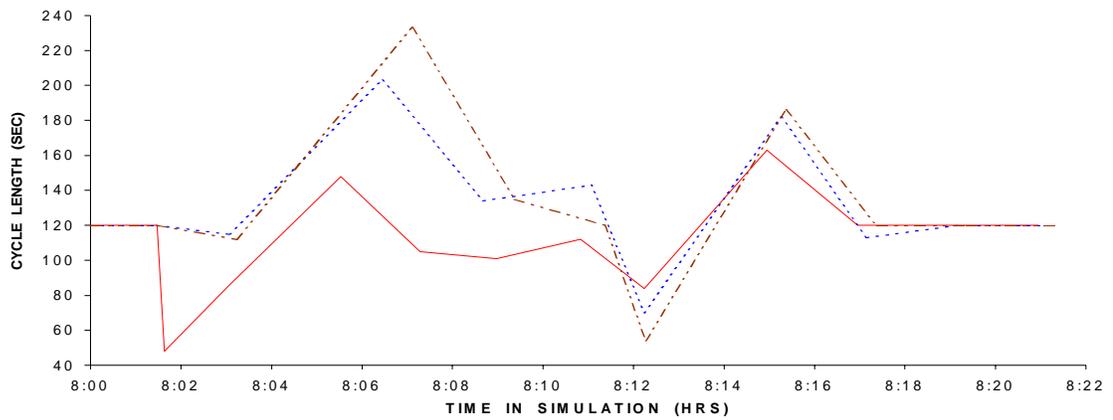
c) Node 4: SR 26 & Meijer Entrance

Figure A-11: SR 26 (South) System Cycle Graphs – 2_Preempts (Path_4)

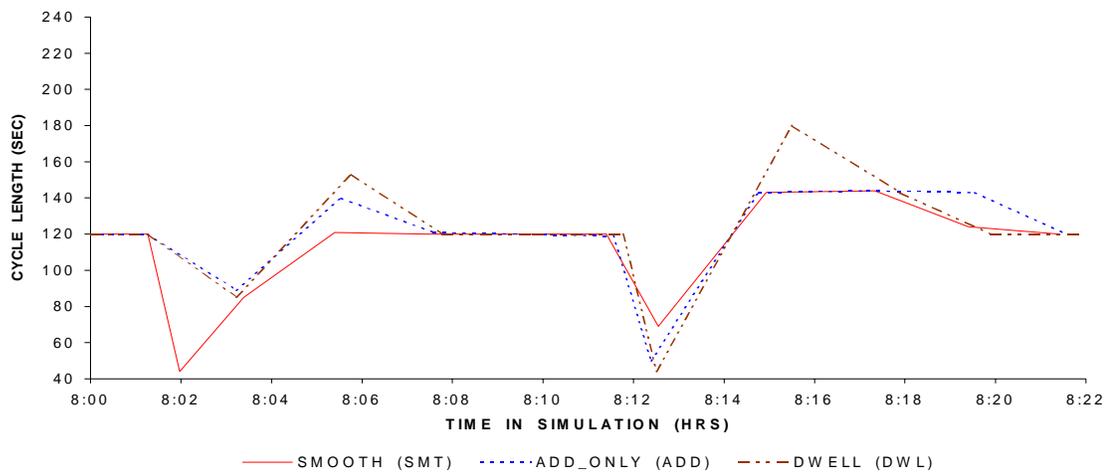
ANALYSIS OF TRANSITIONING ALGORITHMS (3_PREEMPTS)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



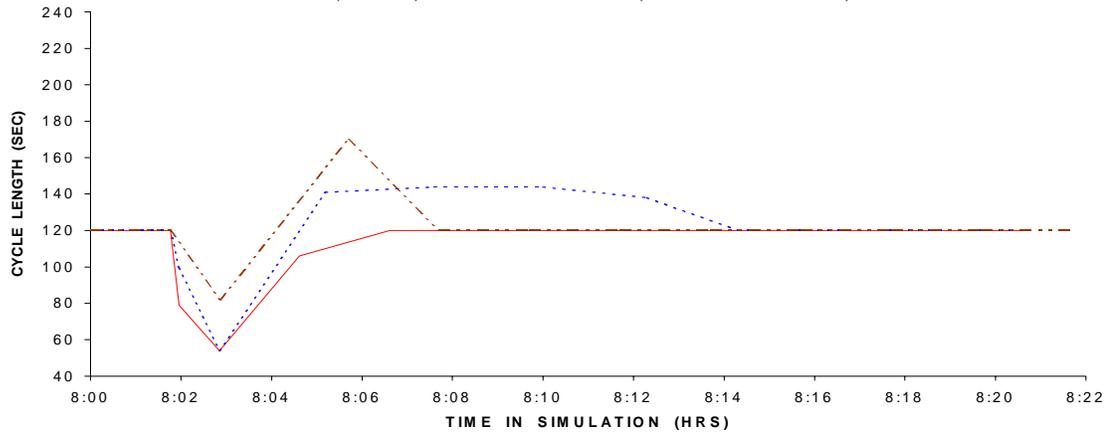
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



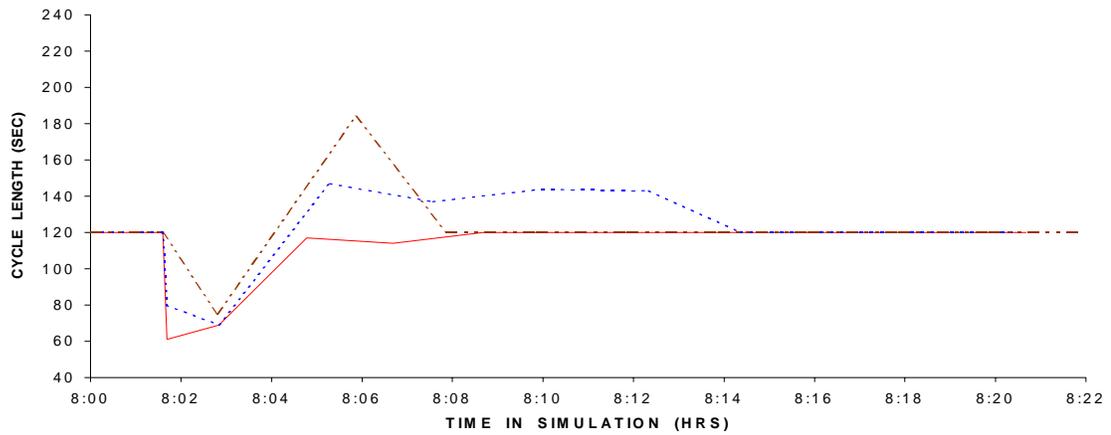
c) Node 4: SR 26 & Meijer Entrance

Figure A-12: SR 26 (South) System Cycle Graphs – 3_Preempts (Path_4)

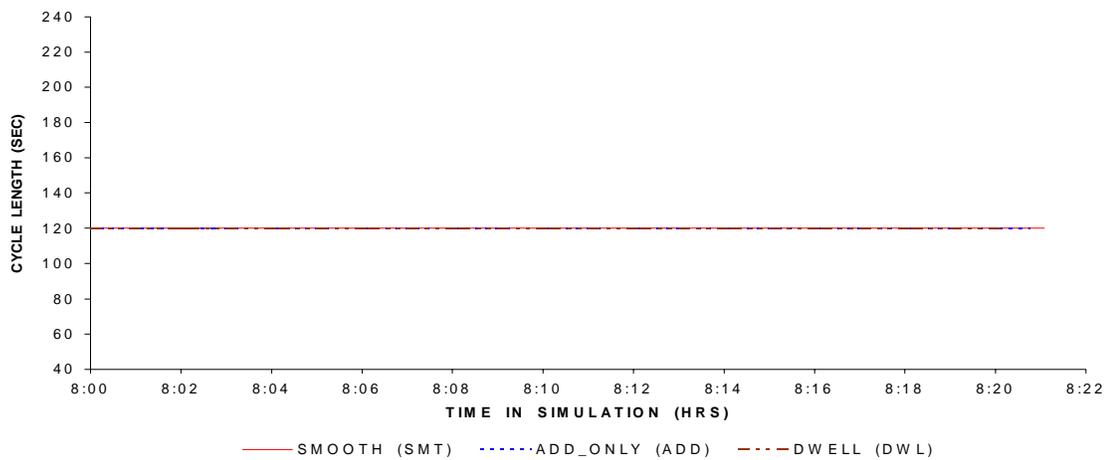
ANALYSIS OF TRANSITIONING ALGORITHMS (1_PREEMPT)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



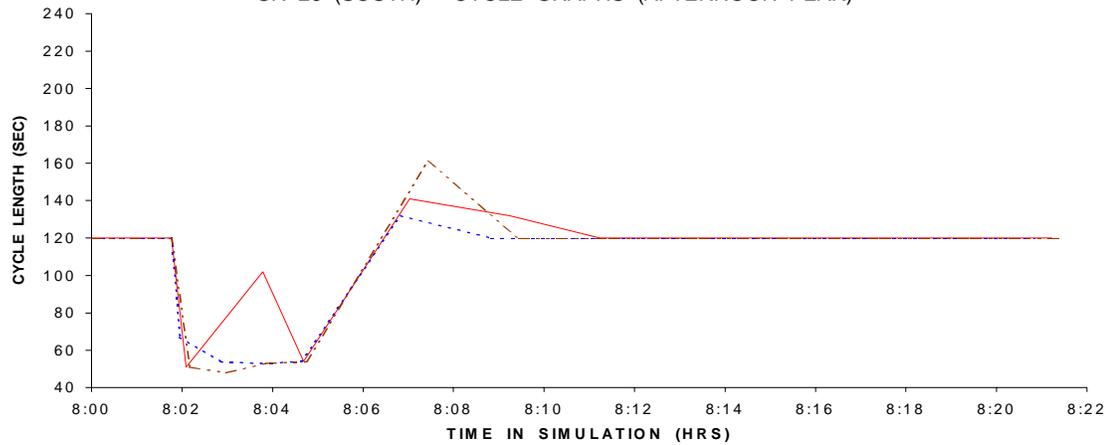
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



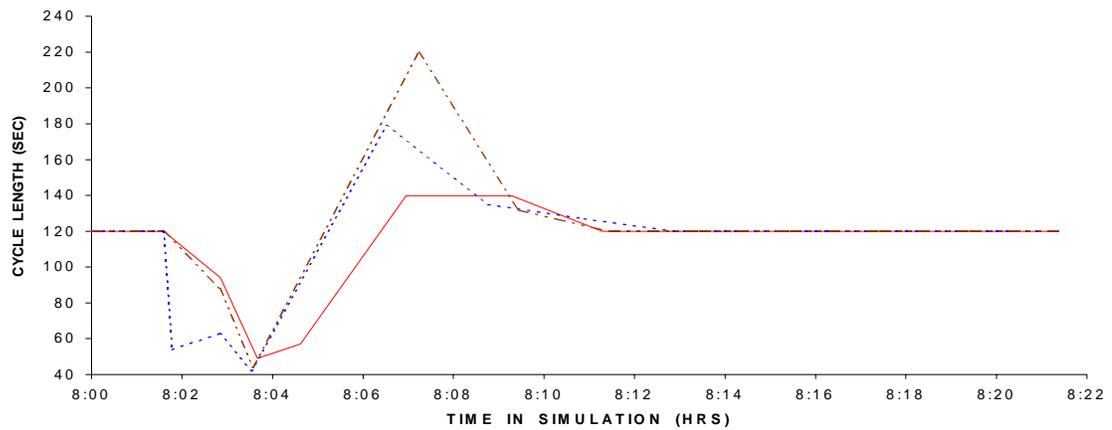
c) Node 4: SR 26 & Meijer Entrance

Figure A-13: SR 26 (South) System Cycle Graphs – 1_Preempt (Path_5)

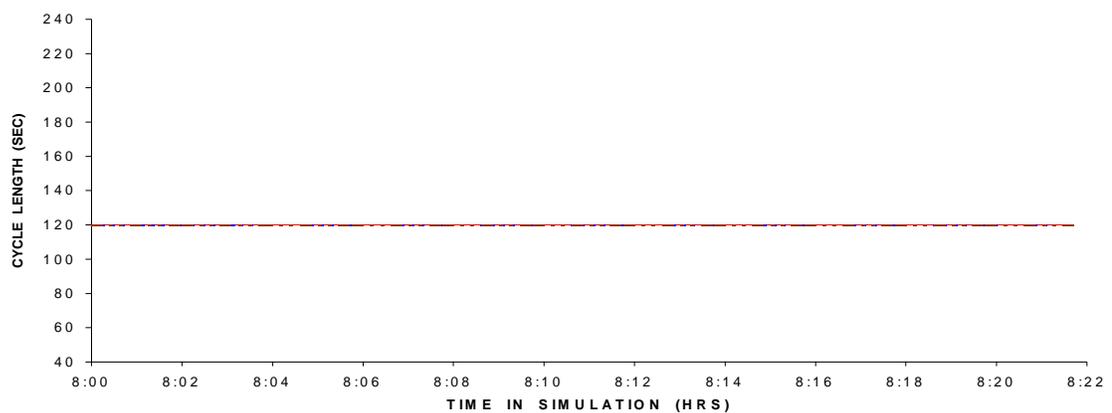
ANALYSIS OF TRANSITIONING ALGORITHMS (2_PREEMPTS)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



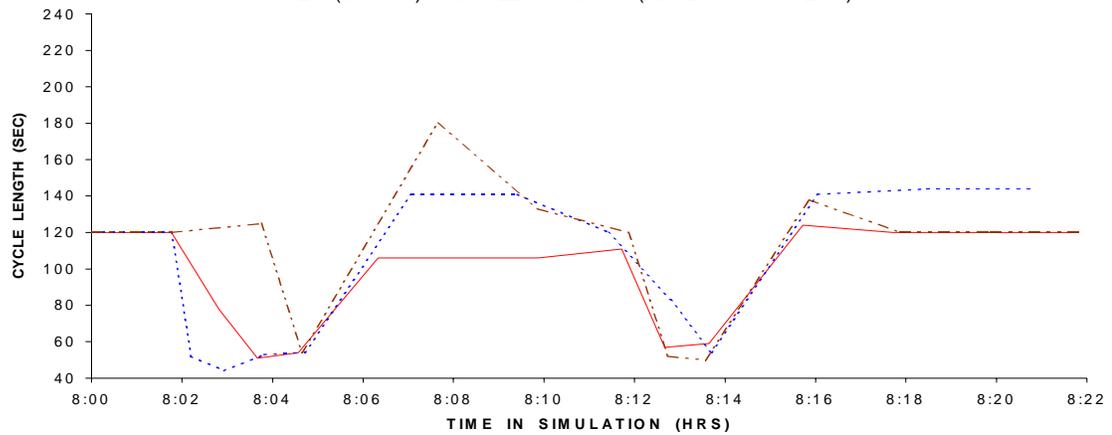
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



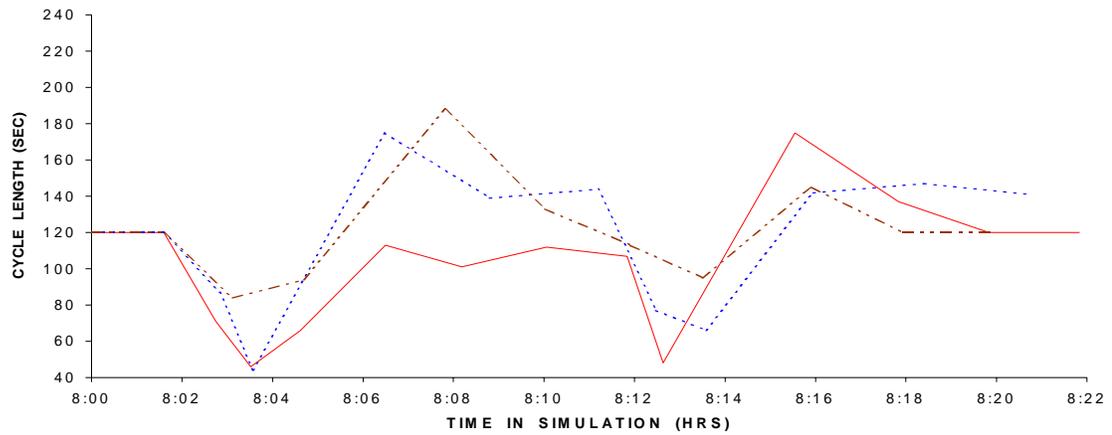
c) Node 4: SR 26 & Meijer Entrance

Figure A-14: SR 26 (South) System Cycle Graphs – 2_Preempts (Path_5)

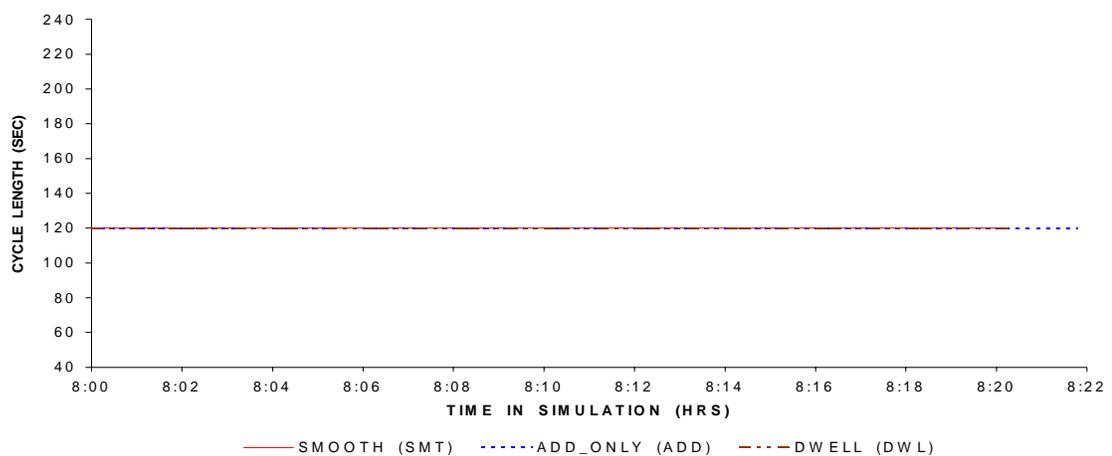
ANALYSIS OF TRANSITIONING ALGORITHMS (3_PREEMPTS)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



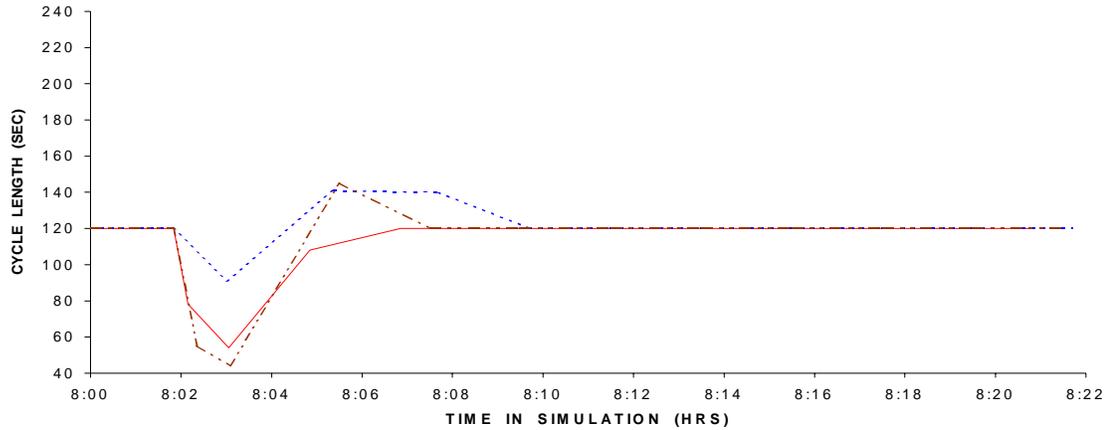
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



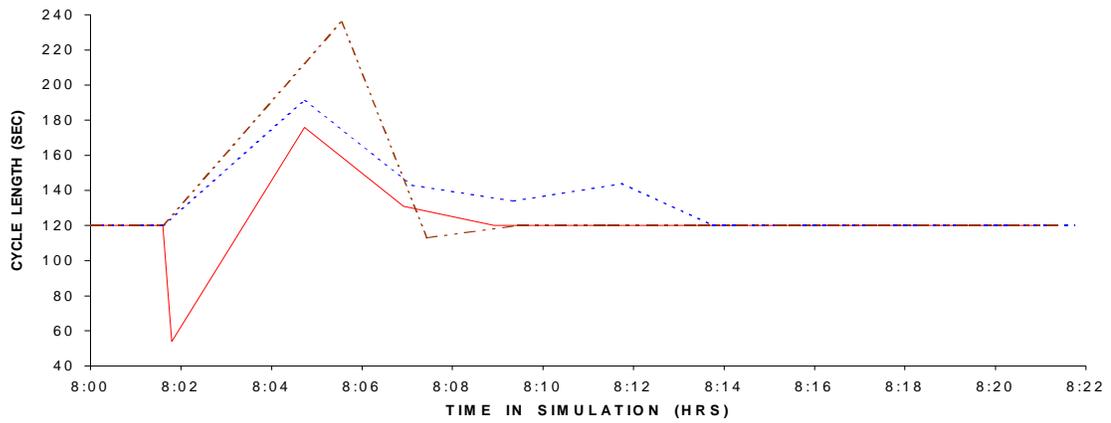
c) Node 4: SR 26 & Meijer Entrance

Figure A-15: SR 26 (South) System Cycle Graphs – 3_Preempts (Path_5)

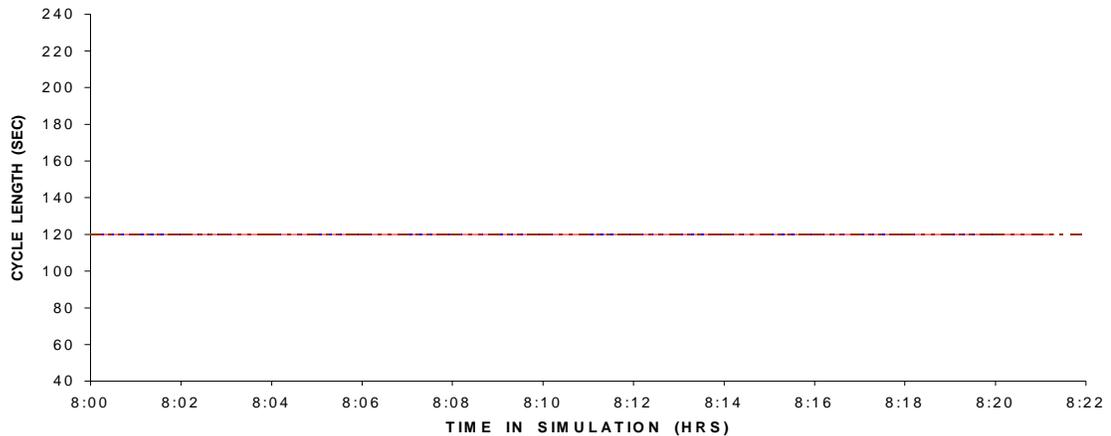
ANALYSIS OF TRANSITIONING ALGORITHMS (1_PREEMPT)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



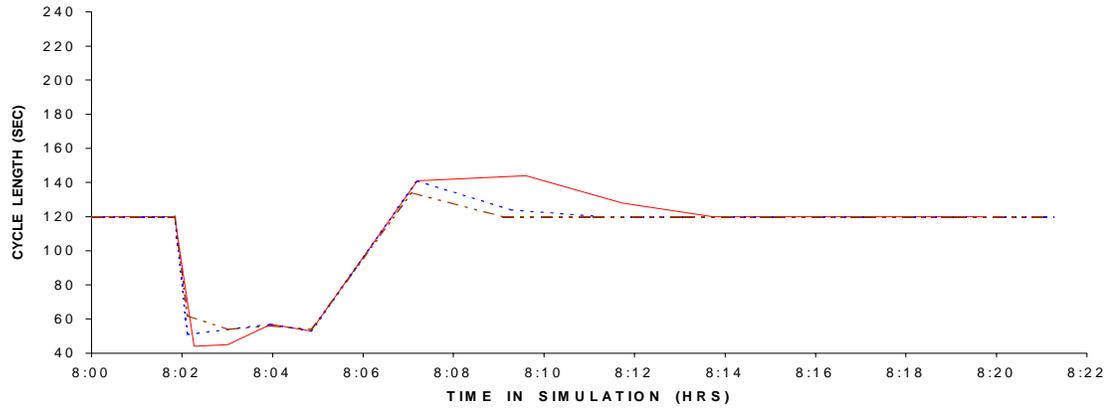
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



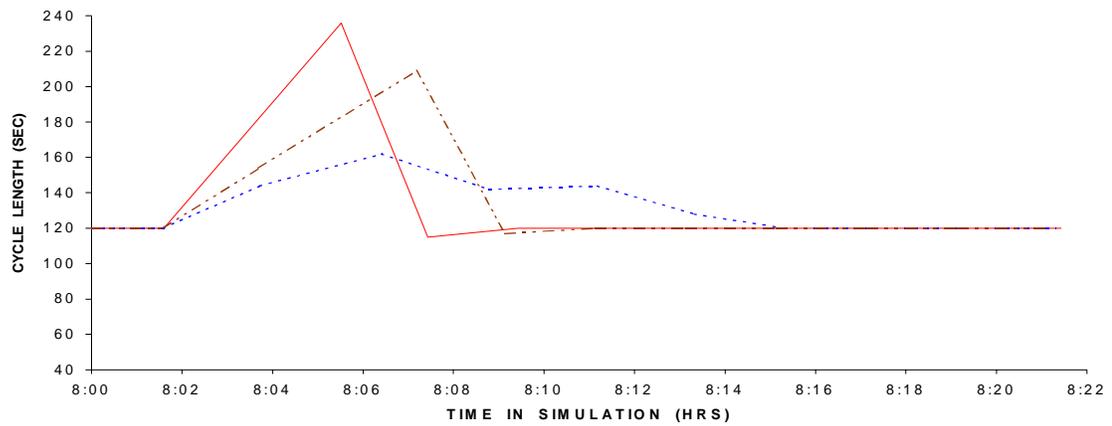
c) Node 4: SR 26 & Meijer Entrance

Figure A-16: SR 26 (South) System Cycle Graphs – 1_Preempt (Path_6)

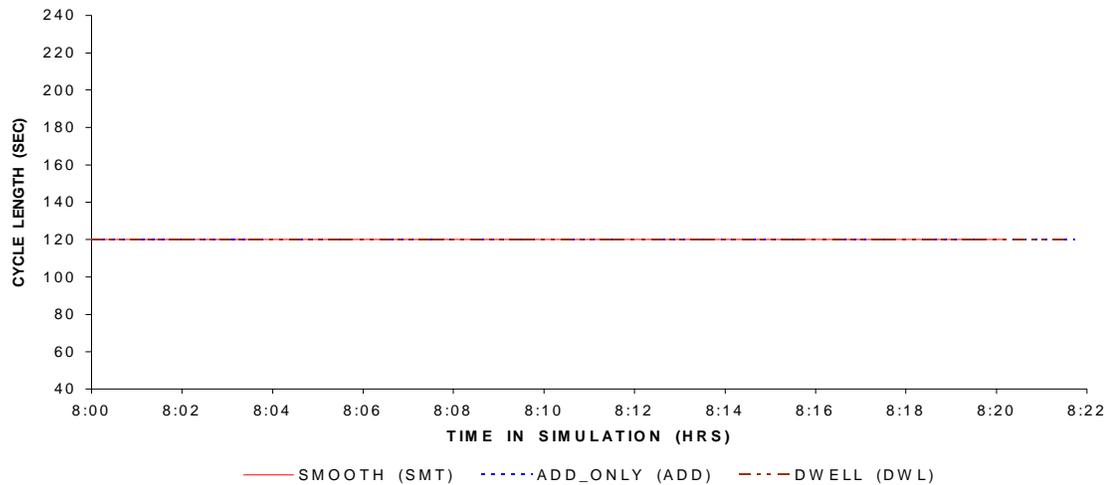
ANALYSIS OF TRANSITIONING ALGORITHMS (2_PREEMPTS)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



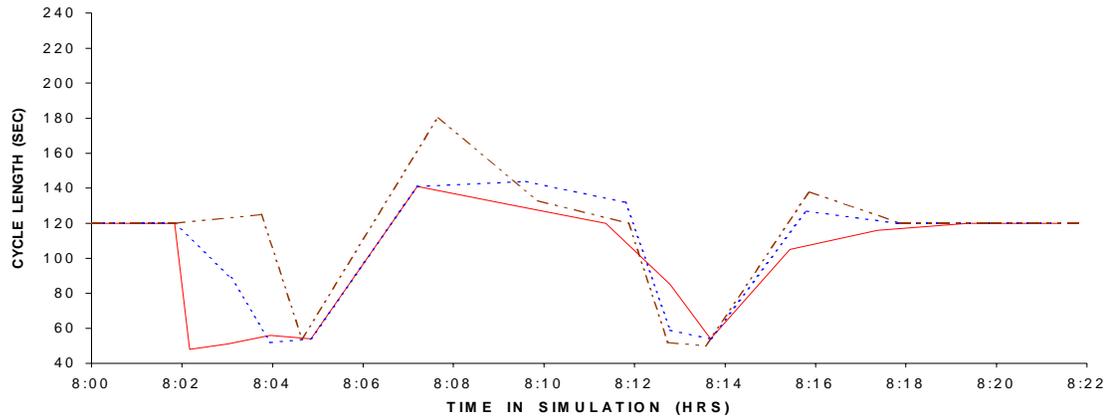
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



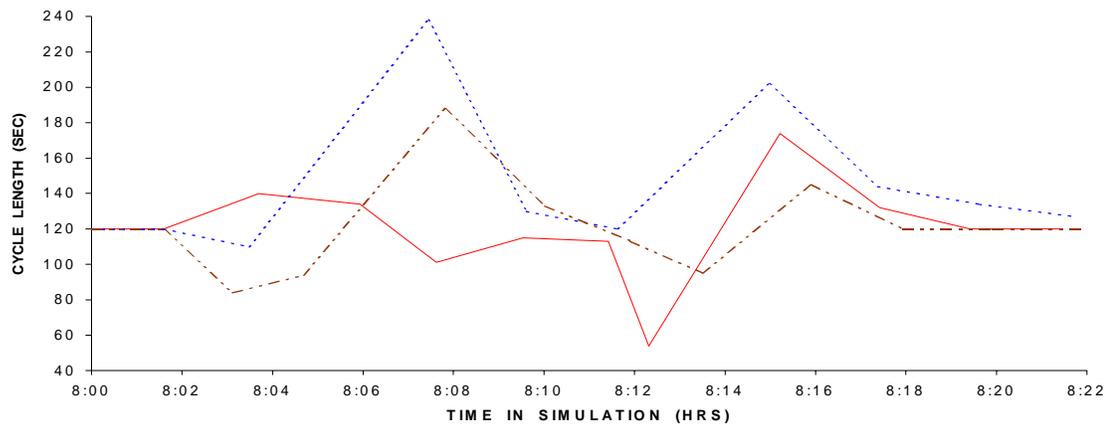
c) Node 4: SR 26 & Meijer Entrance

Figure A-17: SR 26 (South) System Cycle Graphs – 2_Preempts (Path_6)

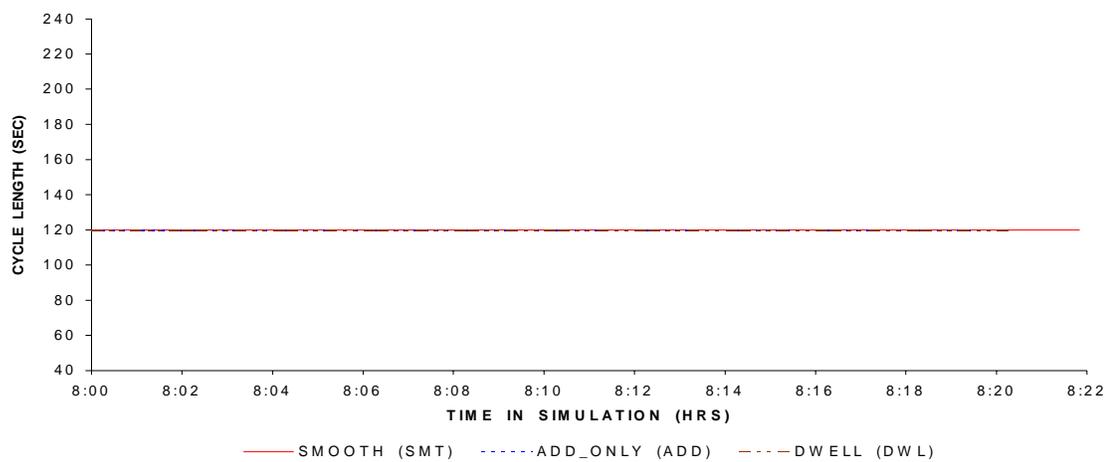
ANALYSIS OF TRANSITIONING ALGORITHMS (3_PREEMPTS)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



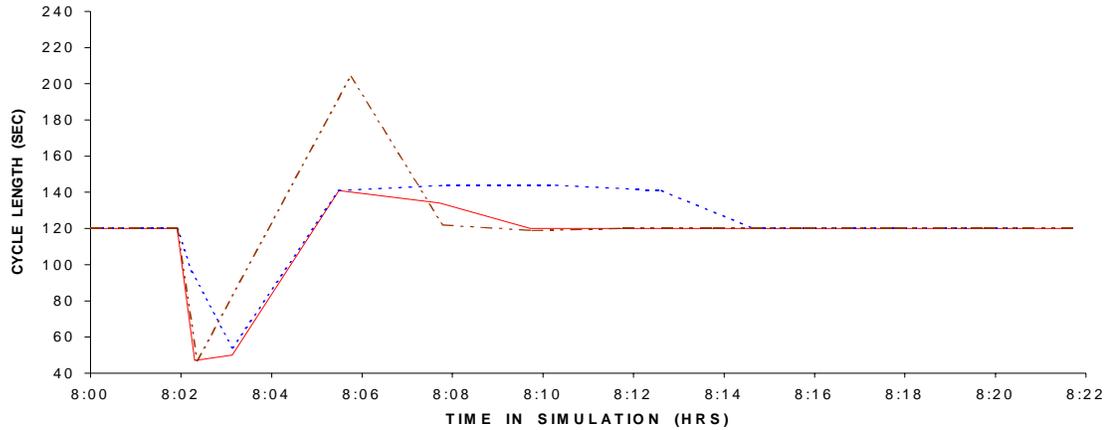
b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



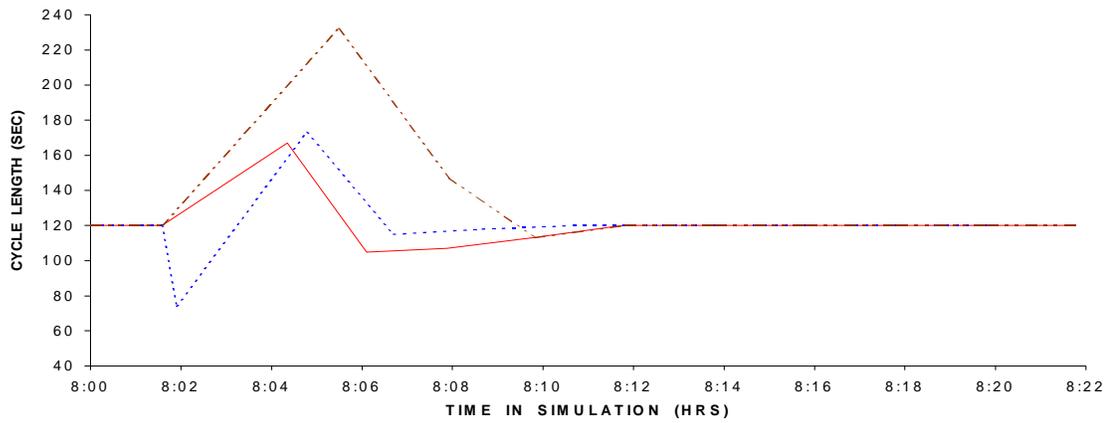
c) Node 4: SR 26 & Meijer Entrance

Figure A-18: SR 26 (South) System Cycle Graphs – 3_Preempts (Path_6)

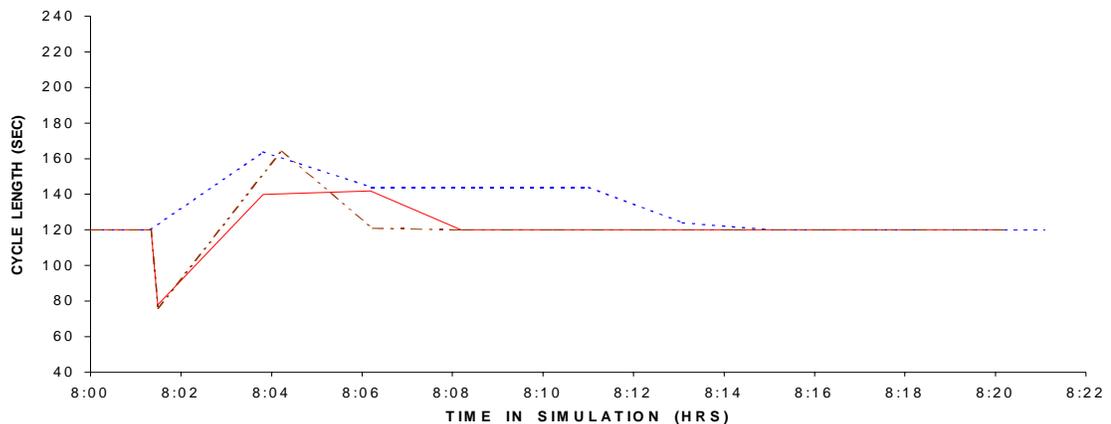
ANALYSIS OF TRANSITIONING ALGORITHMS (1_PREEMPT)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)

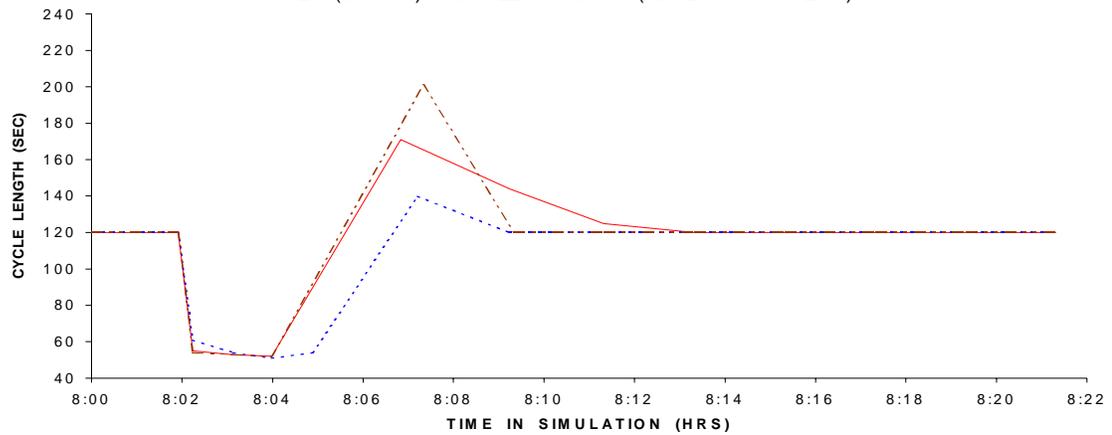


c) Node 4: SR 26 & Meijer Entrance

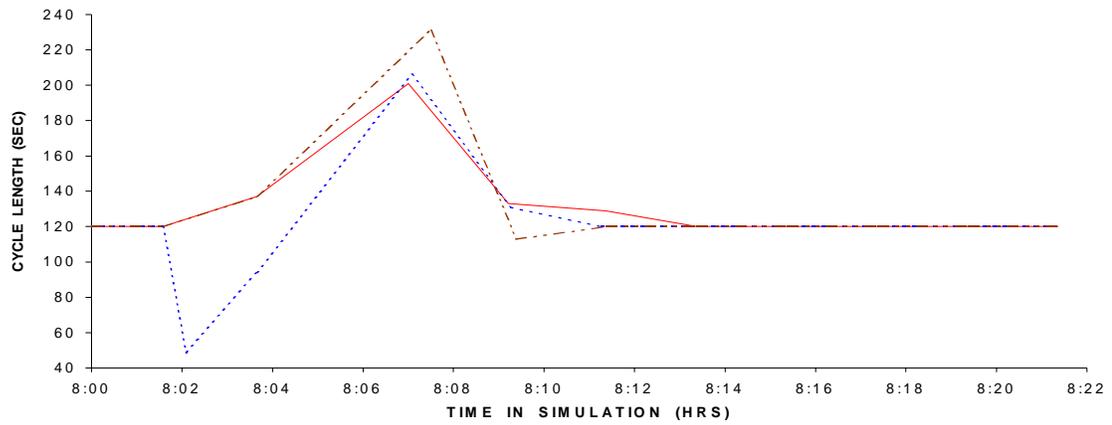
— SMOOTH (SMT) - - - ADD_ONLY (ADD) - - - DWELL (DWL)

Figure A-19: SR 26 (South) System Cycle Graphs – 1_Preempt (Path_7)

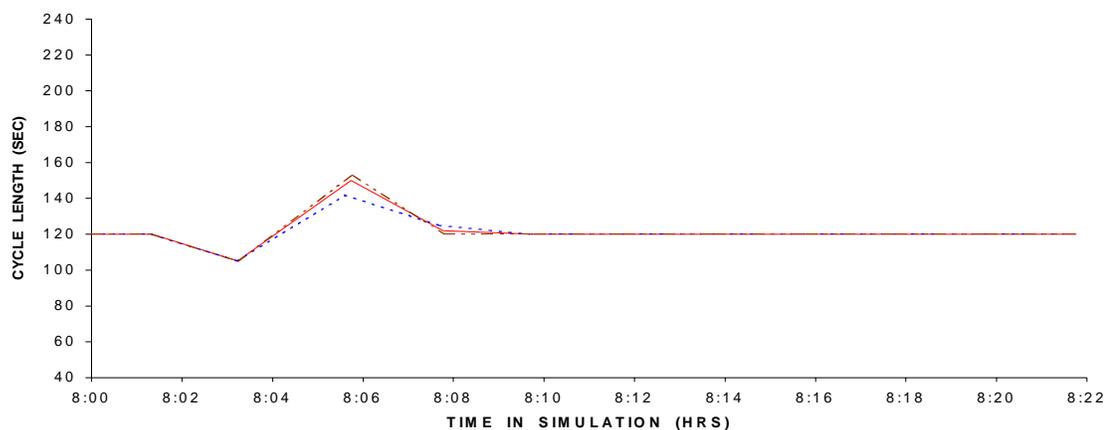
ANALYSIS OF TRANSITIONING ALGORITHMS (2_PREEMPTS)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)

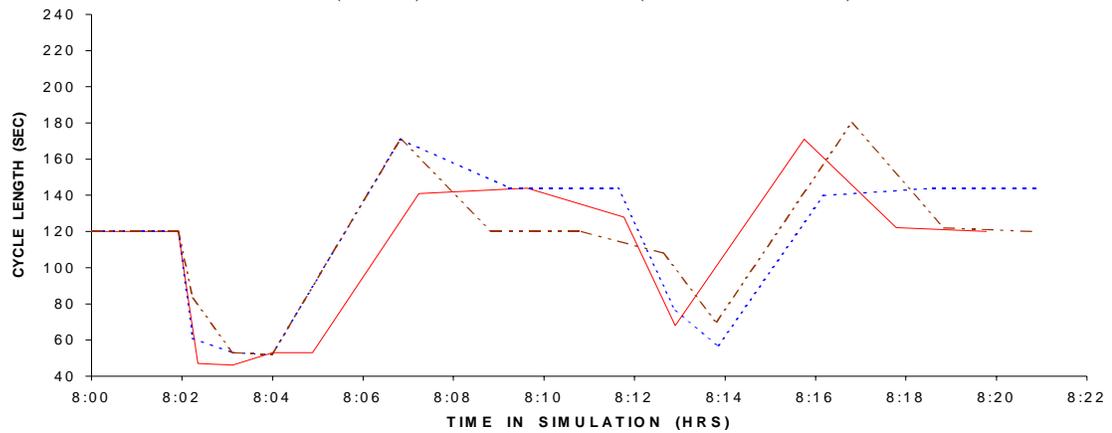


c) Node 4: SR 26 & Meijer Entrance

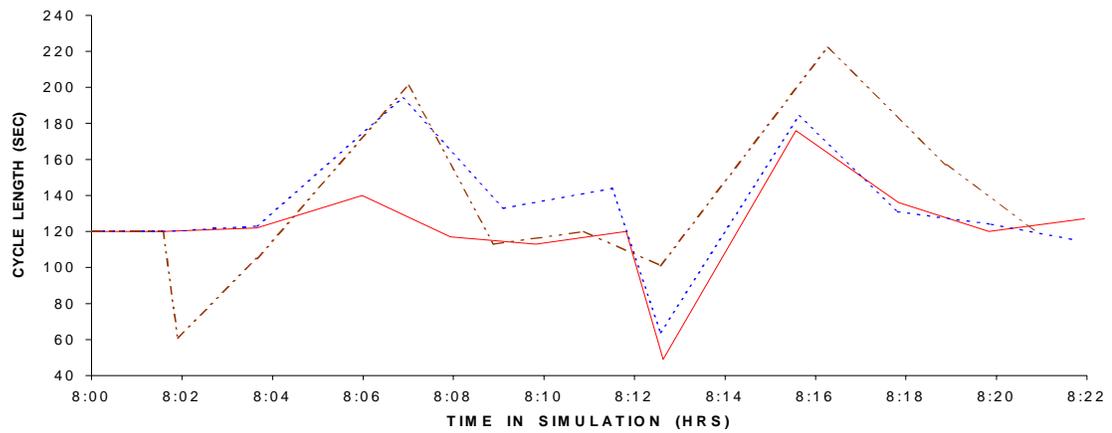
— SMOOTH (SMT) ···· ADD_ONLY (ADD) - - - DWELL (DWL)

Figure A-20: SR 26 (South) System Cycle Graphs – 2_Preempts (Path_7)

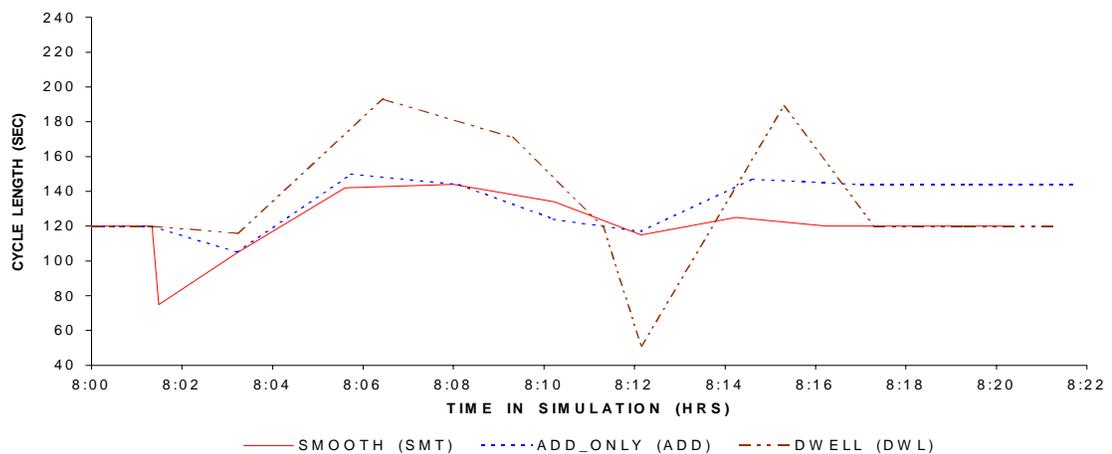
ANALYSIS OF TRANSITIONING ALGORITHMS (3_PREENPTS)
 SR 26 (SOUTH) - CYCLE GRAPHS (AFTERNOON PEAK)



a) Node 1: SR 26 & Red Cloud / Progress



b) Nodes 2 & 3: SR 26 & JCT I-65 (Ramps)



c) Node 4: SR 26 & Meijer Entrance

Figure A-21: SR 26 (South) System Cycle Graphs – 3_Preempts (Path_7)

APPENDIX B – SR 67 (KENTUCKY) QUANTITATIVE RESULTS FOR ALL
APPROACHES AND MOVEMENTS

INT	START END	6:00 AM 7:00 AM	7:00 AM 8:00 AM	8:00 AM 9:00 AM	9:00 AM 10:00 AM	10:00 AM 11:00 AM	11:00 AM 12:00 PM	12:00 PM 1:00 PM
HEATHROW DRIVE / MENDENHALL	NBLT	18.8	88.4	17.9	25.5	20.4	47.8	33.1
	NBTH	77.2	305.6	47.1	54.2	70.2	60.3	73.9
	NBRT	0.0	3.6	1.8	3.7	2.0	1.8	0.7
	SBLT	16.7	101.3	20.5	17.8	18.1	20.8	23.2
	SBTH	39.7	126.2	69.9	83.4	91.4	138.2	140.3
	SBRT	0.4	0.9	0.9	1.3	1.1	1.1	1.8
	EBLT	12.7	25.1	10.2	24.5	36.8	42.7	49.5
	EBTH	0.0	4.5	1.0	1.4	1.7	0.6	3.7
	EBRT	0.0	0.8	0.6	1.4	0.8	2.1	1.5
	WBLT	0.0	0.2	0.0	0.4	1.0	0.0	0.7
	WBTH	2.4	4.7	1.2	0.7	0.0	0.0	1.0
	WBRT	11.6	12.3	3.7	3.1	3.7	2.2	2.2
	STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0
NBTH		198.6	498.4	128.4	109.8	125.1	115.8	119.6
NBRT		2.9	23.9	3.5	4.2	3.6	3.1	3.3
SBLT		6.4	63.1	8.8	6.9	7.9	8.3	9.1
SBTH		43.4	114.0	87.2	89.2	78.6	122.6	120.3
SBRT		0.9	1.6	1.3	1.2	1.2	1.4	1.3
EBLT		4.6	13.5	8.1	6.0	5.3	3.0	4.4
EBTH		0.0	5.0	0.1	0.0	0.0	0.0	0.0
EBRT		0.4	0.1	0.0	0.2	0.2	0.2	0.5
WBLT		0.8	9.3	7.4	6.2	8.3	5.6	8.0
WBTH		0.0	1.4	0.0	0.0	0.0	0.0	0.0
WBRT		0.8	15.2	3.7	2.9	2.7	2.1	2.1
HIGH SCHOOL ROAD		NBLT	39.9	166.0	41.7	43.6	33.3	65.3
	NBTH	469.2	1,408.5	368.4	218.7	230.2	218.5	264.7
	NBRT	0.0	15.2	4.2	6.1	3.6	2.8	1.7
	SBLT	61.9	397.9	149.0	94.1	107.3	122.2	147.1
	SBTH	73.6	246.5	128.5	122.1	108.2	174.4	179.4
	SBRT	4.7	6.5	4.7	11.0	7.7	5.9	16.6
	EBLT	56.5	81.8	41.8	34.4	26.9	29.7	50.4
	EBTH	22.3	69.9	23.8	17.6	22.5	20.8	32.2
	EBRT	2.9	23.3	5.3	3.2	3.1	7.9	9.2
	WBLT	10.0	46.8	19.9	15.3	13.4	18.6	21.2
	WBTH	36.9	86.2	40.3	26.7	14.0	25.7	33.0
	WBRT	90.3	230.6	66.1	31.1	26.7	28.3	25.6
	JCT I-465 (SOUTH)	NBTH	446.0	4,480.6	ERR	143.2	157.6	130.6
NBRT		38.7	58.1	45.8	31.7	29.3	27.8	25.7
SBLT		26.8	85.5	38.8	28.4	55.1	44.3	57.4
SBTH		26.5	81.4	47.0	49.6	49.0	61.4	72.1
WBLT		102.7	334.4	253.1	133.9	152.1	162.0	199.2
WBRT		17.0	81.9	90.1	12.6	19.4	14.8	13.5
JCT I-465 (NORTH)	NBTH	95.9	890.5	498.4	52.9	58.8	60.4	87.7
	NBRT	422.3	2,158.2	1,529.1	157.7	142.2	114.7	94.2
	SBLT	49.6	200.7	44.3	46.1	22.0	32.2	59.1
	SBTH	6.5	24.6	9.7	12.6	15.6	18.4	22.6
	WBLT	68.0	153.7	80.9	70.4	73.4	70.9	86.3
	WBRT	5.4	22.4	6.4	7.6	2.5	4.5	7.2

Table B-1: Case_1 - Vehicular Delay (V-M) - Free Operation - Part 1 of 2

INT	START END	1:00 PM 2:00 PM	2:00 PM 3:00 PM	3:00 PM 4:00 PM	4:00 PM 5:00 PM	5:00 PM 6:00 PM	TOTALS	CUMM- ULATIVE
HEATHROW DRIVE / MENDENHALL	NBLT	25.7	25.0	23.2	22.4	33.7	381.9	382
	NBTH	81.4	109.5	85.2	93.9	72.4	1,131.0	1,513
	NBRT	1.3	0.4	2.9	0.8	2.8	21.8	1,535
	SBLT	31.5	64.8	41.9	54.8	36.6	447.9	1,983
	SBTH	137.0	192.2	441.3	490.0	544.8	2,494.2	4,477
	SBRT	1.5	2.2	4.9	4.8	0.1	20.9	4,498
	EBLT	48.8	60.5	86.3	82.8	76.5	556.5	5,054
	EBTH	0.9	0.4	3.3	3.9	2.0	23.3	5,078
	EBRT	0.7	3.0	7.1	9.4	7.2	34.7	5,112
	WBLT	0.0	0.5	0.0	0.8	0.0	3.7	5,116
	WBTH	0.0	1.5	2.8	0.6	1.5	16.4	5,132
	WBRT	3.1	3.1	2.0	1.5	3.3	51.6	5,184
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	5,184
	NBTH	127.4	136.4	124.8	129.6	111.5	1,925.3	7,109
	NBRT	4.1	4.8	4.8	6.6	8.2	72.9	7,182
	SBLT	8.3	27.9	17.0	18.7	12.0	194.5	7,377
	SBTH	119.7	185.0	368.1	460.7	450.7	2,239.4	9,616
	SBRT	1.8	2.1	4.3	6.9	0.1	23.9	9,640
	EBLT	3.4	2.0	3.3	3.0	0.8	57.2	9,697
	EBTH	0.0	0.0	0.0	2.7	0.2	8.1	9,705
	EBRT	0.1	0.1	0.0	0.1	0.4	2.2	9,708
	WBLT	6.1	4.1	27.5	23.2	26.4	132.9	9,840
	WBTH	0.0	0.0	3.0	1.6	1.1	7.0	9,847
	WBRT	3.0	4.7	14.6	11.9	9.1	72.8	9,920
HIGH SCHOOL ROAD	NBLT	33.3	38.7	29.0	35.0	57.8	640.7	10,561
	NBTH	248.2	350.3	387.2	501.7	440.0	5,105.5	15,666
	NBRT	3.7	1.9	6.4	1.5	6.4	53.7	15,720
	SBLT	135.9	266.8	311.4	645.0	724.1	3,162.7	18,883
	SBTH	164.5	274.4	509.3	614.3	686.8	3,282.0	22,165
	SBRT	8.1	14.2	15.9	21.9	23.7	141.0	22,306
	EBLT	33.6	52.8	70.7	61.3	68.1	608.0	22,914
	EBTH	25.0	28.7	57.9	62.2	89.2	471.9	23,386
	EBRT	6.1	16.6	18.6	51.6	36.0	183.9	23,570
	WBLT	18.3	24.0	29.7	48.6	43.5	309.2	23,879
	WBTH	20.5	24.0	42.5	33.5	40.4	423.6	24,302
	WBRT	24.3	29.9	42.5	52.2	33.0	680.5	24,983
JCT I-465 (SOUTH)	NBTH	155.6	234.4	ERR	ERR	ERR	ERR	24,983
	NBRT	26.5	33.9	54.2	52.0	35.3	459.0	25,442
	SBLT	41.8	58.5	98.2	152.0	161.1	847.9	26,290
	SBTH	73.7	128.5	266.1	329.4	325.6	1,510.4	27,800
	WBLT	196.8	330.5	386.5	686.2	581.0	3,518.3	31,319
	WBRT	15.4	39.8	29.1	45.0	38.8	417.4	31,736
JCT I-465 (NORTH)	NBTH	79.4	110.0	109.5	127.6	114.5	2,285.7	34,022
	NBRT	107.8	141.5	154.6	214.5	160.3	5,397.2	39,419
	SBLT	52.4	77.3	93.2	144.0	103.5	924.5	40,343
	SBTH	18.6	26.8	55.0	56.9	59.1	326.6	40,670
	WBLT	79.1	112.4	148.6	174.2	158.7	1,276.5	41,946
	WBRT	6.1	6.2	3.3	3.9	4.9	80.4	42,027

Table B-2: Case_1 - Vehicular Delay (V-M) - Free Operation - Part 2 of 2

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
HEATHROW DRIVE / MENDENHALL	NBLT	3.3	12.7	5.7	7.1	4.2	6.5	2.7	4.7	4.0	4.6	4.0	3.6
	NBTH	9.4	11.3	6.2	6.3	9.2	8.5	5.6	9.2	12.4	4.3	4.4	8.1
	NBRT	0.0	0.8	0.4	0.6	0.3	0.5	0.2	0.2	0.1	0.4	0.4	0.4
	SBLT	4.9	16.6	1.6	3.2	3.9	5.9	6.7	7.3	6.5	6.4	6.2	9.1
	SBTH	9.4	9.7	12.8	12.2	11.8	18.1	19.0	15.8	41.4	24.1	92.7	42.6
	SBRT	0.2	0.6	0.3	0.9	0.3	0.5	0.6	0.7	0.5	0.9	1.8	0.1
	EBLT	2.2	2.7	2.1	3.0	1.7	3.5	2.3	3.6	4.7	4.9	5.1	5.1
	EBTH	0.0	2.4	0.9	1.3	1.4	0.6	1.1	1.5	0.3	1.0	3.1	1.3
	EBRT	0.0	0.3	0.2	0.4	0.5	0.3	0.7	0.3	0.4	1.6	2.9	0.7
	WBLT	0.0	0.3	0.0	0.7	0.7	0.0	1.2	0.0	0.7	0.0	0.8	0.0
	WBTH	1.4	2.0	1.2	0.7	0.0	0.0	1.6	0.0	1.4	1.6	0.8	1.0
WBRT	2.9	1.9	0.8	0.7	1.0	0.9	0.6	0.6	0.7	0.3	0.4	0.6	
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	115.	313.	71.5	41.2	57.3	51.0	51.3	63.7	73.6	59.1	48.9	50.4
	NBRT	0.7	4.7	1.7	1.3	1.7	1.3	1.4	0.6	1.5	0.7	0.9	1.4
	SBLT	2.8	11.9	7.2	1.4	1.4	2.6	3.4	2.9	4.0	2.3	2.2	2.1
	SBTH	19.7	24.9	34.6	38.0	37.3	59.0	44.2	43.6	83.7	113.	200.	226.
	SBRT	0.3	0.5	0.5	1.0	0.8	0.9	1.0	0.5	1.1	0.9	1.1	0.2
	EBLT	1.1	1.1	1.9	1.8	1.6	1.5	2.5	1.4	0.5	1.0	1.6	0.7
	EBTH	0.0	1.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.5
	EBRT	0.3	0.1	0.0	0.3	0.2	0.2	0.4	0.1	0.1	0.0	0.1	0.5
	WBLT	0.3	2.3	1.6	2.4	4.0	1.0	2.7	1.6	0.8	9.9	5.6	6.8
	WBTH	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	1.1	0.9
WBRT	0.6	2.0	1.5	0.8	0.6	1.0	1.0	1.5	0.7	2.8	2.0	2.0	
HIGH SCHOOL ROAD	NBLT	4.2	14.7	7.3	5.1	3.3	10.5	7.3	5.3	9.0	5.9	7.0	3.7
	NBTH	42.7	190.	19.5	12.6	18.6	20.9	11.4	11.0	24.8	20.9	24.6	22.6
	NBRT	0.0	3.5	1.5	1.8	1.2	1.0	1.1	0.8	0.6	1.1	0.4	1.3
	SBLT	9.0	59.5	11.2	6.0	12.0	18.3	5.4	17.3	8.5	18.1	151.	233.
	SBTH	6.1	14.3	11.4	4.0	10.2	24.0	16.4	8.3	25.1	16.7	36.3	34.2
	SBRT	1.3	1.5	1.5	0.7	2.0	1.5	2.8	1.8	1.5	2.5	2.5	5.5
	EBLT	4.0	12.6	2.8	3.4	2.0	3.7	5.0	3.5	5.9	4.4	7.0	8.2
	EBTH	1.0	6.9	3.0	2.3	1.8	2.6	1.2	2.4	3.9	3.6	4.3	6.8
	EBRT	1.0	3.2	2.3	1.2	1.0	1.2	1.0	1.9	2.1	3.4	6.6	5.7
	WBLT	3.5	7.9	1.5	1.6	3.3	2.4	4.0	4.4	3.2	8.4	8.1	4.7
	WBTH	5.4	13.2	5.9	2.1	3.0	3.0	2.5	3.6	3.8	2.0	3.6	2.5
WBRT	4.0	13.4	4.0	4.2	1.9	3.0	3.9	2.5	2.8	1.7	4.4	4.7	
JCT I-465 (SOUTH)	NBTH	47.5	765.	4.82	132.	144.	119.	153.	145.	214.	4.51	5.32	0.0
	NBRT	5.3	6.2	26.5	0.8	3.6	2.7	1.1	2.7	4.2	3.6	4.1	1.7
	SBLT	3.1	12.8	10.7	4.3	7.7	6.9	5.1	7.8	6.7	14.7	29.7	13.7
	SBTH	3.1	8.8	5.4	3.2	3.9	1.7	4.6	5.1	4.9	20.2	7.3	13.5
	WBLT	5.3	13.9	29.2	7.4	9.1	3.2	2.6	7.4	19.2	17.4	55.0	32.6
	WBRT	1.7	50.6	51.5	1.7	4.5	1.7	1.1	1.4	3.0	4.4	5.5	4.5
JCT I-465 (NORTH)	NBTH	8.2	123.	98.7	2.9	5.9	4.8	10.5	7.6	10.4	17.2	14.7	10.6
	NBRT	39.5	97.3	385.	10.4	9.6	7.9	2.8	5.3	11.7	6.1	24.0	17.5
	SBLT	1.1	50.4	5.3	5.7	4.6	2.4	3.8	4.6	2.7	5.8	11.8	8.5
	SBTH	0.9	2.6	0.5	0.9	1.0	1.4	1.1	1.1	1.5	2.4	3.5	1.3
	WBLT	3.0	26.8	8.2	2.2	2.0	2.0	3.9	4.9	7.0	9.3	16.3	7.4
	WBRT	0.8	2.3	0.8	1.1	0.4	0.9	1.0	1.3	0.8	0.8	1.0	0.4

Table B-3: Case_1 - Standard Deviation of Delay (V-M) - Free Operation

INT	START END	6:00 AM 7:00 AM	7:00 AM 8:00 AM	8:00 AM 9:00 AM	9:00 AM 10:00 AM	10:00 AM 11:00 AM	11:00 AM 12:00 PM	12:00 PM 1:00 PM
HEATHROW DRIVE / MENDENHALL	NBLT	57.5	185.1	52.7	46.5	38.0	79.4	57.0
	NBTH	74.1	263.0	45.9	49.1	62.1	56.3	64.0
	NBRT	0.0	3.2	1.7	3.6	1.8	1.7	0.7
	SBLT	22.8	140.2	40.1	24.2	25.2	31.8	33.5
	SBTH	35.0	77.0	58.3	74.5	62.5	94.9	101.7
	SBRT	0.4	0.9	1.1	1.1	1.0	1.1	1.7
	EBLT	16.7	21.5	15.3	25.3	48.5	58.0	62.7
	EBTH	0.0	4.7	1.5	2.1	2.3	1.1	4.7
	EBRT	0.0	0.7	0.6	1.3	0.7	2.1	1.7
	WBLT	0.0	0.6	0.0	0.6	1.3	0.0	0.8
	WBTH	2.9	5.3	1.3	0.6	0.0	0.0	1.2
	WBRT	14.1	11.5	3.7	2.7	4.1	2.1	1.9
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	142.3	298.2	86.6	76.6	88.0	78.5	80.7
	NBRT	2.8	22.1	3.4	4.0	3.5	3.0	3.1
	SBLT	6.8	50.5	8.1	7.1	7.9	7.4	8.3
	SBTH	40.9	107.3	86.0	76.5	63.1	93.4	99.4
	SBRT	1.0	1.7	1.5	1.2	1.3	1.5	1.4
	EBLT	12.3	23.7	22.2	11.6	10.8	9.0	9.7
	EBTH	0.0	6.9	0.0	0.0	0.0	0.0	0.0
	EBRT	0.3	0.1	0.0	0.2	0.2	0.2	0.5
	WBLT	2.5	17.7	17.7	13.4	13.9	13.1	15.0
	WBTH	0.0	3.1	0.1	0.0	0.0	0.0	0.0
	WBRT	0.7	19.5	4.2	3.5	2.6	2.5	2.4
HIGH SCHOOL ROAD	NBLT	61.8	658.7	256.3	64.0	46.6	101.4	80.7
	NBTH	452.9	2,774.7	951.2	149.9	163.1	140.7	140.5
	NBRT	0.0	40.6	20.3	5.6	3.1	2.5	1.7
	SBLT	88.3	347.8	164.0	125.2	150.5	154.1	223.6
	SBTH	140.7	368.0	275.7	165.3	142.1	202.5	218.1
	SBRT	5.3	8.2	6.4	11.6	8.1	6.3	17.7
	EBLT	114.2	85.4	80.0	60.5	46.4	52.6	154.2
	EBTH	45.6	72.2	47.1	30.4	32.5	35.7	94.2
	EBRT	10.4	26.2	11.7	7.4	5.0	15.0	31.2
	WBLT	19.0	49.2	41.4	28.3	24.0	33.2	37.4
	WBTH	80.5	97.0	80.2	42.6	22.3	45.7	59.1
	WBRT	152.9	230.5	90.1	36.6	32.9	29.1	30.1
JCT I-465 (SOUTH)	NBTH	326.6	1,892.7	1,792.4	180.5	195.7	165.7	199.3
	NBRT	36.5	43.9	28.4	29.5	27.1	25.3	23.9
	SBLT	54.3	146.0	74.9	44.1	110.1	79.9	118.6
	SBTH	19.1	57.1	28.6	29.8	29.7	37.6	45.7
	WBLT	232.8	474.7	439.7	277.6	276.5	308.8	351.1
	WBRT	20.6	75.0	96.0	12.9	20.7	16.1	16.2
JCT I-465 (NORTH)	NBTH	52.4	819.2	388.5	32.0	33.9	36.6	51.6
	NBRT	335.9	1,998.8	1,235.5	121.6	109.6	86.7	75.8
	SBLT	136.0	750.7	309.8	130.0	60.0	83.9	140.1
	SBTH	4.6	20.0	7.2	8.2	9.0	12.4	15.4
	WBLT	144.4	237.1	173.0	117.8	139.2	114.9	152.3
	WBRT	5.2	20.5	6.3	7.6	2.5	4.5	7.0

Table B-4: Case_1 - Vehicular Delay (V-M) - Time of Day - Part 1 of 2

INT	START END	1:00 PM 2:00 PM	2:00 PM 3:00 PM	3:00 PM 4:00 PM	4:00 PM 5:00 PM	5:00 PM 6:00 PM	TOTALS	CUMM- ULATIVE
HEATHROW DRIVE / MENDENHALL	NBLT	34.7	33.9	36.0	33.0	54.2	707.9	708
	NBTH	70.9	90.0	68.4	73.1	61.1	978.0	1,686
	NBRT	1.3	0.4	3.0	0.8	2.7	20.9	1,707
	SBLT	37.7	79.9	68.7	57.1	42.6	603.8	2,311
	SBTH	97.9	108.2	439.5	435.1	492.0	2,076.4	4,387
	SBRT	1.6	1.6	5.0	5.3	0.1	20.9	4,408
	EBLT	65.9	73.5	154.2	138.1	128.7	808.3	5,216
	EBTH	0.9	0.6	7.3	6.1	4.0	35.3	5,252
	EBRT	0.6	2.8	8.8	9.2	7.7	36.2	5,288
	WBLT	0.0	0.2	0.0	0.5	0.0	4.1	5,292
	WBTH	0.0	1.5	4.8	0.9	1.6	20.1	5,312
	WBRT	3.9	3.0	2.3	1.4	3.2	53.9	5,366
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	5,366
	NBTH	83.5	86.9	76.8	85.4	70.6	1,254.0	6,620
	NBRT	3.7	4.6	5.2	6.0	8.0	69.4	6,689
	SBLT	8.5	23.4	14.5	15.4	7.7	165.8	6,855
	SBTH	101.7	126.8	283.9	284.7	279.9	1,643.6	8,499
	SBRT	1.8	1.9	5.3	6.2	0.3	25.2	8,524
	EBLT	7.2	5.0	5.6	5.5	2.7	125.3	8,649
	EBTH	0.0	0.0	0.0	4.4	0.4	11.7	8,661
	EBRT	0.2	0.3	0.0	0.1	0.1	2.0	8,663
	WBLT	13.0	9.2	74.7	46.5	47.7	284.4	8,947
	WBTH	0.0	0.0	8.0	3.0	2.5	16.8	8,964
	WBRT	3.1	6.4	53.8	29.1	18.9	146.7	9,111
HIGH SCHOOL ROAD	NBLT	42.8	47.1	42.6	43.9	73.7	1,519.8	10,630
	NBTH	154.4	151.9	427.7	523.9	406.6	6,437.3	17,068
	NBRT	3.7	1.5	6.3	1.5	6.1	92.8	17,160
	SBLT	191.4	1,046.3	1,706.0	1,445.9	2,763.2	8,406.3	25,567
	SBTH	233.5	290.3	705.2	548.8	735.4	4,025.6	29,592
	SBRT	8.9	11.8	27.1	26.5	34.0	172.0	29,764
	EBLT	61.8	71.6	115.2	91.3	143.0	1,076.2	30,841
	EBTH	43.9	46.7	103.9	100.1	188.9	841.1	31,682
	EBRT	12.7	24.6	38.2	73.1	78.0	333.8	32,016
	WBLT	27.7	31.2	51.4	71.2	64.9	478.9	32,494
	WBTH	32.0	32.5	65.9	50.5	57.9	666.1	33,161
	WBRT	30.0	36.9	53.3	65.5	38.0	825.8	33,986
JCT I-465 (SOUTH)	NBTH	183.4	213.9	355.8	430.7	356.8	6,293.3	40,280
	NBRT	24.8	29.4	51.2	47.3	31.0	398.2	40,678
	SBLT	71.7	84.9	197.1	250.6	275.4	1,507.7	42,186
	SBTH	42.4	58.9	268.0	311.2	303.3	1,231.3	43,417
	WBLT	375.4	3,882.6	1,960.2	906.4	817.3	10,303.2	53,720
	WBRT	17.7	201.8	86.5	52.8	49.4	665.5	54,386
JCT I-465 (NORTH)	NBTH	41.4	54.0	63.8	67.6	55.4	1,696.5	56,082
	NBRT	82.8	102.6	131.7	181.1	138.1	4,600.2	60,682
	SBLT	146.1	235.7	205.9	287.2	206.8	2,692.2	63,374
	SBTH	13.1	15.5	44.7	43.8	47.7	241.6	63,616
	WBLT	126.2	229.7	286.7	334.5	302.5	2,358.2	65,974
	WBRT	6.7	6.6	2.9	3.8	4.9	78.4	66,053

Table B-5: Case_1 - Vehicular Delay (V-M) - Time of Day - Part 2 of 2

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
HEATHROW DRIVE / MENDENHALL	NBLT	8.5	63.5	11.5	5.5	4.1	9.6	5.5	6.1	5.8	2.3	6.0	6.9
	NBTH	7.6	13.6	6.3	7.0	5.1	4.2	3.0	5.2	6.3	3.0	1.7	2.8
	NBRT	0.0	0.7	0.3	0.8	0.3	0.4	0.2	0.2	0.2	0.4	0.4	0.4
	SBLT	6.8	26.2	6.0	4.2	6.4	6.7	8.5	5.3	11.7	12.3	13.5	5.1
	SBTH	7.2	6.7	8.3	3.2	7.1	8.5	5.7	7.3	9.5	30.4	24.0	33.2
	SBRT	0.2	0.6	0.5	0.9	0.4	0.5	0.8	0.4	0.7	0.7	1.6	0.2
	EBLT	2.3	2.2	2.7	2.5	4.0	2.0	5.5	4.7	2.6	9.8	15.2	8.7
	EBTH	0.0	1.7	1.7	2.1	2.1	0.8	0.9	1.2	0.5	1.2	6.2	3.1
	EBRT	0.0	0.5	0.3	0.5	0.4	0.3	0.7	0.3	0.6	0.9	1.8	1.5
	WBLT	0.0	0.9	0.0	0.8	0.9	0.0	1.8	0.0	0.3	0.0	0.6	0.0
	WBTH	2.7	2.8	1.3	0.6	0.0	0.0	1.4	0.0	2.0	2.6	1.0	1.0
WBRT	4.4	2.5	0.9	0.3	1.0	0.9	0.5	0.5	1.4	0.7	0.2	0.5	
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	4.9	17.0	14.4	7.4	2.0	4.0	4.7	4.4	3.9	5.8	7.9	4.5
	NBRT	1.0	2.9	2.0	1.2	1.1	1.5	1.4	0.7	1.3	1.0	1.4	1.2
	SBLT	3.0	11.3	2.4	1.7	2.5	0.9	2.4	3.4	1.8	2.7	1.6	1.2
	SBTH	4.3	7.8	6.7	6.3	8.6	5.8	7.2	6.1	9.3	12.4	21.6	29.0
	SBRT	0.4	0.8	0.5	0.8	0.5	0.8	0.6	0.8	0.7	0.8	1.7	0.3
	EBLT	4.4	3.8	2.9	2.5	2.1	1.7	4.5	2.3	2.3	0.9	3.5	1.5
	EBTH	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	0.7
	EBRT	0.3	0.0	0.0	0.3	0.1	0.1	0.4	0.2	0.2	0.0	0.1	0.1
	WBLT	0.7	2.8	3.3	3.1	2.6	3.4	2.4	4.3	3.6	25.1	5.2	7.2
	WBTH	0.0	2.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	4.5	1.7	1.5
WBRT	0.2	2.9	1.1	0.6	0.5	0.7	0.8	1.5	1.3	11.9	7.1	6.5	
HIGH SCHOOL ROAD	NBLT	9.3	342.	193.	10.7	4.2	14.3	9.2	0.9	4.2	12.2	8.1	6.1
	NBTH	43.5	867.	353.	13.0	15.7	12.3	8.0	5.6	6.1	20.1	35.2	26.2
	NBRT	0.0	19.1	16.7	1.4	0.9	1.0	0.5	0.9	0.3	1.0	0.3	1.1
	SBLT	12.7	48.3	8.7	13.5	33.1	34.7	21.7	32.5	484.	995.	622.	1,21
	SBTH	3.6	43.0	17.9	9.4	12.3	10.9	19.2	7.4	11.9	313.	105.	283.
	SBRT	1.5	2.0	2.0	1.0	2.1	1.1	2.2	2.6	1.1	10.3	4.2	15.3
	EBLT	7.7	7.8	4.5	6.0	3.2	6.7	34.3	12.6	7.3	7.8	16.6	17.5
	EBTH	5.5	7.4	5.9	1.7	1.5	3.6	19.2	4.1	5.0	3.1	4.0	49.0
	EBRT	1.5	6.6	3.3	2.1	1.6	3.5	5.9	5.9	2.3	8.7	4.7	23.3
	WBLT	6.2	7.4	5.3	3.8	4.3	5.8	5.6	3.8	7.1	12.5	5.7	10.6
	WBTH	7.3	6.5	11.7	6.0	3.9	4.4	2.3	2.3	3.0	7.7	7.4	2.4
WBRT	9.9	22.8	6.3	4.2	3.7	0.5	4.2	1.8	6.0	5.5	10.7	6.9	
JCT I-465 (SOUTH)	NBTH	19.4	1.17	1.42	7.0	7.8	12.7	15.1	11.5	6.6	18.4	59.1	24.1
	NBRT	5.4	6.5	5.2	1.4	2.7	2.2	2.4	2.9	2.9	4.8	2.4	2.4
	SBLT	5.7	35.0	24.2	7.3	15.7	11.2	28.0	9.7	17.7	21.7	40.4	50.9
	SBTH	1.8	5.5	3.5	1.1	1.3	2.1	1.7	1.8	5.7	17.2	17.1	3.5
	WBLT	10.2	63.0	15.0	8.5	7.2	6.1	11.8	20.2	164.	373.	72.7	2.9
	WBRT	3.4	25.7	50.2	2.9	2.7	2.1	3.5	2.6	32.5	17.1	7.9	4.2
JCT I-465 (NORTH)	NBTH	2.6	114.	115.	1.6	4.9	3.9	3.2	1.9	5.5	9.0	7.0	4.1
	NBRT	21.1	425.	366.	4.9	7.2	4.3	1.9	6.1	5.3	8.6	22.6	11.8
	SBLT	12.3	278.	299.	18.7	10.5	8.6	14.8	11.2	50.5	26.3	22.3	17.5
	SBTH	0.6	1.8	1.3	1.1	1.0	2.1	1.9	1.5	1.9	3.0	1.3	2.9
	WBLT	6.8	15.9	11.7	3.1	6.3	4.3	14.7	4.3	10.4	12.8	13.9	9.0
	WBRT	1.0	2.8	1.4	0.9	0.7	1.0	0.8	0.9	1.1	0.8	1.0	0.4

Table B-6: Case_1 - Standard Deviation of Delay (V-M) - Time of Day

INT	START END	6:00 AM 7:00 AM	7:00 AM 8:00 AM	8:00 AM 9:00 AM	9:00 AM 10:00 AM	10:00 AM 11:00 AM	11:00 AM 12:00 PM	12:00 PM 1:00 PM
HEATHROW DRIVE / MENDENHALL	NBLT	59.6	173.7	68.2	60.4	36.2	73.7	54.8
	NBTH	67.8	247.9	43.8	51.3	63.3	56.8	66.2
	NBRT	0.0	3.1	1.7	3.0	1.8	1.4	0.8
	SBLT	15.0	141.4	45.1	23.2	27.3	30.3	33.7
	SBTH	33.9	72.8	61.7	69.5	64.0	88.4	102.9
	SBRT	0.7	1.5	2.0	0.7	0.8	1.1	1.0
	EBLT	12.2	22.8	15.1	26.8	46.3	53.8	64.1
	EBTH	0.0	3.0	1.4	1.8	1.7	1.4	5.5
	EBRT	0.1	0.9	0.5	1.2	0.7	2.2	1.4
	WBLT	0.0	0.5	0.0	0.5	0.4	0.0	0.7
	WBTH	1.8	5.1	0.3	1.5	0.0	0.0	1.7
	WBRT	14.5	12.6	3.9	2.7	4.7	1.4	2.5
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	135.6	297.0	78.9	77.2	86.5	75.8	79.5
	NBRT	2.1	21.2	4.0	3.2	3.5	3.3	3.2
	SBLT	5.2	59.7	8.9	6.2	7.6	8.9	9.0
	SBTH	42.6	105.5	85.5	69.3	66.9	87.8	103.1
	SBRT	0.6	2.4	1.2	1.4	1.7	1.8	1.5
	EBLT	10.9	21.3	19.4	11.3	10.1	8.8	11.6
	EBTH	0.0	9.1	0.8	0.0	0.0	0.0	0.0
	EBRT	0.3	0.2	0.0	0.2	0.2	0.1	0.2
	WBLT	2.8	23.6	15.7	13.2	10.9	15.1	12.0
	WBTH	0.0	3.7	0.0	0.0	0.0	0.0	0.0
	WBRT	0.5	20.8	3.8	3.6	3.4	2.3	3.1
HIGH SCHOOL ROAD	NBLT	68.9	424.0	178.4	61.1	46.8	111.0	71.2
	NBTH	401.7	2,598.6	1,033.3	155.7	152.9	135.5	146.4
	NBRT	0.0	42.4	19.6	5.6	3.5	2.6	1.8
	SBLT	78.3	369.9	168.9	125.6	124.8	151.1	203.1
	SBTH	139.8	378.9	274.0	166.7	148.1	191.4	221.0
	SBRT	4.3	9.1	5.7	12.5	8.6	6.4	19.1
	EBLT	120.5	93.5	87.9	68.2	48.5	49.0	153.1
	EBTH	48.5	65.8	38.3	31.1	29.9	33.2	107.8
	EBRT	9.0	25.2	13.7	7.3	5.3	12.6	45.5
	WBLT	20.5	53.6	36.6	28.1	19.9	33.1	36.2
	WBTH	76.7	95.9	77.2	48.2	20.1	44.7	64.5
	WBRT	161.5	235.8	97.2	36.9	31.0	29.2	32.7
JCT I-465 (SOUTH)	NBTH	346.2	1,137.5	1,244.6	175.3	193.4	161.3	192.8
	NBRT	32.7	40.9	30.7	33.5	28.6	28.1	24.1
	SBLT	59.1	120.3	73.3	50.8	92.9	75.7	98.1
	SBTH	18.7	56.3	29.7	29.1	31.5	38.3	45.9
	WBLT	222.4	525.3	428.7	312.5	276.1	306.6	352.4
	WBRT	23.3	54.5	97.6	13.2	21.5	17.5	18.1
JCT I-465 (NORTH)	NBTH	57.2	768.4	395.9	29.7	36.6	36.9	51.3
	NBRT	356.1	1,654.5	1,241.7	111.1	107.1	84.7	75.6
	SBLT	145.4	986.2	476.3	136.8	54.4	97.8	127.9
	SBTH	4.4	19.2	7.9	9.3	9.5	13.0	15.6
	WBLT	141.1	238.6	171.5	123.4	140.7	110.4	144.7
	WBRT	5.2	21.6	6.0	9.0	2.4	4.7	6.6

Table B-7: Case_1 - Vehicular Delay (V-M) - Time of Day (2) - Part 1 of 2

INT	START END	1:00 PM 2:00 PM	2:00 PM 3:00 PM	3:00 PM 4:00 PM	4:00 PM 5:00 PM	5:00 PM 6:00 PM	TOTALS	CUMM- ULATIVE
HEATHROW DRIVE / MENDENHALL	NBLT	38.4	43.8	28.6	33.1	54.8	725.2	725
	NBTH	65.3	83.7	68.9	73.8	59.6	948.5	1,674
	NBRT	1.5	0.7	3.1	0.8	2.5	20.3	1,694
	SBLT	33.4	95.9	53.6	67.5	38.7	605.0	2,299
	SBTH	94.7	147.9	334.2	432.5	459.1	1,961.6	4,261
	SBRT	1.9	1.8	3.2	4.4	0.1	19.1	4,280
	EBLT	62.7	103.0	165.3	165.2	136.8	874.2	5,154
	EBTH	1.7	1.7	4.7	4.9	4.4	32.3	5,186
	EBRT	0.7	2.9	8.2	8.5	7.8	35.2	5,221
	WBLT	0.0	0.7	0.0	2.7	0.0	5.5	5,227
	WBTH	0.0	1.6	1.9	1.7	2.8	18.4	5,245
	WBRT	4.0	2.9	2.3	1.3	3.9	56.5	5,302
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	5,302
	NBTH	81.4	82.4	80.2	81.9	71.6	1,227.8	6,530
	NBRT	3.1	2.8	4.8	5.3	9.6	66.1	6,596
	SBLT	10.4	25.2	13.5	13.7	10.9	179.3	6,775
	SBTH	104.0	124.3	238.6	281.1	262.4	1,571.0	8,346
	SBRT	2.2	3.2	5.2	4.6	0.3	26.2	8,372
	EBLT	7.7	6.5	5.2	4.8	3.0	120.6	8,493
	EBTH	0.0	0.0	0.0	3.7	0.7	14.3	8,507
	EBRT	0.2	0.1	0.0	0.2	0.1	1.9	8,509
	WBLT	14.3	11.2	63.1	51.1	49.2	282.1	8,791
	WBTH	0.0	0.0	6.0	3.2	1.4	14.2	8,806
	WBRT	2.6	6.7	50.4	31.0	20.8	148.9	8,954
HIGH SCHOOL ROAD	NBLT	39.5	56.0	47.2	47.1	73.1	1,224.3	10,179
	NBTH	145.9	436.7	455.4	511.5	386.6	6,560.3	16,739
	NBRT	3.5	1.9	8.4	1.7	4.9	95.9	16,835
	SBLT	185.6	611.7	338.9	1,436.2	2,609.1	6,403.2	23,238
	SBTH	225.4	219.1	333.5	547.5	697.0	3,542.4	26,780
	SBRT	8.6	14.5	15.0	30.4	31.8	165.8	26,946
	EBLT	67.8	86.5	112.0	112.3	138.5	1,137.8	28,084
	EBTH	55.7	53.3	104.1	140.9	198.1	906.7	28,991
	EBRT	19.4	37.8	42.9	90.4	70.5	379.5	29,370
	WBLT	30.4	39.5	49.5	75.9	62.8	486.0	29,856
	WBTH	33.5	38.2	70.6	62.0	59.7	691.2	30,547
	WBRT	28.5	35.3	49.6	60.5	38.5	836.6	31,384
JCT I-465 (SOUTH)	NBTH	181.5	281.7	296.4	453.0	347.2	5,010.9	36,395
	NBRT	26.4	33.2	50.5	47.8	29.5	406.0	36,801
	SBLT	75.8	113.2	195.4	230.7	280.5	1,465.7	38,267
	SBTH	40.6	94.8	226.2	308.4	291.4	1,211.0	39,478
	WBLT	386.9	900.3	700.7	859.8	835.9	6,107.6	45,585
	WBRT	17.2	48.3	28.0	54.2	48.9	442.4	46,027
JCT I-465 (NORTH)	NBTH	41.4	63.7	42.8	64.0	56.2	1,644.1	47,672
	NBRT	87.3	113.0	120.6	168.2	147.9	4,267.8	51,939
	SBLT	152.6	196.4	172.6	333.5	244.2	3,124.2	55,064
	SBTH	14.3	17.9	44.0	43.2	44.4	242.8	55,306
	WBLT	126.9	230.4	278.4	343.7	303.3	2,353.2	57,660
	WBRT	6.5	7.5	3.2	3.9	4.8	81.4	57,741

Table B-8: Case_1 - Vehicular Delay (V-M) - Time of Day (2) - Part 2 of 2

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
HEATHROW DRIVE / MENDENHALL	NBLT	11.7	18.2	17.5	10.2	4.8	7.7	8.2	6.6	5.6	4.8	8.7	7.5
	NBTH	9.7	14.6	4.1	5.1	4.9	4.2	5.4	3.4	1.6	2.9	4.5	8.3
	NBRT	0.0	0.4	0.6	0.6	0.4	0.3	0.2	0.5	0.4	0.5	0.2	0.6
	SBLT	4.8	37.9	11.5	3.4	5.2	5.6	5.8	4.5	17.5	5.6	11.4	9.0
	SBTH	6.3	8.3	4.8	9.1	6.3	1.8	7.7	8.1	16.9	14.5	19.8	41.4
	SBRT	0.5	0.4	0.7	0.4	0.7	0.5	0.4	0.6	0.5	1.0	0.8	0.1
	EBLT	6.2	2.4	2.5	2.6	2.2	3.9	6.7	4.6	10.8	4.6	13.2	7.1
	EBTH	0.0	2.3	1.1	0.7	1.5	1.3	3.0	1.2	1.8	3.2	1.5	2.8
	EBRT	0.1	0.3	0.2	0.3	0.3	0.7	0.5	0.3	0.6	3.1	2.3	1.3
	WBLT	0.0	1.0	0.0	0.6	0.7	0.0	0.5	0.0	0.7	0.0	2.7	0.0
	WBTH	2.1	1.4	0.3	2.2	0.0	0.0	1.1	0.0	1.0	2.1	1.7	2.2
WBRT	3.4	2.7	0.8	0.8	1.0	0.4	1.0	0.8	0.7	0.4	0.5	1.2	
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	9.2	5.7	4.1	6.1	3.7	1.1	8.6	7.9	3.8	3.2	4.6	2.0
	NBRT	0.5	4.0	0.6	1.1	0.9	2.1	1.1	1.1	1.0	1.5	0.7	1.1
	SBLT	1.4	11.5	2.4	2.0	2.0	1.3	2.0	1.6	4.0	2.1	3.1	2.6
	SBTH	3.3	10.2	5.9	8.4	5.2	6.9	12.0	5.5	11.7	6.3	14.5	17.5
	SBRT	0.5	1.6	0.5	0.6	0.6	0.5	0.9	0.9	1.6	1.3	0.7	0.3
	EBLT	5.0	4.5	1.8	2.5	1.1	1.1	5.1	2.3	0.9	1.1	2.6	0.8
	EBTH	0.0	3.1	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	1.0
	EBRT	0.3	0.2	0.0	0.3	0.1	0.1	0.1	0.3	0.1	0.0	0.2	0.2
	WBLT	1.9	5.9	3.4	2.5	1.1	4.6	2.9	2.2	2.8	10.0	7.2	5.2
	WBTH	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	1.0	1.0
WBRT	0.2	5.6	1.4	0.5	1.5	0.4	0.3	0.4	2.5	14.7	7.2	2.2	
HIGH SCHOOL ROAD	NBLT	13.6	121.	76.1	6.7	6.8	10.3	10.2	2.2	10.4	5.3	12.3	9.8
	NBTH	20.0	939.	486.	8.4	10.7	8.7	19.3	10.3	75.9	19.5	35.5	15.9
	NBRT	0.0	29.3	12.1	1.9	1.8	0.6	0.5	1.0	0.7	1.9	0.6	0.7
	SBLT	14.4	41.4	10.1	7.1	11.1	14.9	31.6	33.6	511.	34.1	588.	696.
	SBTH	8.1	30.4	24.5	10.2	15.0	17.2	11.6	13.1	30.1	19.2	125.	82.2
	SBRT	0.6	2.4	1.5	1.1	1.8	1.9	4.5	1.5	2.3	3.9	4.8	5.3
	EBLT	16.0	8.8	8.6	10.5	2.6	7.1	47.9	18.8	6.3	22.8	49.1	21.9
	EBTH	2.9	6.5	9.9	5.7	3.1	4.1	25.4	19.0	4.5	8.1	55.3	51.1
	EBRT	2.6	2.5	5.4	1.7	1.8	2.7	6.5	10.9	1.5	7.4	38.6	19.4
	WBLT	5.7	6.5	6.5	4.8	2.5	5.2	4.8	9.5	7.1	8.2	9.6	6.6
	WBTH	6.2	9.8	12.2	6.9	7.3	4.0	11.5	7.7	7.4	7.8	14.4	3.1
WBRT	15.7	17.2	9.7	3.6	5.2	2.0	3.6	4.2	3.2	4.2	4.1	1.9	
JCT I-465 (SOUTH)	NBTH	16.1	490.	433.	12.8	15.1	9.2	19.9	9.8	14.6	25.2	39.5	13.3
	NBRT	4.6	1.0	3.3	2.7	2.4	2.5	3.4	1.7	2.3	3.1	6.1	2.8
	SBLT	11.4	12.5	26.2	12.6	21.1	12.9	20.6	15.0	23.6	19.5	26.7	47.4
	SBTH	2.0	3.1	1.3	1.5	2.7	1.4	1.3	3.7	11.8	15.4	9.1	12.5
	WBLT	7.7	113.	31.7	22.6	4.3	12.1	4.7	15.8	346.	27.4	16.8	26.0
	WBRT	3.4	5.6	24.2	1.6	1.5	3.1	2.3	2.7	7.0	9.0	3.7	5.1
JCT I-465 (NORTH)	NBTH	4.0	155.	70.6	4.0	2.0	1.8	3.5	3.6	2.6	4.2	2.1	4.1
	NBRT	13.1	332.	323.	6.7	10.7	4.1	6.6	2.4	5.6	7.8	12.2	9.6
	SBLT	5.6	318.	407.	23.4	5.1	13.1	10.2	39.7	20.0	18.5	17.2	33.6
	SBTH	1.1	2.6	0.9	1.2	0.4	1.9	1.4	1.1	1.6	0.9	1.5	2.8
	WBLT	14.7	12.4	13.0	8.3	6.0	6.9	6.0	6.4	7.5	7.0	12.9	8.7
	WBRT	1.3	1.2	0.6	0.8	0.4	1.3	1.2	0.8	1.4	0.6	0.3	0.2

Table B-9: Case_1 - Standard Deviation of Delay (V-M) - Time of Day (2)

INT	START END	6:00 AM 7:00 AM	7:00 AM 8:00 AM	8:00 AM 9:00 AM	9:00 AM 10:00 AM	10:00 AM 11:00 AM	11:00 AM 12:00 PM	12:00 PM 1:00 PM
HEATHROW DRIVE / MENDENHALL	NBLT	49.2	171.4	51.9	53.1	36.7	82.0	56.2
	NBTH	72.4	248.2	47.0	50.2	65.1	57.8	68.2
	NBRT	0.0	3.2	1.8	3.6	1.8	1.6	0.7
	SBLT	20.6	149.8	37.1	24.2	25.5	29.8	30.6
	SBTH	34.2	75.1	62.3	71.1	66.8	94.2	98.8
	SBRT	0.4	0.9	1.0	1.0	1.0	1.0	1.7
	EBLT	13.8	23.1	14.3	29.0	49.2	57.7	67.6
	EBTH	0.0	3.8	1.2	2.4	2.5	0.8	4.7
	EBRT	0.0	0.7	0.5	1.3	0.9	1.8	1.5
	WBLT	0.0	0.2	0.0	0.6	1.4	0.0	1.0
	WBTH	2.9	5.5	1.3	0.8	0.0	0.0	1.2
	WBRT	13.5	12.0	3.6	2.7	3.4	2.0	2.1
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	143.6	298.5	82.6	75.2	89.0	80.9	81.9
	NBRT	2.8	20.8	3.2	3.7	3.5	2.9	3.1
	SBLT	5.7	54.1	7.3	7.5	8.3	7.8	8.5
	SBTH	39.4	107.5	88.8	76.9	65.4	93.2	96.5
	SBRT	1.0	1.9	1.8	1.3	1.5	1.3	1.3
	EBLT	12.7	21.0	19.6	11.8	10.9	8.3	8.1
	EBTH	0.0	8.2	0.2	0.0	0.0	0.0	0.0
	EBRT	0.3	0.1	0.0	0.2	0.3	0.2	0.5
	WBLT	2.7	15.5	15.6	13.9	14.3	14.5	17.0
	WBTH	0.0	3.1	0.0	0.0	0.0	0.0	0.0
	WBRT	0.9	17.5	4.5	3.2	2.8	2.3	2.5
HIGH SCHOOL ROAD	NBLT	64.4	572.8	265.4	65.3	48.6	99.0	80.9
	NBTH	452.2	2,826.6	1,016.0	152.2	156.4	133.3	142.4
	NBRT	0.0	34.7	20.2	4.9	3.4	2.6	1.4
	SBLT	86.1	346.5	165.3	118.9	148.8	159.3	219.1
	SBTH	133.7	368.6	270.1	174.6	148.3	208.8	224.9
	SBRT	5.6	7.4	6.1	12.1	7.8	6.3	17.8
	EBLT	118.0	85.8	81.1	60.6	42.1	50.2	170.6
	EBTH	50.4	77.0	42.1	31.4	34.5	34.9	106.8
	EBRT	9.1	25.9	12.6	7.5	5.8	15.2	36.5
	WBLT	18.6	47.1	41.8	33.2	23.1	32.3	33.9
	WBTH	79.9	91.8	81.8	45.5	22.3	46.2	59.8
	WBRT	154.3	226.7	101.7	39.6	31.5	29.4	31.2
JCT I-465 (SOUTH)	NBTH	334.9	2,039.4	1,895.0	178.5	202.3	166.7	195.3
	NBRT	35.4	43.6	29.7	29.8	27.3	25.7	24.1
	SBLT	49.9	150.9	77.0	45.0	101.8	88.1	116.8
	SBTH	18.1	55.2	28.6	31.2	31.3	37.9	46.3
	WBLT	228.6	471.6	483.7	287.4	275.5	311.6	360.5
	WBRT	22.3	78.9	97.3	14.0	23.4	17.4	14.3
JCT I-465 (NORTH)	NBTH	51.3	886.6	463.4	31.0	33.7	35.9	52.5
	NBRT	337.7	1,981.6	1,217.0	120.3	112.5	85.0	74.2
	SBLT	138.2	731.5	261.5	136.5	57.2	82.6	145.4
	SBTH	4.5	19.8	6.4	9.4	9.3	13.4	14.2
	WBLT	136.6	244.0	170.3	117.8	141.0	108.7	152.4
	WBRT	5.6	24.4	6.2	7.5	2.6	4.5	6.9

Table B-10: Case_1 - Vehicular Delay (V-M) - Traffic Responsive - Part 1 of 2

INT	START END	1:00 PM 2:00 PM	2:00 PM 3:00 PM	3:00 PM 4:00 PM	4:00 PM 5:00 PM	5:00 PM 6:00 PM	TOTALS	CUMM- ULATIVE
HEATHROW DRIVE / MENDENHALL	NBLT	37.5	48.9	37.8	31.8	55.6	711.9	712
	NBTH	69.1	88.4	64.9	74.2	59.5	965.0	1,677
	NBRT	1.3	0.4	2.8	0.8	2.6	20.7	1,698
	SBLT	36.2	98.1	49.6	66.7	42.6	610.6	2,308
	SBTH	97.7	154.0	352.4	446.7	449.9	2,003.1	4,311
	SBRT	1.4	1.9	3.5	4.3	0.1	18.3	4,330
	EBLT	66.0	100.4	163.5	146.3	138.3	869.3	5,199
	EBTH	1.0	1.4	7.1	6.0	3.6	34.5	5,234
	EBRT	0.6	3.7	7.8	8.7	8.1	35.5	5,269
	WBLT	0.0	1.1	0.0	1.0	0.0	5.2	5,274
	WBTH	0.0	2.6	4.2	0.9	1.7	21.0	5,295
	WBRT	4.0	3.2	2.2	1.6	3.1	53.4	5,349
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	5,349
	NBTH	82.5	89.0	75.4	86.2	69.4	1,254.3	6,603
	NBRT	3.6	4.5	4.9	6.0	7.8	66.8	6,670
	SBLT	9.3	24.4	13.5	15.5	8.6	170.4	6,840
	SBTH	104.4	130.5	234.9	293.4	264.1	1,595.0	8,435
	SBRT	2.2	2.1	3.8	6.2	0.1	24.4	8,460
	EBLT	7.4	4.8	5.4	4.6	2.6	117.1	8,577
	EBTH	0.0	0.0	0.0	5.2	0.4	13.9	8,591
	EBRT	0.1	0.3	0.0	0.0	0.4	2.3	8,593
	WBLT	13.1	12.7	70.5	44.2	45.1	279.1	8,872
	WBTH	0.0	0.0	6.8	2.9	2.7	15.4	8,888
	WBRT	3.6	6.6	50.3	26.7	18.1	139.1	9,027
HIGH SCHOOL ROAD	NBLT	48.5	58.0	37.3	48.3	77.6	1,466.0	10,493
	NBTH	153.1	445.9	444.6	513.9	393.2	6,829.9	17,322
	NBRT	3.6	1.8	6.6	1.3	5.5	86.1	17,409
	SBLT	192.2	495.1	341.2	1,321.4	2,913.9	6,507.8	23,916
	SBTH	237.5	217.6	329.4	491.9	727.0	3,532.4	27,449
	SBRT	8.6	13.5	14.8	23.5	33.5	157.0	27,606
	EBLT	79.9	95.5	114.1	98.9	157.6	1,154.4	28,760
	EBTH	59.3	50.8	98.5	100.8	211.2	897.8	29,658
	EBRT	19.1	34.2	31.5	78.3	88.2	363.7	30,022
	WBLT	29.2	37.5	50.1	69.3	63.3	479.2	30,501
	WBTH	30.4	40.2	66.5	51.4	58.6	674.4	31,175
	WBRT	27.5	37.6	50.8	59.8	40.7	830.7	32,006
JCT I-465 (SOUTH)	NBTH	186.4	264.8	313.5	430.5	367.6	6,574.8	38,581
	NBRT	24.8	31.2	51.1	45.8	31.1	399.6	38,980
	SBLT	67.4	110.0	196.3	249.2	289.8	1,542.3	40,523
	SBTH	42.1	99.4	219.7	306.1	297.0	1,212.9	41,736
	WBLT	373.9	914.1	689.5	863.9	852.9	6,113.2	47,849
	WBRT	17.4	45.3	29.3	54.3	49.3	463.2	48,312
JCT I-465 (NORTH)	NBTH	44.5	66.6	50.4	62.1	61.7	1,839.8	50,152
	NBRT	84.3	115.1	120.7	179.1	138.9	4,566.4	54,718
	SBLT	161.7	180.2	191.0	293.4	203.9	2,583.1	57,301
	SBTH	13.4	19.7	43.8	46.8	45.4	246.2	57,547
	WBLT	131.6	239.6	276.9	327.7	318.1	2,364.7	59,912
	WBRT	6.2	6.7	3.4	4.0	5.3	83.2	59,995

Table B-11: Case_1 - Vehicular Delay (V-M) - Traffic Responsive - Part 2 of 2

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
HEATHROW DRIVE / MENDENHALL	NBLT	8.3	46.6	12.9	7.8	4.3	9.5	5.5	4.5	10.4	3.4	5.5	8.6
	NBTH	8.0	16.3	5.7	5.9	5.1	5.5	4.9	5.2	7.4	3.3	2.4	2.9
	NBRT	0.0	0.7	0.2	0.7	0.2	0.4	0.2	0.2	0.2	0.4	0.3	0.3
	SBLT	5.4	30.8	7.9	3.3	5.1	7.6	7.1	4.6	13.7	13.7	14.7	7.7
	SBTH	5.3	5.8	9.3	5.7	7.9	6.1	5.5	5.9	27.2	55.3	26.4	34.3
	SBRT	0.3	0.5	0.5	0.8	0.4	0.4	0.7	0.5	0.8	1.1	1.5	0.1
	EBLT	3.3	3.1	2.2	4.0	3.1	2.2	5.6	3.7	14.6	10.8	11.9	9.5
	EBTH	0.0	1.6	1.4	1.9	2.1	0.7	0.9	1.3	0.9	1.7	5.1	3.4
	EBRT	0.0	0.3	0.3	0.5	0.3	0.3	0.6	0.3	0.8	1.5	1.6	1.7
	WBLT	0.0	0.7	0.0	0.9	1.0	0.0	1.7	0.0	0.9	0.0	0.8	0.0
	WBTH	2.1	2.3	1.2	0.9	0.0	0.0	1.5	0.0	2.3	2.1	1.0	1.2
WBRT	4.3	2.2	0.7	0.3	1.0	0.6	0.6	0.7	1.0	0.7	0.3	0.4	
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	6.5	15.7	10.7	6.1	3.8	4.3	5.5	5.3	6.1	5.1	7.9	3.5
	NBRT	0.8	2.8	1.6	0.9	1.5	1.4	1.3	0.7	1.2	0.8	1.1	1.2
	SBLT	2.3	11.4	2.8	1.5	2.6	1.2	2.2	3.2	1.6	2.0	2.2	1.1
	SBTH	3.3	8.0	5.9	5.8	7.2	7.3	6.9	6.2	9.6	28.3	16.6	24.2
	SBRT	0.3	0.7	0.5	0.7	0.6	0.9	0.7	0.7	0.9	1.1	1.2	0.3
	EBLT	3.4	3.6	2.5	2.4	1.9	1.9	4.6	2.5	1.9	1.6	2.9	1.3
	EBTH	0.0	1.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.7
	EBRT	0.3	0.0	0.0	0.2	0.2	0.1	0.4	0.2	0.2	0.0	0.1	0.4
	WBLT	0.7	3.3	3.8	3.1	2.5	2.7	2.7	3.2	3.4	22.2	8.6	6.4
	WBTH	0.0	2.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	4.0	1.3	1.4
WBRT	0.3	2.9	0.9	0.6	0.5	0.6	0.7	1.3	1.5	15.9	6.0	4.7	
HIGH SCHOOL ROAD	NBLT	10.1	353.	201.	8.4	5.0	12.4	7.4	5.0	10.7	10.1	8.0	6.6
	NBTH	35.5	815.	455.	17.0	15.3	10.7	11.2	4.6	156.	35.6	38.2	26.1
	NBRT	0.0	14.2	14.2	1.3	0.7	1.0	0.5	0.7	0.4	1.2	0.3	1.2
	SBLT	13.7	42.8	9.4	10.7	26.3	31.0	29.7	29.6	442.	979.	485.	931.
	SBTH	8.6	33.3	15.9	11.0	11.7	10.2	14.3	10.2	40.9	288.	82.2	193.
	SBRT	1.5	1.8	1.9	0.9	1.7	1.0	2.2	2.3	1.5	9.5	3.7	10.7
	EBLT	9.0	8.1	4.5	4.9	3.7	7.6	42.9	16.6	14.0	10.4	15.7	31.5
	EBTH	6.6	9.0	6.7	2.0	3.2	4.0	24.2	11.3	5.9	5.7	9.8	53.9
	EBRT	3.7	4.8	3.2	1.9	1.3	2.6	7.7	6.3	8.7	7.6	11.7	27.3
	WBLT	5.1	6.2	4.6	4.2	3.9	4.7	6.4	3.2	6.9	11.8	5.3	8.1
	WBTH	8.8	9.3	10.3	6.3	2.8	4.7	3.1	2.7	5.2	5.4	6.1	3.7
WBRT	9.8	19.9	9.9	4.1	4.0	3.2	4.4	2.4	5.8	4.8	8.3	5.8	
JCT I-465 (SOUTH)	NBTH	15.0	977.	1.30	9.3	7.9	9.2	10.9	12.0	27.7	27.2	45.6	21.1
	NBRT	4.6	4.8	4.3	1.1	2.4	1.8	2.1	2.8	3.3	5.0	2.2	2.6
	SBLT	6.2	33.8	21.0	8.2	12.1	15.5	23.4	10.3	20.4	16.1	32.4	48.8
	SBTH	1.6	4.2	3.0	1.5	1.6	2.6	1.4	2.6	22.2	29.7	15.4	11.5
	WBLT	11.5	63.8	73.5	15.1	5.9	10.0	12.0	14.9	1.57	714.	58.7	32.4
	WBRT	3.1	29.7	43.2	2.7	3.4	2.1	3.8	2.1	85.4	32.3	6.3	3.4
JCT I-465 (NORTH)	NBTH	4.1	101.	181.	1.4	3.8	2.9	2.9	2.7	8.9	9.3	5.6	4.5
	NBRT	17.0	316.	336.	7.5	7.4	3.4	2.0	5.4	8.9	8.8	17.9	12.5
	SBLT	11.6	242.	232.	17.7	12.0	9.4	13.0	21.0	45.5	25.2	19.6	23.5
	SBTH	1.0	1.8	1.2	1.2	1.2	1.6	1.6	1.3	2.7	2.6	2.1	3.4
	WBLT	7.8	15.4	13.8	10.0	6.9	6.3	11.1	7.9	11.6	10.5	13.6	18.2
	WBRT	1.0	3.5	1.1	0.9	0.6	0.9	0.7	0.9	0.9	0.8	1.1	0.4

Table B-12: Case_1 - Standard Deviation of Delay (V-M) - Traffic Responsive

INT	START END	6:00 AM 7:00 AM	7:00 AM 8:00 AM	8:00 AM 9:00 AM	9:00 AM 10:00 AM	10:00 AM 11:00 AM	11:00 AM 12:00 PM	12:00 PM 1:00 PM
HEATHROW DRIVE / MENDENHALL	NBLT	40.3	66.4	76.3	108.1	40.5	82.8	57.1
	NBTH	40.0	76.3	73.8	159.0	67.1	58.8	65.0
	NBRT	0.0	1.5	2.2	6.5	1.9	1.7	0.7
	SBLT	20.8	144.3	39.5	25.1	23.5	30.8	31.5
	SBTH	33.4	71.4	60.7	88.4	66.3	93.5	104.3
	SBRT	0.4	0.8	1.1	1.1	1.0	1.0	1.8
	EBLT	13.9	22.1	14.1	25.7	45.8	55.7	63.0
	EBTH	0.0	3.6	1.1	1.9	2.2	0.9	5.1
	EBRT	0.0	0.7	0.6	1.2	0.9	2.1	1.4
	WBLT	0.0	0.4	0.0	0.6	0.8	0.0	0.7
	WBTH	1.9	5.6	1.3	1.0	0.0	0.0	0.8
	WBRT	6.7	4.5	6.6	5.3	4.0	1.9	2.2
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	75.0	78.8	140.3	291.2	92.0	79.7	82.4
	NBRT	1.6	7.4	6.7	9.1	3.8	3.3	3.3
	SBLT	5.2	36.9	8.4	11.6	8.5	8.2	8.1
	SBTH	40.6	106.4	87.9	77.2	65.2	93.3	101.2
	SBRT	1.1	1.5	1.5	1.3	1.3	1.4	1.3
	EBLT	11.1	22.2	21.5	10.7	8.9	8.4	8.9
	EBTH	0.0	9.7	0.0	0.0	0.0	0.0	0.0
	EBRT	0.3	0.1	0.0	0.3	0.3	0.3	0.5
	WBLT	3.2	18.9	19.9	11.4	13.6	13.0	12.8
	WBTH	0.0	2.5	0.4	0.0	0.0	0.0	0.0
	WBRT	0.7	14.0	5.6	5.0	2.8	2.5	2.3
HIGH SCHOOL ROAD	NBLT	40.5	73.2	93.1	154.2	52.2	101.7	79.5
	NBTH	239.7	336.0	434.0	482.6	176.1	135.7	141.4
	NBRT	0.0	3.6	5.7	15.9	3.3	2.6	1.4
	SBLT	89.1	330.2	166.7	123.0	145.8	154.9	224.5
	SBTH	139.9	341.4	284.6	173.6	149.7	208.9	221.5
	SBRT	5.3	6.9	6.2	11.6	8.3	6.2	18.1
	EBLT	115.4	87.5	78.9	61.8	46.5	51.7	214.1
	EBTH	45.7	73.0	46.5	27.5	30.5	34.9	127.4
	EBRT	8.6	25.0	10.6	7.5	5.6	15.8	48.8
	WBLT	19.9	48.9	38.8	27.5	23.6	34.0	35.5
	WBTH	78.5	92.9	81.3	43.5	20.7	46.2	59.5
	WBRT	107.0	147.9	114.9	72.5	33.3	27.4	29.1
JCT I-465 (SOUTH)	NBTH	224.7	295.6	291.0	488.8	214.6	166.3	196.6
	NBRT	26.5	24.2	32.2	57.8	29.0	25.5	22.6
	SBLT	61.7	155.5	80.2	45.4	95.4	78.0	105.3
	SBTH	18.7	56.2	28.1	31.5	31.5	37.9	46.4
	WBLT	239.0	445.4	442.7	281.5	280.9	311.1	358.0
	WBRT	15.2	25.0	53.4	25.2	21.6	15.7	15.6
JCT I-465 (NORTH)	NBTH	35.6	34.8	45.1	71.4	35.7	35.5	51.7
	NBRT	192.6	226.1	326.5	352.0	123.4	84.2	76.6
	SBLT	137.5	764.1	286.2	135.0	58.1	84.9	144.4
	SBTH	5.0	18.4	6.6	9.5	9.4	12.6	14.8
	WBLT	145.9	235.9	172.0	115.0	135.5	111.2	157.5
	WBRT	5.5	20.1	6.1	8.2	2.9	4.4	7.1

Table B-13: Case_2 - Vehicular Delay (V-M) - Time of Day - Part 1 of 2

INT	START END	1:00 PM 2:00 PM	2:00 PM 3:00 PM	3:00 PM 4:00 PM	4:00 PM 5:00 PM	5:00 PM 6:00 PM	TOTALS	CUMM- ULATIVE
HEATHROW DRIVE / MENDENHALL	NBLT	39.0	45.2	35.9	37.7	54.6	684.0	684
	NBTH	71.4	88.7	66.1	75.5	58.5	900.1	1,584
	NBRT	1.3	0.5	2.9	0.8	2.9	22.8	1,607
	SBLT	36.4	122.7	53.1	62.3	40.2	630.0	2,237
	SBTH	96.8	205.4	377.4	456.7	333.3	1,987.6	4,225
	SBRT	1.6	2.6	4.4	4.0	0.1	20.0	4,244
	EBLT	63.2	107.3	164.9	139.4	131.6	846.6	5,091
	EBTH	0.6	1.4	5.5	6.7	4.3	33.3	5,124
	EBRT	0.6	4.0	7.8	9.6	7.2	36.2	5,161
	WBLT	0.0	0.6	0.0	0.7	0.0	3.8	5,164
	WBTH	0.0	2.9	4.4	1.0	2.1	20.8	5,185
	WBRT	3.7	3.0	2.2	1.4	3.2	44.8	5,230
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	5,230
	NBTH	85.6	84.9	74.4	83.4	69.8	1,237.5	6,467
	NBRT	3.6	4.1	4.8	5.6	7.8	61.1	6,528
	SBLT	8.0	27.5	14.8	14.8	7.6	159.4	6,688
	SBTH	101.9	162.7	248.1	284.9	214.8	1,584.1	8,272
	SBRT	2.2	2.4	4.3	5.6	0.2	24.2	8,296
	EBLT	6.0	4.5	5.1	5.0	2.1	114.5	8,411
	EBTH	0.0	0.0	0.0	4.9	0.5	15.2	8,426
	EBRT	0.1	0.2	0.0	0.0	0.2	2.2	8,428
	WBLT	11.8	12.8	72.9	41.2	55.1	286.5	8,715
	WBTH	0.0	0.0	6.8	3.0	1.8	14.7	8,729
	WBRT	2.7	7.2	47.1	23.7	20.8	134.2	8,864
HIGH SCHOOL ROAD	NBLT	45.5	59.1	39.6	43.6	78.1	860.4	9,724
	NBTH	156.2	500.4	451.7	505.6	391.4	3,950.8	13,675
	NBRT	3.5	1.8	6.0	1.5	5.3	50.6	13,725
	SBLT	198.8	491.7	380.3	1,278.9	1,106.1	4,689.8	18,415
	SBTH	223.4	248.7	337.8	470.1	303.7	3,103.3	21,519
	SBRT	9.1	16.3	15.1	24.1	19.7	146.8	21,665
	EBLT	77.0	90.9	108.4	91.0	129.5	1,152.6	22,818
	EBTH	52.5	55.5	94.6	99.2	175.1	862.4	23,680
	EBRT	17.3	36.3	31.6	74.0	77.8	359.0	24,039
	WBLT	29.7	35.6	47.7	69.8	61.3	472.3	24,512
	WBTH	33.7	41.9	63.9	46.8	57.3	666.2	25,178
	WBRT	26.6	37.9	55.5	65.0	42.4	759.6	25,938
JCT I-465 (SOUTH)	NBTH	190.9	286.1	312.8	428.2	322.2	3,417.8	29,355
	NBRT	26.2	30.7	50.8	47.4	30.9	403.8	29,759
	SBLT	71.7	164.4	190.0	242.4	174.5	1,464.5	31,224
	SBTH	42.8	176.6	235.7	296.5	162.1	1,164.1	32,388
	WBLT	372.4	675.6	685.5	860.6	812.7	5,765.3	38,153
	WBRT	17.8	47.2	30.2	52.8	43.5	363.0	38,516
JCT I-465 (NORTH)	NBTH	43.1	78.0	50.7	61.5	50.7	593.8	39,110
	NBRT	88.7	124.9	115.7	184.6	123.2	2,018.8	41,129
	SBLT	155.0	439.5	198.5	301.9	121.9	2,826.9	43,956
	SBTH	12.9	36.0	46.7	43.0	24.8	239.7	44,195
	WBLT	122.8	251.5	283.4	326.8	298.2	2,355.7	46,551
	WBRT	6.8	6.0	3.2	4.3	5.1	79.6	46,631

Table B-14: Case_2 - Vehicular Delay (V-M) - Time of Day - Part 2 of 2

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
HEATHROW DRIVE / MENDENHALL	NBLT	4.1	8.9	10.6	19.0	6.3	8.9	4.4	3.5	4.9	11.8	9.1	5.8
	NBTH	3.8	3.3	6.9	20.2	6.2	5.9	6.0	4.8	3.5	2.6	3.9	2.1
	NBRT	0.0	0.3	0.6	0.5	0.3	0.4	0.3	0.1	0.2	0.6	0.3	0.3
	SBLT	3.8	17.2	4.9	4.8	4.8	6.6	4.8	5.8	22.2	9.3	7.5	10.8
	SBTH	4.0	5.6	4.5	8.0	6.7	6.2	5.5	3.0	22.6	23.8	52.9	23.3
	SBRT	0.2	0.7	0.4	0.9	0.4	0.5	0.8	0.7	1.0	1.2	0.8	0.2
	EBLT	2.8	2.0	4.4	6.1	3.5	2.8	2.1	3.1	7.0	6.3	9.6	7.1
	EBTH	0.0	1.2	0.9	1.8	1.8	0.8	1.0	0.8	1.4	1.0	5.3	3.6
	EBRT	0.0	0.4	0.2	0.2	0.5	0.2	0.3	0.3	0.9	1.3	1.2	0.5
	WBLT	0.0	0.6	0.0	0.9	0.7	0.0	1.4	0.0	1.0	0.0	0.9	0.0
	WBTH	1.6	2.2	0.7	0.7	0.0	0.0	1.4	0.0	3.0	2.2	1.0	2.0
WBRT	2.1	1.5	1.9	0.8	0.9	0.9	0.9	0.6	0.5	0.4	0.3	0.5	
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	1.7	4.2	7.7	26.9	3.6	5.2	3.8	7.5	5.2	2.4	7.7	5.5
	NBRT	0.3	2.2	1.6	2.8	1.5	1.2	1.2	0.8	1.1	0.8	1.0	1.3
	SBLT	1.6	4.3	3.3	3.6	2.1	1.5	2.4	3.0	4.8	2.8	2.1	2.3
	SBTH	3.2	7.8	1.6	8.1	7.1	8.4	5.6	5.6	5.5	18.3	27.9	15.5
	SBRT	0.5	0.5	0.5	1.1	0.6	0.9	0.9	0.6	1.4	0.7	0.8	0.2
	EBLT	2.2	3.8	1.9	1.2	1.6	0.3	3.8	3.0	2.4	0.5	3.1	1.4
	EBTH	0.0	3.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	1.2
	EBRT	0.3	0.1	0.0	0.3	0.3	0.2	0.4	0.2	0.1	0.0	0.0	0.3
	WBLT	1.4	3.3	5.9	1.8	2.3	1.9	1.8	3.9	2.7	14.6	6.1	9.2
	WBTH	0.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	1.0	1.0
WBRT	0.3	1.7	0.5	1.6	0.6	0.3	0.6	0.5	1.0	6.7	5.1	2.2	
HIGH SCHOOL ROAD	NBLT	6.0	10.6	28.6	25.4	4.4	10.7	9.4	3.4	15.8	9.6	8.0	11.5
	NBTH	15.1	23.4	15.4	30.0	9.1	10.6	4.8	9.1	13.4	17.2	43.7	20.8
	NBRT	0.0	0.7	1.5	1.2	0.8	0.8	0.6	0.8	0.4	1.3	0.5	1.4
	SBLT	8.8	28.4	10.7	12.8	20.0	27.7	27.2	21.9	82.7	27.3	283.	308.
	SBTH	9.6	27.7	19.3	13.3	16.4	14.6	12.9	15.4	9.5	9.9	50.7	41.8
	SBRT	1.4	1.4	1.6	0.7	1.6	1.2	3.2	2.5	2.5	1.5	4.7	3.4
	EBLT	8.3	6.4	5.3	4.1	2.3	5.3	82.3	16.8	6.3	6.9	11.8	15.8
	EBTH	5.2	5.8	5.0	3.3	2.4	5.2	44.4	9.0	4.8	2.9	6.4	38.7
	EBRT	4.0	4.1	2.8	2.1	1.7	3.0	20.2	3.9	8.8	7.7	6.9	28.5
	WBLT	5.4	9.7	4.5	2.8	4.2	4.2	4.7	5.8	6.6	12.2	8.3	7.6
	WBTH	8.0	8.2	8.2	5.7	4.0	6.1	5.2	2.1	5.3	6.5	5.7	7.8
WBRT	16.5	30.4	11.0	6.4	3.4	2.8	3.9	2.5	4.7	3.2	7.7	3.2	
JCT I-465 (SOUTH)	NBTH	7.9	25.9	9.1	51.7	8.9	14.9	12.5	15.5	19.3	19.2	42.5	13.5
	NBRT	4.5	2.4	3.2	4.0	3.0	2.5	2.3	3.7	2.9	5.1	1.4	2.3
	SBLT	13.1	36.9	26.5	11.2	13.0	15.0	19.1	13.0	20.6	9.3	23.8	17.6
	SBTH	1.4	5.1	2.2	1.8	0.8	1.6	2.2	2.2	4.5	12.3	20.2	22.4
	WBRT	2.6	7.6	3.2	5.4	1.4	1.7	1.7	1.9	5.1	3.3	3.1	6.5
JCT I-465 (NORTH)	NBTH	3.0	3.3	3.1	7.1	2.3	4.2	2.5	1.5	5.5	2.1	2.6	2.6
	NBRT	8.1	16.8	44.1	31.8	10.4	2.8	3.9	8.2	9.9	6.2	15.7	11.4
	SBLT	11.4	253.	218.	23.5	13.6	13.4	17.2	32.2	91.4	19.3	32.9	10.1
	SBTH	0.5	1.1	1.2	1.2	1.4	1.5	1.6	1.5	3.8	0.9	1.2	2.0
	WBRT	8.0	13.8	11.6	12.4	5.8	5.5	6.9	6.1	7.8	15.4	10.9	8.5
WBRT	1.0	1.2	1.1	0.8	0.9	0.7	0.6	1.1	0.8	0.6	1.3	0.6	

Table B-15: Case_2 - Standard Deviation of Delay (V-M) - Time of Day

INT	START END	6:00 AM 7:00 AM	7:00 AM 8:00 AM	8:00 AM 9:00 AM	9:00 AM 10:00 AM	10:00 AM 11:00 AM	11:00 AM 12:00 PM	12:00 PM 1:00 PM
HEATHROW DRIVE / MENDENHALL	NBLT	30.4	51.9	66.2	175.2	55.2	82.2	56.4
	NBTH	37.4	79.0	76.4	157.7	63.1	56.0	65.5
	NBRT	0.0	1.4	2.1	6.8	1.7	1.5	0.8
	SBLT	15.6	101.7	38.1	33.8	30.4	31.6	33.6
	SBTH	29.2	66.6	66.0	70.0	70.8	91.2	98.5
	SBRT	0.4	0.7	0.9	1.5	1.4	1.1	1.7
	EBLT	12.1	17.9	13.5	37.0	58.9	58.7	66.5
	EBTH	0.0	2.5	1.1	2.6	3.0	0.6	3.8
	EBRT	0.0	0.6	0.5	1.4	0.9	1.9	1.6
	WBLT	0.0	0.2	0.0	1.0	1.4	0.0	0.9
	WBTH	3.1	4.1	1.5	1.5	0.0	0.0	0.9
WBRT	7.2	4.4	6.6	6.8	3.9	1.8	2.5	
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	74.9	86.1	146.5	258.4	93.2	79.3	81.2
	NBRT	1.5	7.8	6.9	9.1	3.5	3.0	3.1
	SBLT	4.5	36.9	10.8	10.3	8.7	8.0	8.0
	SBTH	34.3	88.0	88.8	86.4	71.7	91.0	99.0
	SBRT	0.8	1.7	1.4	1.4	1.3	1.3	1.4
	EBLT	8.7	17.0	20.9	15.3	13.3	7.8	9.8
	EBTH	0.0	6.8	0.2	0.0	0.0	0.0	0.0
	EBRT	0.2	0.1	0.0	0.4	0.2	0.2	0.5
	WBLT	2.6	15.4	17.1	16.8	18.0	14.9	15.2
	WBTH	0.0	1.9	0.0	0.0	0.0	0.0	0.0
WBRT	0.6	10.2	5.2	5.0	3.6	2.6	2.1	
HIGH SCHOOL ROAD	NBLT	35.8	58.8	96.8	385.7	155.1	98.3	81.8
	NBTH	183.1	189.4	495.6	896.9	451.2	148.4	141.8
	NBRT	0.0	3.5	5.9	20.8	7.9	2.8	1.4
	SBLT	77.6	1,290.2	1,049.2	125.3	152.1	164.0	240.6
	SBTH	83.1	218.7	251.9	267.9	174.5	199.1	220.9
	SBRT	5.2	6.7	5.8	14.0	7.8	7.0	17.4
	EBLT	186.2	371.5	249.0	78.5	56.4	56.0	171.8
	EBTH	81.6	298.5	187.0	40.1	41.2	38.3	103.5
	EBRT	17.4	123.0	55.9	11.8	8.4	14.5	36.4
	WBLT	17.7	59.5	42.1	38.7	26.2	30.7	36.7
	WBTH	70.1	106.7	90.9	58.2	27.3	48.3	56.1
WBRT	101.2	144.5	114.7	91.9	37.5	29.7	31.5	
JCT I-465 (SOUTH)	NBTH	237.4	313.6	342.5	304.7	206.0	170.4	198.1
	NBRT	26.7	23.5	33.1	52.0	30.2	26.2	23.9
	SBLT	35.2	95.0	100.0	66.5	154.7	84.9	113.3
	SBTH	19.5	57.1	34.8	31.2	33.7	37.4	45.7
	WBRT	17.0	23.4	48.9	25.2	25.1	16.0	14.6
JCT I-465 (NORTH)	NBTH	47.4	45.8	55.5	50.5	38.8	36.5	51.3
	NBRT	216.2	259.5	370.1	317.2	141.0	85.0	74.4
	SBLT	126.5	1,555.0	2,603.9	149.5	69.1	88.8	134.2
	SBTH	4.9	21.7	824.0	9.2	10.1	13.1	14.6
	WBRT	110.8	228.8	166.9	151.9	176.0	109.9	150.1
	WBRT	5.2	20.4	6.4	7.9	2.6	4.8	7.1

Table B-16: Case_2 - Vehicular Delay (V-M) - Traffic Responsive - Part 1 of 2

INT	START END	1:00 PM 2:00 PM	2:00 PM 3:00 PM	3:00 PM 4:00 PM	4:00 PM 5:00 PM	5:00 PM 6:00 PM	TOTALS	CUMM- ULATIVE
HEATHROW DRIVE / MENDENHALL	NBLT	38.8	46.0	37.1	35.0	53.6	727.9	728
	NBTH	73.2	89.3	68.6	75.5	55.4	897.3	1,625
	NBRT	1.3	0.4	2.6	0.8	3.0	22.5	1,648
	SBLT	40.0	130.8	55.1	67.3	37.8	615.8	2,263
	SBTH	100.5	209.3	379.3	439.9	320.3	1,941.5	4,205
	SBRT	1.5	2.9	3.7	3.9	0.0	19.7	4,225
	EBLT	65.6	100.4	167.9	143.6	129.1	871.1	5,096
	EBTH	0.8	1.4	8.2	5.8	3.6	33.5	5,129
	EBRT	0.7	4.0	8.1	9.3	7.3	36.5	5,166
	WBLT	0.0	0.8	0.0	1.6	0.0	5.9	5,172
	WBTH	0.0	1.5	4.5	0.7	1.7	19.5	5,191
	WBRT	3.8	3.3	2.2	1.9	3.4	47.7	5,239
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	5,239
	NBTH	86.1	90.8	77.8	85.8	69.2	1,229.2	6,468
	NBRT	3.8	4.3	5.1	6.0	7.7	61.7	6,530
	SBLT	8.5	28.9	13.5	16.3	7.8	162.2	6,692
	SBTH	103.6	177.2	255.9	292.8	202.6	1,591.3	8,283
	SBRT	2.2	2.6	4.4	5.9	0.2	24.7	8,308
	EBLT	7.0	5.0	4.8	4.8	2.3	116.8	8,425
	EBTH	0.0	0.0	0.0	4.3	0.6	11.9	8,437
	EBRT	0.1	0.2	0.0	0.1	0.3	2.2	8,439
	WBLT	12.7	10.4	72.9	43.8	47.2	287.0	8,726
	WBTH	0.0	0.0	7.0	3.5	2.3	14.7	8,741
	WBRT	3.1	6.5	49.1	27.0	18.0	133.0	8,874
HIGH SCHOOL ROAD	NBLT	47.2	53.9	38.4	42.1	84.1	1,178.0	10,052
	NBTH	169.4	433.0	469.1	511.5	408.6	4,497.9	14,550
	NBRT	3.4	2.0	6.3	1.5	5.4	60.8	14,610
	SBLT	172.8	1,273.8	504.9	1,203.0	962.8	7,216.2	21,827
	SBTH	221.9	344.7	345.8	500.4	283.8	3,112.6	24,939
	SBRT	8.9	17.0	14.5	25.1	19.6	149.1	25,088
	EBLT	79.9	89.6	112.2	87.6	132.3	1,670.9	26,759
	EBTH	51.3	51.5	101.8	98.5	174.9	1,268.2	28,027
	EBRT	18.3	35.6	33.3	78.1	71.3	503.9	28,531
	WBLT	31.2	37.3	46.9	74.0	63.7	504.7	29,036
	WBTH	30.8	38.9	67.5	51.7	58.5	705.1	29,741
	WBRT	27.0	35.6	51.5	60.9	40.9	766.8	30,508
JCT I-465 (SOUTH)	NBTH	195.8	306.1	304.2	433.1	325.4	3,337.2	33,845
	NBRT	23.9	31.1	51.9	44.6	30.6	397.7	34,243
	SBLT	79.7	164.4	198.6	238.9	175.9	1,507.0	35,750
	SBTH	44.2	169.6	239.3	310.6	160.3	1,183.2	36,933
	WBLT	397.4	1,128.5	683.8	865.9	816.9	6,240.5	43,174
	WBRT	15.7	57.4	35.8	54.4	49.1	382.5	43,556
JCT I-465 (NORTH)	NBTH	44.5	79.0	45.8	63.4	54.0	612.4	44,168
	NBRT	86.1	123.2	116.3	182.0	128.8	2,099.9	46,268
	SBLT	197.2	973.8	545.5	326.5	130.0	6,900.0	53,168
	SBTH	13.5	46.0	47.8	44.5	24.0	1,073.4	54,242
	WBLT	130.7	242.6	278.5	334.0	299.1	2,379.3	56,621
	WBRT	6.5	7.1	3.1	3.7	5.3	80.2	56,701

Table B-17: Case_2 - Vehicular Delay (V-M) - Traffic Responsive - Part 2 of 2

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
HEATHROW DRIVE / MENDENHALL	NBLT	7.2	12.7	12.1	54.4	12.3	7.7	4.1	3.0	5.3	8.7	7.6	7.7
	NBTH	4.0	5.2	7.4	17.8	7.2	4.8	5.1	4.9	3.5	5.2	4.3	6.0
	NBRT	0.0	0.3	0.5	0.5	0.2	0.4	0.3	0.2	0.2	0.5	0.3	0.4
	SBLT	4.2	26.6	5.4	7.3	6.1	5.7	5.9	7.4	23.3	10.7	8.9	10.2
	SBTH	4.6	6.0	6.1	11.9	6.5	8.4	6.9	6.1	17.7	22.0	42.9	33.9
	SBRT	0.2	0.6	0.4	1.0	0.5	0.4	0.7	0.9	1.2	1.1	1.2	0.1
	EBLT	2.9	4.5	4.4	8.4	8.0	4.8	3.3	4.5	8.2	8.8	9.7	5.8
	EBTH	0.0	1.7	0.8	1.8	2.2	0.7	1.3	1.0	1.3	2.0	5.0	2.4
	EBRT	0.0	0.4	0.2	0.4	0.5	0.3	0.5	0.3	0.8	1.3	1.4	1.7
	WBLT	0.0	0.4	0.0	1.2	1.3	0.0	1.4	0.0	1.0	0.0	1.3	0.0
	WBTH	1.4	2.0	1.0	1.1	0.0	0.0	1.5	0.0	2.4	2.1	0.9	1.5
WBRT	1.6	1.1	1.5	1.3	1.0	0.7	1.0	0.6	0.7	0.4	0.5	0.6	
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	2.4	5.5	9.4	28.0	4.0	3.9	4.5	6.5	5.6	3.9	6.9	4.7
	NBRT	0.3	2.1	1.4	2.5	1.6	1.2	1.0	0.9	1.0	0.7	1.2	1.3
	SBLT	1.6	7.6	3.8	3.2	2.5	1.1	2.1	2.3	4.1	2.1	2.6	1.8
	SBTH	5.2	11.2	6.0	9.5	9.7	8.2	4.8	7.5	11.4	16.5	21.6	17.2
	SBRT	0.4	0.5	0.6	0.9	0.7	0.9	0.8	0.7	1.2	0.8	1.0	0.2
	EBLT	2.4	5.1	1.8	3.0	2.7	1.1	3.5	3.2	1.7	0.7	2.8	1.4
	EBTH	0.0	2.9	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	1.0
	EBRT	0.2	0.1	0.0	0.3	0.2	0.1	0.4	0.2	0.1	0.0	0.1	0.4
	WBLT	1.2	3.7	6.6	5.1	3.4	1.8	2.1	3.7	2.3	23.6	6.5	7.8
	WBTH	0.0	1.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	5.2	1.9	1.4
WBRT	0.3	2.8	1.8	1.3	1.0	0.7	0.6	0.6	1.1	15.1	4.5	3.7	
HIGH SCHOOL ROAD	NBLT	5.0	12.5	24.1	145.	79.8	14.0	9.5	2.8	12.1	8.6	8.0	10.3
	NBTH	36.8	91.8	47.0	407.	319.	17.5	5.5	32.5	55.0	15.4	31.8	23.1
	NBRT	0.0	0.6	1.6	6.3	6.5	0.8	0.6	0.6	0.4	1.1	0.5	1.3
	SBLT	10.3	643.	626.	10.0	17.2	33.9	32.7	22.7	797.	169.	276.	282.
	SBTH	36.0	75.3	21.8	51.2	27.3	14.0	13.2	21.9	76.1	12.0	97.3	31.1
	SBRT	1.1	1.5	1.6	1.5	1.6	1.2	2.6	2.5	2.6	2.1	3.9	2.9
	EBLT	76.5	205.	122.	10.2	7.7	4.9	76.9	26.5	8.8	9.9	9.6	14.6
	EBTH	32.5	163.	97.7	8.0	6.4	5.0	41.9	14.2	5.8	7.2	13.0	35.4
	EBRT	9.1	67.8	31.0	3.3	1.9	3.8	17.4	6.9	6.9	6.7	13.3	23.6
	WBLT	6.0	17.7	5.8	6.2	5.1	4.5	6.2	5.0	5.3	10.1	7.8	7.1
	WBTH	10.5	24.8	16.9	10.2	5.5	4.8	5.2	2.9	5.1	6.7	5.6	6.9
WBRT	12.7	22.5	8.8	12.3	4.9	2.8	4.0	3.3	4.7	3.5	8.3	3.6	
JCT I-465 (SOUTH)	NBTH	16.6	22.5	41.4	103.	17.9	10.7	9.6	16.2	21.2	17.0	48.4	21.8
	NBRT	3.9	2.1	2.6	5.2	3.2	2.2	2.1	3.0	3.1	5.0	2.2	2.3
	SBLT	16.9	48.3	25.2	15.0	36.4	20.2	16.7	11.3	22.4	10.6	21.0	19.9
	SBTH	1.4	3.9	5.8	2.7	1.4	2.5	2.0	2.8	7.6	11.4	17.8	15.3
	WBLT	36.9	75.6	25.7	66.3	45.6	12.3	12.9	21.9	478.	15.2	29.7	23.7
	WBRT	2.3	6.7	9.9	4.7	3.4	1.6	1.8	2.1	13.1	5.6	6.3	6.2
JCT I-465 (NORTH)	NBTH	8.1	7.1	7.8	12.3	4.9	4.2	2.8	1.9	7.7	3.2	3.8	3.3
	NBRT	18.8	26.8	43.2	39.0	21.3	2.4	3.7	7.3	8.5	5.6	18.3	11.1
	SBLT	13.0	470.	1,43	18.9	15.5	10.8	19.0	53.9	580.	391.	44.0	12.5
	SBTH	0.9	2.2	677.	1.0	1.5	1.6	1.5	1.5	10.1	3.1	1.5	1.9
	WBLT	19.8	34.9	12.0	22.0	22.7	6.1	7.9	10.0	10.2	11.7	9.9	8.8
	WBRT	1.0	1.3	1.1	0.9	0.8	0.9	0.5	0.9	1.2	0.6	1.0	0.6

Table B-18: Case_2 - Standard Deviation of Delay (V-M) - Traffic Responsive

INT	START END	6:00 AM 7:00 AM	7:00 AM 8:00 AM	8:00 AM 9:00 AM	9:00 AM 10:00 AM	10:00 AM 11:00 AM	11:00 AM 12:00 PM	12:00 PM 1:00 PM
HEATHROW DRIVE / MENDENHALL	NBLT	57.9	183.8	59.4	47.6	37.1	79.7	57.5
	NBTH	73.9	265.7	47.6	49.6	64.6	55.6	63.8
	NBRT	0.0	3.4	1.8	3.5	1.9	1.7	0.8
	SBLT	22.3	148.1	41.4	26.6	23.4	28.7	31.9
	SBTH	33.8	77.5	61.0	73.4	64.8	91.8	99.3
	SBRT	0.4	0.8	1.1	1.0	1.1	1.1	1.7
	EBLT	13.0	21.6	15.2	25.1	46.3	56.5	65.3
	EBTH	0.0	4.4	0.4	1.6	3.1	0.4	5.2
	EBRT	0.0	0.7	0.5	1.5	0.7	1.9	1.5
	WBLT	0.0	0.7	0.0	0.6	0.8	0.0	0.7
	WBTH	2.6	6.0	1.5	1.0	0.0	0.0	1.2
	WBRT	12.8	12.2	3.7	2.7	3.9	2.0	2.2
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	139.6	302.7	83.4	77.5	88.2	78.8	79.7
	NBRT	2.7	21.9	3.5	3.9	3.8	2.9	3.0
	SBLT	6.6	53.1	8.0	7.0	7.7	8.2	8.2
	SBTH	41.1	102.2	88.9	75.9	63.6	91.6	99.0
	SBRT	1.0	1.3	1.7	1.4	1.4	1.4	1.4
	EBLT	15.8	21.4	19.9	11.4	11.7	8.4	9.3
	EBTH	0.0	8.3	0.3	0.0	0.0	0.0	0.0
	EBRT	0.3	0.1	0.0	0.3	0.2	0.3	0.3
	WBLT	2.3	16.9	15.3	12.4	14.5	13.6	15.8
	WBTH	0.0	2.3	0.3	0.0	0.0	0.0	0.0
	WBRT	0.9	18.6	4.8	2.8	2.9	2.4	2.3
HIGH SCHOOL ROAD	NBLT	63.8	497.8	242.7	65.3	48.5	103.0	81.0
	NBTH	454.3	2,271.1	787.5	154.3	157.9	138.3	139.5
	NBRT	0.0	25.9	12.9	5.0	3.6	2.8	1.3
	SBLT	88.3	314.0	177.0	129.7	147.7	157.5	222.2
	SBTH	148.8	339.5	303.2	160.1	143.7	202.0	217.6
	SBRT	5.1	7.3	6.7	11.7	7.9	6.6	17.8
	EBLT	115.5	89.3	78.3	57.8	45.9	51.2	188.9
	EBTH	42.0	75.2	43.7	28.9	32.5	35.0	112.1
	EBRT	8.0	25.1	11.5	6.9	5.1	16.1	38.5
	WBLT	19.2	35.4	53.7	29.4	20.1	29.9	33.5
	WBTH	80.9	61.4	110.7	44.5	22.0	45.5	58.0
	WBRT	156.3	146.6	174.9	36.5	34.1	29.2	28.7
JCT I-465 (SOUTH)	NBTH	317.6	748.7	685.9	181.9	198.6	169.4	196.6
	NBRT	36.7	38.1	27.8	29.8	27.5	25.6	23.7
	SBLT	58.9	149.0	83.9	45.1	102.2	79.9	103.9
	SBTH	18.9	55.0	28.4	29.5	30.2	38.1	45.7
	WBLT	233.4	458.1	439.6	281.7	275.4	310.3	351.2
	WBRT	22.0	47.3	76.1	14.7	22.0	15.5	16.1
JCT I-465 (NORTH)	NBTH	53.0	559.7	264.1	33.4	34.2	36.5	51.8
	NBRT	337.8	1,128.7	807.4	118.7	110.4	85.3	77.1
	SBLT	135.2	774.8	296.6	134.0	57.9	85.9	142.0
	SBTH	4.6	18.7	7.4	9.0	9.5	13.9	14.6
	WBLT	138.2	227.7	174.3	113.1	141.2	113.3	149.0
	WBRT	5.4	21.7	6.6	7.9	2.7	4.5	7.0

Table B-19: Case_3 - Vehicular Delay (V-M) - Time of Day - Part 1 of 2

INT	START END	1:00 PM 2:00 PM	2:00 PM 3:00 PM	3:00 PM 4:00 PM	4:00 PM 5:00 PM	5:00 PM 6:00 PM	TOTALS	CUMM- ULATIVE
HEATHROW DRIVE / MENDENHALL	NBLT	38.7	46.7	41.2	32.6	53.8	736.0	736
	NBTH	73.6	85.3	68.6	71.9	56.4	976.6	1,713
	NBRT	1.3	0.5	2.9	0.8	2.7	21.2	1,734
	SBLT	36.1	133.0	68.0	60.7	40.3	660.6	2,394
	SBTH	98.0	213.7	475.8	331.2	362.0	1,982.3	4,377
	SBRT	1.8	2.6	4.4	3.4	0.0	19.3	4,396
	EBLT	63.9	104.4	161.1	146.4	124.8	843.6	5,240
	EBTH	0.8	1.7	8.7	6.0	4.5	36.8	5,276
	EBRT	0.7	3.9	8.5	8.6	7.1	35.6	5,312
	WBLT	0.0	1.5	0.0	0.6	0.0	4.9	5,317
	WBTH	0.0	2.1	3.9	0.8	2.6	21.8	5,339
	WBRT	3.8	3.4	2.2	1.3	3.2	53.5	5,392
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	5,392
	NBTH	86.4	86.4	76.0	81.6	71.3	1,251.5	6,644
	NBRT	3.9	4.5	5.1	6.1	7.8	69.0	6,713
	SBLT	8.4	28.4	16.9	14.9	8.7	176.1	6,889
	SBTH	101.4	156.9	302.7	235.3	237.1	1,595.8	8,485
	SBRT	2.1	2.1	5.6	5.3	0.1	24.9	8,509
	EBLT	6.7	4.7	4.9	5.0	2.6	121.7	8,631
	EBTH	0.0	0.0	0.0	4.4	0.2	13.2	8,644
	EBRT	0.2	0.2	0.0	0.0	0.2	2.0	8,646
	WBLT	12.8	11.6	70.1	43.8	47.1	276.1	8,922
	WBTH	0.0	0.0	6.9	3.0	2.0	14.4	8,937
	WBRT	3.1	6.6	44.4	26.3	17.9	132.9	9,070
HIGH SCHOOL ROAD	NBLT	45.2	54.7	40.8	44.4	79.9	1,366.9	10,437
	NBTH	152.0	488.8	454.0	491.9	399.4	6,089.0	16,526
	NBRT	3.6	1.6	6.3	1.4	5.2	69.7	16,595
	SBLT	205.7	468.3	431.7	534.4	502.5	3,378.9	19,974
	SBTH	231.4	228.6	439.6	304.6	310.5	3,029.6	23,004
	SBRT	8.7	18.0	18.2	16.8	17.7	142.4	23,146
	EBLT	81.1	88.3	106.1	87.0	145.8	1,135.1	24,281
	EBTH	57.1	53.5	95.9	96.2	188.7	860.7	25,142
	EBRT	19.1	34.4	34.5	70.4	75.9	345.4	25,488
	WBLT	26.7	36.0	48.6	73.4	61.8	467.6	25,955
	WBTH	31.7	43.3	60.9	49.2	55.2	663.3	26,619
	WBRT	28.1	39.1	52.2	64.2	40.3	830.3	27,449
JCT I-465 (SOUTH)	NBTH	183.3	319.2	366.2	372.7	306.6	4,046.8	31,496
	NBRT	24.9	31.3	51.5	45.2	30.2	392.3	31,888
	SBLT	72.4	111.1	201.9	227.7	257.2	1,493.1	33,381
	SBTH	42.6	136.9	310.3	224.9	216.3	1,176.7	34,558
	WBLT	387.5	824.9	829.4	725.7	694.5	5,811.8	40,370
	WBRT	16.8	75.0	43.6	37.4	33.1	419.5	40,789
JCT I-465 (NORTH)	NBTH	43.0	71.9	56.3	54.8	48.9	1,307.7	42,097
	NBRT	82.8	134.2	140.6	156.0	113.2	3,292.1	45,389
	SBLT	160.4	170.9	193.1	318.6	206.3	2,675.8	48,065
	SBTH	13.6	19.3	47.1	43.7	46.7	248.2	48,313
	WBLT	128.2	246.1	278.0	339.8	307.5	2,356.3	50,669
	WBRT	6.7	7.0	3.3	3.8	5.1	81.7	50,751

Table B-20: Case_3 - Vehicular Delay (V-M) - Time of Day - Part 2 of 2

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
HEATHROW DRIVE / MENDENHALL	NBLT	4.3	57.0	13.2	8.6	5.4	8.5	4.5	5.4	7.1	3.8	5.8	2.8
	NBTH	7.9	23.0	7.1	4.1	4.8	7.1	4.1	7.7	7.2	5.3	3.7	7.6
	NBRT	0.0	0.8	0.2	0.7	0.3	0.4	0.2	0.4	0.2	0.6	0.4	0.4
	SBLT	5.0	30.8	7.6	5.6	6.1	4.3	9.2	6.8	35.0	21.0	10.8	8.1
	SBTH	6.5	5.6	5.4	5.5	5.3	3.1	5.1	3.4	22.5	35.9	11.3	36.9
	SBRT	0.2	0.6	0.5	0.8	0.3	0.3	0.8	1.2	1.0	1.0	0.8	0.1
	EBLT	3.3	2.2	2.4	3.0	2.2	3.1	2.6	3.6	5.7	6.8	15.3	7.5
	EBTH	0.0	2.1	0.6	1.5	2.6	0.4	1.2	1.2	1.7	2.5	5.3	2.3
	EBRT	0.0	0.5	0.3	0.7	0.5	0.3	0.4	0.3	1.0	1.3	1.9	2.0
	WBLT	0.0	0.9	0.0	0.8	0.7	0.0	1.6	0.0	1.4	0.0	0.8	0.0
	WBTH	2.0	2.2	1.5	0.6	0.0	0.0	1.4	0.0	2.6	0.8	0.8	1.2
WBRT	4.0	2.9	0.7	0.4	0.9	0.6	0.5	0.5	0.7	0.5	0.1	0.7	
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	4.7	15.3	2.8	5.2	1.9	3.4	3.4	5.0	1.9	3.0	8.3	5.6
	NBRT	0.7	3.1	1.4	0.7	1.6	1.4	1.4	0.7	1.3	0.7	1.5	1.2
	SBLT	2.5	7.6	2.2	1.6	2.3	0.8	2.5	4.3	2.0	3.8	2.3	1.7
	SBTH	5.5	7.1	2.6	5.6	7.2	6.6	5.1	7.9	13.9	15.9	10.0	9.1
	SBRT	0.3	0.5	0.8	1.1	0.5	0.8	0.7	0.8	1.3	1.7	1.5	0.2
	EBLT	4.4	4.0	1.8	3.0	1.9	1.4	6.0	2.0	1.0	0.9	2.9	1.2
	EBTH	0.0	1.9	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.4
	EBRT	0.3	0.1	0.0	0.3	0.2	0.3	0.2	0.3	0.2	0.0	0.0	0.1
	WBLT	1.2	4.8	2.6	2.9	2.4	2.9	3.0	3.4	1.7	29.8	5.3	3.1
	WBTH	0.0	1.9	0.6	0.0	0.0	0.0	0.0	0.0	0.0	5.3	1.3	1.8
WBRT	0.3	2.2	1.5	0.4	0.5	0.6	0.7	0.7	1.3	22.5	6.4	5.3	
HIGH SCHOOL ROAD	NBLT	11.8	356.	237.	4.2	6.4	20.4	7.4	4.3	5.0	9.5	10.2	9.5
	NBTH	39.2	998.	517.	19.3	12.1	10.1	8.0	7.0	15.3	29.2	39.5	26.1
	NBRT	0.0	11.9	10.5	1.1	0.8	1.0	0.5	0.6	0.4	1.0	0.3	1.4
	SBLT	9.6	36.1	6.8	11.8	21.0	43.9	31.5	33.3	100.	74.2	57.0	80.1
	SBTH	14.9	27.9	9.8	8.1	13.7	16.0	7.0	18.1	9.2	20.4	15.7	9.9
	SBRT	1.3	1.2	2.3	1.0	2.1	1.2	3.2	2.2	2.4	1.9	2.4	4.9
	EBLT	8.5	6.7	8.9	5.6	2.2	8.1	65.6	19.8	6.4	4.4	12.8	20.3
	EBTH	6.6	6.3	9.2	2.1	3.9	5.4	32.3	10.3	8.4	5.4	4.8	37.5
	EBRT	3.3	3.0	5.0	2.2	1.3	2.0	17.6	6.9	8.3	4.6	5.5	17.8
	WBLT	6.4	1.8	5.5	3.1	4.8	3.9	7.1	2.6	4.5	11.5	10.0	11.3
	WBTH	11.1	6.5	9.5	3.5	4.3	5.8	7.5	5.7	4.2	5.8	5.9	3.6
WBRT	14.7	9.1	27.6	2.1	0.7	3.4	7.4	0.8	4.4	4.6	7.5	5.1	
JCT I-465 (SOUTH)	NBTH	14.1	432.	513.	9.3	8.2	8.7	13.6	9.4	18.9	18.6	41.2	17.3
	NBRT	5.7	3.1	4.4	1.9	2.7	2.2	1.6	1.9	3.8	4.4	1.9	2.6
	SBLT	6.7	44.9	25.8	7.8	14.3	20.3	21.6	7.6	8.2	25.5	20.6	15.1
	SBTH	1.0	5.4	2.4	1.7	1.3	1.2	1.7	2.9	5.4	19.5	6.6	9.6
	WBLT	8.4	40.6	14.3	4.6	5.1	4.6	8.7	22.9	18.7	22.8	21.4	34.1
	WBRT	3.2	22.3	54.2	1.9	3.9	1.4	3.4	2.0	6.0	5.1	8.7	4.8
JCT I-465 (NORTH)	NBTH	4.3	449.	100.	1.1	3.7	2.6	3.2	2.5	4.0	0.7	6.1	3.5
	NBRT	12.2	592.	481.	6.8	5.4	3.6	0.7	3.6	7.6	5.1	15.9	10.8
	SBLT	14.7	279.	232.	19.4	8.7	9.9	13.4	24.1	16.5	24.4	29.0	22.9
	SBTH	0.8	1.6	0.9	1.9	0.9	1.2	1.5	2.0	1.2	2.2	1.4	3.2
	WBLT	11.6	18.7	16.9	8.0	8.2	3.9	8.3	8.3	10.0	15.7	25.1	5.7
	WBRT	1.1	4.2	1.2	1.0	0.8	1.0	0.6	1.3	0.8	0.8	1.0	0.5

Table B-21: Case_3 - Standard Deviation of Delay (V-M) - Time of Day

INT	START END	6:00 AM 7:00 AM	7:00 AM 8:00 AM	8:00 AM 9:00 AM	9:00 AM 10:00 AM	10:00 AM 11:00 AM	11:00 AM 12:00 PM	12:00 PM 1:00 PM
HEATHROW DRIVE / MENDENHALL	NBLT	57.1	165.4	53.8	53.6	41.3	82.5	58.3
	NBTH	74.5	249.7	47.2	48.0	62.4	55.2	62.9
	NBRT	0.0	3.4	1.8	3.7	1.9	1.7	0.6
	SBLT	23.4	145.8	38.9	26.1	22.3	30.4	32.2
	SBTH	32.3	72.9	62.8	70.4	65.2	95.0	101.2
	SBRT	0.3	0.8	1.1	1.2	1.1	1.1	1.7
	EBLT	12.9	23.7	13.7	29.2	48.0	54.7	64.3
	EBTH	0.0	4.5	1.4	2.3	2.0	1.0	4.7
	EBRT	0.0	1.0	0.6	1.4	0.8	2.2	1.4
	WBLT	0.0	0.4	0.0	0.8	1.0	0.0	1.1
	WBTH	2.2	4.8	1.2	1.4	0.0	0.0	1.1
	WBRT	13.5	13.7	3.6	2.9	3.7	1.8	2.2
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	141.3	302.2	80.0	74.2	88.2	80.4	79.2
	NBRT	3.0	21.6	3.1	3.8	3.9	2.8	3.0
	SBLT	6.8	52.5	8.8	6.5	7.5	7.5	7.8
	SBTH	40.7	99.7	92.9	77.8	65.8	89.2	99.1
	SBRT	0.9	1.8	1.6	1.1	1.4	1.4	1.3
	EBLT	12.1	20.9	19.2	13.0	11.4	8.1	8.7
	EBTH	0.0	7.9	0.7	0.0	0.0	0.0	0.0
	EBRT	0.4	0.1	0.0	0.2	0.2	0.3	0.5
	WBLT	1.3	19.0	17.1	15.2	13.7	14.2	15.5
	WBTH	0.0	1.6	0.0	0.0	0.0	0.0	0.0
	WBRT	1.0	20.6	3.7	3.5	2.4	2.3	2.3
HIGH SCHOOL ROAD	NBLT	64.1	556.7	214.2	75.1	49.5	100.7	80.4
	NBTH	441.0	2,150.8	849.3	176.1	162.2	135.8	144.6
	NBRT	0.0	27.2	13.5	5.0	3.3	2.4	1.4
	SBLT	85.4	316.4	175.1	120.7	147.2	151.8	220.8
	SBTH	142.1	337.7	312.9	184.3	148.2	198.1	223.7
	SBRT	5.2	7.1	6.0	12.2	8.3	6.3	17.6
	EBLT	123.5	86.7	80.2	67.6	45.6	52.4	145.6
	EBTH	49.8	76.5	44.1	30.4	31.0	33.8	93.6
	EBRT	8.3	25.9	16.1	10.1	5.2	15.8	31.6
	WBLT	19.7	33.2	53.7	33.3	21.4	32.4	35.9
	WBTH	80.0	58.4	117.7	49.2	21.8	42.8	62.6
	WBRT	164.7	153.5	174.5	38.0	35.0	30.3	30.9
JCT I-465 (SOUTH)	NBTH	330.2	605.7	621.4	172.4	192.6	167.4	195.6
	NBRT	36.4	37.9	27.3	29.5	26.8	25.0	23.3
	SBLT	52.8	159.5	81.3	55.2	97.1	77.7	103.6
	SBTH	19.3	56.9	27.2	31.0	30.7	37.8	45.5
	WBLT	232.7	493.9	464.9	308.7	277.9	307.2	355.6
	WBRT	23.6	52.7	78.3	15.1	20.3	15.5	15.9
JCT I-465 (NORTH)	NBTH	55.9	706.3	326.5	31.4	34.6	37.0	51.3
	NBRT	342.6	1,437.6	887.7	122.5	108.8	84.6	75.5
	SBLT	141.3	758.8	315.3	134.9	56.5	82.4	134.0
	SBTH	4.7	21.1	7.4	8.8	9.2	13.3	14.1
	WBLT	135.7	229.3	174.0	128.0	140.1	110.8	146.7
	WBRT	5.6	18.3	7.1	7.9	2.7	4.4	7.0

Table B-22: Case_3 - Vehicular Delay (V-M) - Traffic Responsive - Part 1 of 2

INT	START END	1:00 PM 2:00 PM	2:00 PM 3:00 PM	3:00 PM 4:00 PM	4:00 PM 5:00 PM	5:00 PM 6:00 PM	TOTALS	CUMM- ULATIVE
HEATHROW DRIVE / MENDENHALL	NBLT	35.5	45.8	37.4	35.6	56.3	722.7	723
	NBTH	70.4	87.9	68.4	72.4	57.1	956.0	1,679
	NBRT	1.3	0.4	2.9	0.7	2.9	21.3	1,700
	SBLT	35.6	132.6	61.3	60.0	39.5	648.1	2,348
	SBTH	96.2	219.4	484.6	342.0	365.1	2,006.8	4,355
	SBRT	1.4	2.7	4.8	3.1	0.1	19.5	4,374
	EBLT	63.7	104.8	163.1	146.4	126.9	851.3	5,226
	EBTH	1.1	1.6	8.7	5.7	3.7	36.8	5,262
	EBRT	0.7	3.7	8.8	8.2	6.0	34.9	5,297
	WBLT	0.0	1.2	0.0	0.6	0.0	5.1	5,302
	WBTH	0.0	2.0	3.6	0.8	2.8	19.9	5,322
	WBRT	3.9	3.0	2.0	1.4	3.3	55.1	5,377
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	5,377
	NBTH	85.8	86.0	77.5	82.9	71.7	1,249.2	6,627
	NBRT	3.7	4.4	4.7	5.8	8.0	67.7	6,694
	SBLT	8.3	28.7	15.8	14.7	9.4	174.4	6,869
	SBTH	100.6	164.5	303.3	237.8	232.0	1,603.3	8,472
	SBRT	2.0	2.1	5.3	5.3	0.1	24.4	8,496
	EBLT	6.7	5.3	5.4	5.2	3.0	119.1	8,615
	EBTH	0.0	0.0	0.0	5.8	0.5	14.9	8,630
	EBRT	0.2	0.3	0.0	0.0	0.2	2.4	8,633
	WBLT	13.0	11.9	73.7	45.9	43.9	284.3	8,917
	WBTH	0.0	0.0	8.4	2.8	2.7	15.5	8,932
	WBRT	3.0	6.8	54.3	29.4	18.2	147.4	9,080
HIGH SCHOOL ROAD	NBLT	43.9	53.5	40.9	45.6	78.8	1,403.3	10,483
	NBTH	149.7	490.1	466.6	499.9	383.1	6,049.3	16,533
	NBRT	3.2	1.8	6.2	1.5	5.5	71.1	16,604
	SBLT	190.2	562.7	410.4	555.3	500.9	3,436.8	20,040
	SBTH	228.6	257.5	440.3	302.5	307.7	3,083.5	23,124
	SBRT	9.0	18.2	18.6	16.9	17.9	143.1	23,267
	EBLT	69.9	90.4	118.5	102.8	125.4	1,108.4	24,376
	EBTH	54.2	54.6	107.4	110.1	157.8	843.2	25,219
	EBRT	15.4	35.6	35.8	84.3	65.7	349.6	25,568
	WBLT	26.6	32.9	49.5	77.0	65.2	480.6	26,049
	WBTH	30.4	40.6	63.1	47.4	57.2	671.3	26,720
	WBRT	29.0	36.4	49.2	60.9	41.4	843.6	27,564
JCT I-465 (SOUTH)	NBTH	184.4	343.6	352.6	376.0	306.1	3,848.0	31,412
	NBRT	24.4	31.5	51.0	45.8	29.9	388.9	31,801
	SBLT	70.7	114.5	200.3	236.8	259.9	1,509.5	33,310
	SBTH	44.3	140.7	307.5	221.6	218.2	1,180.6	34,491
	WBLT	385.7	843.4	842.0	722.2	680.4	5,914.4	40,405
	WBRT	17.6	73.6	43.6	36.3	32.1	424.6	40,830
JCT I-465 (NORTH)	NBTH	43.6	76.4	54.4	52.7	47.4	1,517.4	42,347
	NBRT	86.7	133.5	134.2	156.1	112.1	3,681.9	46,029
	SBLT	152.5	177.4	194.9	297.0	205.7	2,650.8	48,680
	SBTH	13.8	19.8	44.3	43.9	47.6	248.0	48,928
	WBLT	127.2	250.5	284.8	332.8	298.0	2,358.1	51,286
	WBRT	6.3	6.6	3.5	3.7	5.5	78.5	51,365

Table B-23: Case_3 - Vehicular Delay (V-M) - Traffic Responsive - Part 2 of 2

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
HEATHROW DRIVE / MENDENHALL	NBLT	6.6	42.1	13.2	7.5	6.5	8.4	4.8	5.2	6.1	5.7	7.2	2.6
	NBTH	8.0	20.8	5.7	5.4	4.6	6.3	4.0	6.0	6.0	5.3	5.7	6.1
	NBRT	0.0	0.7	0.2	0.6	0.3	0.4	0.2	0.3	0.2	0.5	0.3	0.3
	SBLT	4.8	30.8	6.5	6.0	5.8	5.8	8.0	6.0	31.6	18.2	8.9	9.1
	SBTH	6.1	5.5	5.0	6.1	5.4	6.1	3.6	2.9	24.9	39.6	21.5	30.1
	SBRT	0.2	0.5	0.6	0.8	0.2	0.4	0.8	0.9	0.8	0.9	1.0	0.1
	EBLT	3.8	3.5	3.3	5.0	2.2	2.6	2.1	3.8	5.7	7.6	15.4	6.9
	EBTH	0.0	2.0	1.2	1.9	2.3	0.8	1.1	1.3	1.5	2.5	5.2	2.0
	EBRT	0.0	0.6	0.4	0.5	0.4	0.4	0.4	0.3	0.9	1.7	1.7	1.7
	WBLT	0.0	0.8	0.0	1.0	0.8	0.0	1.6	0.0	1.3	0.0	0.7	0.0
	WBTH	1.9	2.0	1.5	0.9	0.0	0.0	1.2	0.0	2.5	0.8	0.7	1.1
WBRT	3.2	2.5	0.8	0.5	0.9	0.5	0.6	0.4	0.7	0.5	0.2	0.6	
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	5.4	12.4	4.7	5.5	2.1	3.4	4.6	5.5	2.8	3.5	8.8	4.7
	NBRT	0.7	3.2	1.4	0.8	1.5	1.3	1.3	0.7	1.1	0.7	1.3	1.2
	SBLT	2.2	7.9	2.5	1.4	2.2	0.8	2.2	3.2	2.0	3.5	2.4	1.8
	SBTH	4.3	6.9	4.1	6.3	7.8	6.3	5.7	7.3	13.3	16.1	11.6	9.2
	SBRT	0.4	0.5	0.7	0.9	0.5	0.9	0.7	0.8	1.2	1.5	1.3	0.2
	EBLT	5.4	3.3	1.5	2.9	2.1	1.4	5.7	1.5	0.9	1.2	2.8	1.3
	EBTH	0.0	2.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.8
	EBRT	0.4	0.1	0.0	0.2	0.2	0.2	0.4	0.3	0.2	0.0	0.0	0.2
	WBLT	1.1	4.3	4.5	4.6	2.2	2.9	2.6	3.0	1.3	21.0	6.4	4.5
	WBTH	0.0	1.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0	5.2	1.3	1.8
WBRT	0.4	2.4	1.3	0.6	0.5	0.5	0.6	0.8	1.1	19.5	5.0	4.6	
HIGH SCHOOL ROAD	NBLT	10.4	282.	170.	17.1	6.6	16.3	6.2	3.1	5.8	9.4	8.2	8.5
	NBTH	37.9	742.	522.	37.3	14.1	8.2	7.0	7.9	18.8	25.0	29.4	22.4
	NBRT	0.0	9.8	9.2	1.0	0.9	0.9	0.5	0.6	0.4	1.2	0.4	1.2
	SBLT	12.7	36.0	10.3	13.0	19.5	37.1	30.2	27.7	121.	57.7	58.7	69.5
	SBTH	16.9	19.9	16.3	26.2	14.6	12.0	12.2	16.0	19.6	20.5	13.2	11.2
	SBRT	1.2	1.1	2.0	1.0	1.8	1.1	2.8	2.4	2.1	1.6	2.3	4.6
	EBLT	10.8	8.6	8.2	10.9	1.9	6.3	51.6	19.4	7.3	8.7	16.2	22.5
	EBTH	7.5	6.1	8.7	2.7	3.0	5.2	24.9	15.8	6.6	10.3	13.3	32.4
	EBRT	3.0	3.4	5.3	2.6	1.5	2.2	13.2	6.7	6.4	6.0	15.1	15.6
	WBLT	5.8	3.9	4.6	5.4	3.6	5.2	6.9	3.3	5.8	9.7	9.7	12.3
	WBTH	9.6	5.6	8.9	5.2	3.7	5.3	6.9	3.9	3.5	6.1	5.2	5.1
WBRT	17.9	10.9	23.8	3.4	3.6	2.6	6.2	1.9	4.7	5.5	7.3	5.7	
JCT I-465 (SOUTH)	NBTH	16.7	304.	454.	10.5	9.0	9.0	12.7	12.1	29.6	18.2	43.6	16.4
	NBRT	5.2	3.4	3.3	1.6	2.5	2.3	1.7	2.0	3.4	4.0	2.9	2.3
	SBLT	7.6	37.4	23.8	18.4	14.3	19.6	17.9	10.3	8.4	22.9	22.6	15.4
	SBTH	1.3	4.5	2.5	2.3	1.5	1.8	1.8	3.0	4.4	13.8	5.3	8.2
	WBLT	7.9	62.3	50.7	31.2	6.0	6.8	11.0	18.4	19.9	26.4	21.4	28.2
	WBRT	2.9	17.2	53.1	2.0	3.3	1.9	3.2	1.7	4.5	3.7	6.5	3.5
JCT I-465 (NORTH)	NBTH	4.1	332.	134.	2.3	3.5	3.1	3.3	2.1	4.3	3.0	4.8	4.6
	NBRT	11.2	453.	476.	10.1	5.1	3.3	3.2	5.3	5.4	6.3	12.1	8.7
	SBLT	13.0	265.	259.	18.8	8.9	8.9	12.1	24.5	12.9	25.6	23.2	20.0
	SBTH	0.8	2.6	1.0	1.6	0.9	1.2	1.2	2.0	1.4	3.3	1.3	3.0
	WBLT	12.0	14.3	15.3	14.5	8.2	3.9	7.5	6.5	8.7	11.6	18.6	11.7
	WBRT	0.9	3.4	1.4	1.0	0.7	1.0	0.6	1.1	0.9	0.8	1.0	0.6

Table B-24: Case_3 - Standard Deviation of Delay (V-M) - Traffic Responsive

INT	START END	6:00 AM 7:00 AM	7:00 AM 8:00 AM	8:00 AM 9:00 AM	9:00 AM 10:00 AM	10:00 AM 11:00 AM	11:00 AM 12:00 PM	12:00 PM 1:00 PM
HEATHROW DRIVE / MENDENHALL	NBLT	57.6	189.4	51.6	49.6	35.8	81.4	52.0
	NBTH	74.2	220.9	42.2	49.5	72.3	63.7	70.0
	NBRT	0.0	3.3	1.7	3.7	1.8	1.6	0.6
	SBLT	21.1	89.2	31.5	21.3	32.5	39.3	34.0
	SBTH	31.6	47.1	45.3	58.7	95.0	130.4	116.5
	SBRT	0.4	0.5	0.7	1.0	1.8	1.7	2.2
	EBLT	15.6	23.1	13.7	27.5	44.6	56.2	61.0
	EBTH	0.0	2.8	1.1	1.9	2.8	0.9	3.8
	EBRT	0.0	0.7	0.5	1.2	1.4	2.2	1.4
	WBLT	0.0	0.6	0.0	0.4	1.2	0.0	0.8
	WBTH	2.2	5.6	1.6	0.8	0.0	0.0	0.7
	WBRT	12.8	12.8	4.0	2.9	4.0	1.3	2.0
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	138.9	289.9	79.3	74.6	93.8	79.4	84.2
	NBRT	2.7	21.2	3.2	4.2	3.3	3.0	3.2
	SBLT	6.4	35.2	6.4	5.8	9.6	11.6	9.0
	SBTH	40.5	64.8	64.3	61.3	98.7	134.0	116.2
	SBRT	1.1	0.9	1.3	1.3	2.0	2.1	1.7
	EBLT	9.7	21.2	22.9	10.9	8.8	8.7	9.1
	EBTH	0.0	10.1	0.3	0.0	0.0	0.0	0.0
	EBRT	0.3	0.1	0.0	0.2	0.4	0.2	0.4
	WBLT	2.6	20.7	19.0	12.2	13.6	12.6	13.5
	WBTH	0.0	1.6	0.0	0.0	0.0	0.0	0.0
	WBRT	0.9	18.4	5.2	3.0	2.7	2.4	2.4
HIGH SCHOOL ROAD	NBLT	61.8	550.7	227.8	63.9	48.3	99.3	74.4
	NBTH	447.3	1,513.5	360.2	134.1	163.1	137.1	142.8
	NBRT	0.0	16.9	5.2	5.2	3.4	2.6	1.5
	SBLT	87.2	197.9	119.4	100.6	246.1	463.8	427.6
	SBTH	151.0	267.6	242.2	137.0	192.4	260.7	250.2
	SBRT	5.2	5.3	5.2	10.8	10.8	9.0	20.2
	EBLT	116.7	87.0	77.5	62.2	43.4	49.7	156.8
	EBTH	45.8	71.4	47.8	29.4	34.9	34.7	97.5
	EBRT	9.4	24.2	12.0	6.1	5.3	15.2	34.2
	WBLT	21.5	52.8	38.7	30.2	21.8	35.6	34.4
	WBTH	83.3	94.2	79.1	46.8	19.0	46.4	55.5
	WBRT	152.2	273.8	93.9	37.9	33.4	29.9	30.5
JCT I-465 (SOUTH)	NBTH	321.4	582.4	243.0	172.9	196.5	179.7	201.3
	NBRT	35.3	39.5	23.7	29.5	27.6	26.0	23.9
	SBLT	56.2	51.9	38.8	29.5	1,069.5	2,100.6	1,400.7
	SBTH	18.7	22.9	14.7	20.6	66.7	88.2	64.6
	WBLT	234.0	462.6	451.7	272.5	275.0	304.3	353.6
	WBRT	21.2	44.6	48.3	14.2	20.2	16.1	15.5
JCT I-465 (NORTH)	NBTH	51.7	335.8	55.4	30.5	39.3	40.6	53.1
	NBRT	344.7	924.7	364.0	119.0	116.4	94.1	78.1
	SBLT	136.0	39.3	6.1	54.6	192.6	556.2	737.3
	SBTH	5.0	1.9	0.4	3.7	24.3	26.7	20.3
	WBLT	143.3	232.7	171.8	111.9	138.8	109.7	154.6
	WBRT	5.1	20.0	6.3	7.4	2.6	4.5	6.7

Table B-25: Case_4 - Vehicular Delay (V-M) - Time of Day - Part 1 of 2

INT	START END	1:00 PM 2:00 PM	2:00 PM 3:00 PM	3:00 PM 4:00 PM	4:00 PM 5:00 PM	5:00 PM 6:00 PM	TOTALS	CUMM- ULATIVE
HEATHROW DRIVE / MENDENHALL	NBLT	35.9	53.1	37.8	32.9	57.3	734.4	734
	NBTH	69.6	85.8	65.0	72.9	59.3	945.2	1,680
	NBRT	1.3	0.4	2.9	0.8	2.8	21.0	1,701
	SBLT	37.7	108.7	51.2	64.5	40.8	571.7	2,272
	SBTH	97.6	145.4	370.2	444.4	386.5	1,968.7	4,241
	SBRT	1.6	2.0	3.7	4.1	0.1	19.9	4,261
	EBLT	64.5	110.4	163.4	137.5	137.4	854.9	5,116
	EBTH	1.2	2.0	6.9	6.6	5.0	35.1	5,151
	EBRT	0.7	3.8	7.4	9.1	7.5	35.9	5,187
	WBLT	0.0	0.9	0.0	0.5	0.0	4.5	5,191
	WBTH	0.0	2.1	4.0	0.8	2.6	20.3	5,212
	WBRT	3.6	3.3	2.1	1.7	3.5	53.7	5,265
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	5,265
	NBTH	84.9	84.3	75.1	85.4	71.0	1,240.7	6,506
	NBRT	3.4	4.2	5.3	5.7	7.4	66.9	6,573
	SBLT	8.8	23.5	13.2	16.0	7.7	153.2	6,726
	SBTH	102.3	123.0	245.0	293.1	230.1	1,573.2	8,299
	SBRT	2.2	1.8	3.9	5.8	0.3	24.3	8,324
	EBLT	6.2	4.5	5.7	4.8	2.2	114.6	8,438
	EBTH	0.0	0.0	0.0	4.4	0.5	15.3	8,454
	EBRT	0.1	0.3	0.0	0.0	0.3	2.3	8,456
	WBLT	11.2	12.5	75.7	39.5	45.7	278.6	8,735
	WBTH	0.0	0.0	7.8	3.2	1.8	14.4	8,749
	WBRT	3.3	7.3	55.3	24.4	19.9	145.2	8,894
HIGH SCHOOL ROAD	NBLT	47.8	59.6	38.0	46.6	70.7	1,388.7	10,283
	NBTH	154.7	489.1	435.4	528.2	357.7	4,863.2	15,146
	NBRT	3.2	1.7	5.6	1.5	4.9	51.6	15,198
	SBLT	196.6	332.0	339.0	1,238.8	2,412.4	6,161.4	21,359
	SBTH	223.2	177.0	330.4	510.0	678.2	3,419.9	24,779
	SBRT	9.1	13.7	15.3	25.2	29.7	159.6	24,938
	EBLT	80.8	88.2	109.8	98.3	141.4	1,111.7	26,050
	EBTH	48.7	55.4	99.5	103.4	189.5	858.0	26,908
	EBRT	15.9	32.8	35.3	78.3	74.1	342.8	27,251
	WBLT	25.5	38.0	46.3	70.6	58.7	474.1	27,725
	WBTH	33.1	39.8	64.5	47.3	50.4	659.6	28,385
	WBRT	28.1	36.6	50.2	61.7	38.0	866.2	29,251
JCT I-465 (SOUTH)	NBTH	183.9	268.9	312.6	433.7	292.9	3,389.2	32,640
	NBRT	24.8	31.5	50.6	46.8	25.3	384.4	33,024
	SBLT	216.1	120.6	196.6	244.3	211.3	5,736.0	38,760
	SBTH	42.4	98.4	220.6	311.5	283.5	1,253.0	40,013
	WBLT	370.2	665.4	673.7	880.4	664.6	5,607.9	45,621
	WBRT	16.8	42.8	32.5	56.7	39.6	368.5	45,990
JCT I-465 (NORTH)	NBTH	42.9	69.9	46.3	62.0	47.9	875.2	46,865
	NBRT	85.7	111.8	117.7	184.5	109.9	2,650.6	49,516
	SBLT	266.3	177.2	192.1	288.5	195.9	2,842.1	52,358
	SBTH	13.4	20.2	45.5	45.5	44.8	251.7	52,609
	WBLT	123.2	246.6	287.1	337.4	269.6	2,326.7	54,936
	WBRT	6.7	6.6	3.1	3.8	5.1	78.0	55,014

Table B-26: Case_4 - Vehicular Delay (V-M) - Time of Day - Part 2 of 2

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
HEATHROW DRIVE / MENDENHALL	NBLT	6.1	46.6	11.7	9.7	10.9	15.0	2.0	5.7	9.0	5.9	2.9	7.2
	NBTH	4.5	12.6	2.4	6.7	6.3	2.5	5.1	6.4	3.3	3.4	3.3	6.2
	NBRT	0.0	0.6	0.2	0.6	0.3	0.5	0.1	0.3	0.2	0.7	0.4	0.3
	SBLT	4.9	8.4	7.9	5.7	7.9	7.7	6.7	6.7	17.9	4.8	14.1	17.6
	SBTH	5.7	4.6	4.7	6.0	8.5	6.8	3.1	7.8	12.5	30.0	29.7	139.
	SBRT	0.2	0.4	0.4	0.3	0.6	0.6	0.8	0.9	1.3	0.5	1.0	0.2
	EBLT	2.7	3.5	3.9	4.9	3.4	3.3	3.5	3.0	7.0	7.9	9.3	4.7
	EBTH	0.0	2.3	1.1	2.0	2.2	0.9	1.4	2.2	1.4	1.6	5.1	4.5
	EBRT	0.1	0.5	0.3	0.3	0.9	0.3	0.5	0.1	0.8	2.1	1.9	1.5
	WBLT	0.0	0.9	0.0	0.9	1.7	0.0	1.5	0.0	1.2	0.0	0.7	0.0
	WBTH	1.8	2.1	0.9	0.6	0.0	0.0	0.8	0.0	2.1	2.2	0.8	1.4
WBRT	2.9	2.5	1.3	0.8	1.4	0.4	0.2	0.8	1.4	0.3	0.4	0.9	
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	4.4	11.1	4.4	7.2	5.5	3.0	5.9	6.1	2.8	2.0	5.5	3.8
	NBRT	0.8	2.8	1.2	1.3	2.1	1.5	1.3	0.7	1.2	1.1	1.2	1.2
	SBLT	1.7	10.0	4.5	2.2	2.1	2.3	3.2	3.2	1.9	1.1	1.6	3.1
	SBTH	2.0	4.7	4.0	4.2	7.3	5.4	5.0	10.4	8.8	12.3	15.3	90.4
	SBRT	0.4	0.6	0.8	0.8	1.0	0.6	1.0	0.9	0.9	1.0	0.4	0.3
	EBLT	2.7	4.1	1.8	2.3	1.0	0.8	2.7	2.4	2.1	0.8	2.8	1.4
	EBTH	0.0	2.6	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	1.1
	EBRT	0.2	0.0	0.0	0.3	0.5	0.1	0.2	0.2	0.4	0.0	0.0	0.3
	WBLT	1.3	5.3	6.8	2.5	3.7	2.8	2.9	1.9	2.7	20.2	8.0	10.6
	WBTH	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	1.4	1.5
WBRT	0.3	2.6	0.6	0.3	0.8	0.3	0.5	0.7	0.8	14.9	4.4	2.7	
HIGH SCHOOL ROAD	NBLT	9.5	352.	217.	7.1	5.0	14.2	4.7	5.8	5.0	10.2	6.9	19.8
	NBTH	33.7	392.	112.	7.6	19.1	3.7	5.2	10.5	33.2	31.5	22.6	71.8
	NBRT	0.0	8.2	3.2	1.2	0.6	1.0	0.4	0.9	0.5	1.4	0.6	1.6
	SBLT	10.6	19.5	8.3	13.0	40.0	218.	283.	47.8	29.7	35.4	322.	832.
	SBTH	11.1	29.5	7.6	7.4	16.2	16.7	14.0	15.4	3.9	22.1	70.2	268.
	SBRT	1.6	1.6	1.9	0.8	1.8	1.1	1.9	2.2	2.1	1.7	3.0	10.7
	EBLT	9.1	5.3	7.7	6.4	3.3	4.3	86.2	36.1	5.9	11.2	23.1	54.7
	EBTH	5.0	5.1	8.3	0.9	5.2	4.3	46.4	17.5	7.2	12.0	10.9	72.2
	EBRT	3.9	4.4	3.5	2.0	0.6	3.5	24.0	8.3	7.7	5.3	3.0	27.3
	WBLT	5.4	8.1	4.4	5.3	2.8	4.8	6.4	3.1	6.6	12.6	8.1	17.6
	WBTH	9.0	10.7	7.2	4.0	4.0	6.7	9.3	4.0	6.1	10.0	5.4	16.5
WBRT	15.1	39.4	7.9	2.7	3.7	2.9	4.4	2.6	5.5	2.9	5.4	6.0	
JCT I-465 (SOUTH)	NBTH	5.9	74.4	28.2	8.7	13.4	5.9	4.6	8.0	16.2	17.1	54.4	140.
	NBRT	5.8	2.9	2.5	1.1	3.7	2.8	1.9	2.6	3.6	4.7	2.5	9.6
	SBLT	8.4	13.0	8.5	5.3	205.	297.	1.01	274.	14.7	14.1	27.7	109.
	SBTH	2.2	1.4	1.9	1.2	6.1	16.5	11.6	2.9	5.0	15.5	18.5	27.7
	WBLT	12.5	30.3	11.0	12.0	6.8	7.9	6.6	14.7	11.3	16.7	32.0	340.
	WBRT	4.2	17.7	13.4	3.5	2.8	0.9	2.7	2.7	3.8	4.8	7.4	21.6
JCT I-465 (NORTH)	NBTH	3.2	224.	37.9	1.8	4.8	2.3	2.0	2.3	2.8	2.3	7.2	23.2
	NBRT	15.2	278.	171.	7.1	8.6	6.9	3.3	5.4	7.8	2.9	12.7	62.7
	SBLT	11.9	3.8	0.7	7.0	6.8	300.	515.	164.	6.5	24.3	14.3	34.5
	SBTH	0.8	0.9	0.3	0.8	2.1	2.6	2.5	2.1	1.0	3.4	2.5	6.6
	WBLT	12.7	10.6	13.2	7.6	8.3	3.4	12.2	3.9	8.4	9.6	8.8	66.0
WBRT	1.0	2.2	1.1	1.1	0.7	1.0	0.6	1.0	1.1	0.4	1.0	1.3	

Table B-27: Case_4 - Standard Deviation of Delay (V-M) - Time of Day

INT	START END	6:00 AM 7:00 AM	7:00 AM 8:00 AM	8:00 AM 9:00 AM	9:00 AM 10:00 AM	10:00 AM 11:00 AM	11:00 AM 12:00 PM	12:00 PM 1:00 PM
HEATHROW DRIVE / MENDENHALL	NBLT	51.0	186.5	53.9	64.1	38.0	81.3	54.8
	NBTH	71.9	212.2	43.3	43.2	73.9	66.8	69.8
	NBRT	0.0	3.1	1.7	3.6	1.9	1.6	0.7
	SBLT	19.2	90.2	31.4	24.8	34.2	39.6	35.4
	SBTH	33.5	44.5	41.5	56.7	98.8	132.1	114.1
	SBRT	0.4	0.4	0.6	1.0	2.0	1.3	2.1
	EBLT	13.8	24.7	13.5	31.9	48.8	56.7	62.2
	EBTH	0.0	3.8	1.2	1.8	2.5	0.5	3.7
	EBRT	0.0	0.6	0.4	1.3	0.9	2.6	1.3
	WBLT	0.0	0.2	0.0	0.6	0.8	0.0	0.7
	WBTH	2.6	5.7	2.0	1.6	0.0	0.0	0.8
	WBRT	13.4	11.8	3.6	2.6	3.6	1.5	2.1
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	138.6	287.8	83.1	70.8	91.7	82.7	83.9
	NBRT	2.8	20.4	3.3	3.6	3.7	2.7	3.1
	SBLT	5.2	35.1	5.0	6.6	9.6	12.4	9.6
	SBTH	38.6	64.7	65.0	65.5	101.2	138.5	116.7
	SBRT	1.0	0.9	1.3	1.3	2.2	2.1	1.9
	EBLT	11.3	20.5	22.0	13.0	10.2	9.1	9.8
	EBTH	0.0	8.2	0.5	0.0	0.0	0.0	0.0
	EBRT	0.3	0.1	0.0	0.2	0.3	0.3	0.7
	WBLT	2.0	15.7	16.7	14.0	14.9	12.4	13.0
	WBTH	0.0	2.5	0.0	0.0	0.0	0.0	0.0
	WBRT	0.8	18.3	4.0	2.8	2.6	2.7	2.1
HIGH SCHOOL ROAD	NBLT	60.8	522.7	161.2	77.7	50.4	101.9	79.3
	NBTH	433.4	1,278.2	321.8	158.5	163.2	135.7	143.0
	NBRT	0.0	13.0	4.4	5.1	3.7	2.5	1.3
	SBLT	85.4	203.1	118.1	94.0	227.6	367.8	419.8
	SBTH	131.6	280.7	244.4	192.5	196.9	271.7	240.0
	SBRT	5.4	5.4	5.6	11.3	10.8	9.1	20.3
	EBLT	111.8	84.7	84.1	68.4	45.4	48.5	152.0
	EBTH	50.7	76.9	42.4	35.2	35.5	35.1	94.2
	EBRT	9.5	26.5	14.7	9.0	6.0	15.3	28.5
	WBLT	19.0	47.5	40.8	32.4	20.9	34.7	33.6
	WBTH	77.5	88.9	86.0	49.4	22.0	46.3	54.8
	WBRT	159.6	261.7	98.5	38.8	35.6	29.7	31.2
JCT I-465 (SOUTH)	NBTH	345.0	645.9	232.5	154.8	198.8	177.2	200.0
	NBRT	36.5	40.8	23.6	28.8	26.6	26.2	23.8
	SBLT	55.1	55.5	36.4	39.5	983.7	2,029.3	1,452.5
	SBTH	18.1	22.5	14.1	21.5	67.5	90.2	66.7
	WBLT	229.2	486.5	435.3	346.4	274.1	312.4	353.1
	WBRT	22.1	42.4	46.1	13.8	22.2	17.3	14.4
JCT I-465 (NORTH)	NBTH	56.7	437.8	75.3	23.4	39.8	38.2	55.1
	NBRT	370.2	1,080.2	304.7	113.0	115.7	90.0	75.9
	SBLT	141.0	38.2	7.5	65.7	200.8	486.1	566.6
	SBTH	5.2	1.3	0.1	4.9	23.8	25.2	20.6
	WBLT	134.8	243.5	170.7	137.1	140.9	110.6	149.9
	WBRT	5.1	20.7	6.6	7.8	2.6	4.6	7.7

Table B-28: Case_4 - Vehicular Delay (V-M) - Traffic Responsive - Part 1 of 2

INT	START END	1:00 PM 2:00 PM	2:00 PM 3:00 PM	3:00 PM 4:00 PM	4:00 PM 5:00 PM	5:00 PM 6:00 PM	TOTALS	CUMM- ULATIVE
HEATHROW DRIVE / MENDENHALL	NBLT	38.0	46.9	33.7	32.7	62.3	743.2	743
	NBTH	70.2	85.1	63.6	72.8	59.2	932.2	1,675
	NBRT	1.3	0.4	2.9	0.7	2.7	20.6	1,696
	SBLT	38.7	107.6	48.7	69.0	45.9	584.7	2,281
	SBTH	99.3	154.1	345.6	432.2	440.7	1,993.1	4,274
	SBRT	1.6	1.9	4.2	4.3	0.1	19.6	4,293
	EBLT	64.5	103.7	161.1	144.2	137.0	862.1	5,155
	EBTH	1.1	1.9	8.4	6.9	3.5	35.4	5,191
	EBRT	0.8	3.8	8.2	9.7	7.7	37.3	5,228
	WBLT	0.0	1.1	0.0	1.0	0.0	4.3	5,233
	WBTH	0.0	2.4	3.7	0.8	1.6	21.1	5,254
	WBRT	3.5	2.9	1.9	1.4	3.4	51.6	5,305
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	5,305
	NBTH	85.7	85.1	75.9	84.9	72.3	1,242.3	6,547
	NBRT	3.7	4.4	4.9	6.0	8.2	66.6	6,614
	SBLT	9.0	23.2	13.3	16.6	8.8	154.4	6,768
	SBTH	103.4	128.2	240.6	286.8	265.0	1,614.3	8,383
	SBRT	1.8	1.9	3.5	5.7	0.1	23.7	8,406
	EBLT	6.8	4.7	4.8	5.5	2.6	120.2	8,527
	EBTH	0.0	0.0	0.0	5.4	0.7	14.8	8,542
	EBRT	0.1	0.3	0.0	0.0	0.3	2.5	8,544
	WBLT	12.4	11.7	70.6	44.6	49.1	276.9	8,821
	WBTH	0.0	0.0	7.5	2.6	2.9	15.5	8,837
	WBRT	3.4	6.5	52.3	27.1	20.1	142.8	8,979
HIGH SCHOOL ROAD	NBLT	47.7	53.8	43.1	48.2	81.1	1,327.9	10,307
	NBTH	144.7	439.8	438.6	495.9	396.7	4,549.4	14,857
	NBRT	3.4	1.9	6.6	1.5	5.7	49.2	14,906
	SBLT	200.8	405.3	333.9	1,277.5	2,687.5	6,420.7	21,326
	SBTH	241.3	209.3	326.3	498.7	773.0	3,606.4	24,933
	SBRT	8.8	13.5	15.1	23.8	35.8	164.9	25,098
	EBLT	58.6	90.6	112.4	90.6	139.8	1,086.9	26,185
	EBTH	46.0	52.0	96.7	101.5	194.2	860.5	27,045
	EBRT	13.5	33.9	31.3	78.0	81.8	348.0	27,393
	WBLT	27.4	37.4	49.8	71.8	64.5	479.9	27,873
	WBTH	31.9	40.9	62.7	50.8	54.4	665.8	28,539
	WBRT	29.7	36.0	54.1	62.8	40.3	878.2	29,417
JCT I-465 (SOUTH)	NBTH	186.0	287.2	306.2	458.9	360.3	3,552.8	32,970
	NBRT	24.8	31.1	51.9	45.3	30.8	390.0	33,360
	SBLT	432.3	114.2	195.0	237.8	255.8	5,887.2	39,247
	SBTH	44.4	101.4	225.3	309.2	307.7	1,288.7	40,536
	WBLT	383.9	722.6	696.9	923.5	813.6	5,977.5	46,513
	WBRT	17.2	44.0	28.7	52.8	46.6	367.6	46,881
JCT I-465 (NORTH)	NBTH	40.7	64.8	47.7	68.3	63.5	1,011.3	47,892
	NBRT	84.0	113.7	116.2	188.9	137.2	2,789.6	50,682
	SBLT	169.5	179.2	193.1	293.2	203.9	2,544.8	53,227
	SBTH	13.0	19.3	44.4	43.1	46.4	247.4	53,474
	WBLT	130.8	241.8	276.4	342.0	316.0	2,394.6	55,868
	WBRT	6.1	7.0	3.1	3.9	5.1	80.5	55,949

Table B-29: Case_4 - Vehicular Delay (V-M) - Traffic Responsive - Part 2 of 2

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
HEATHROW DRIVE / MENDENHALL	NBLT	7.5	40.3	13.4	14.7	10.7	12.5	2.6	5.4	7.7	7.6	4.5	7.6
	NBTH	6.7	12.6	2.5	6.6	6.2	6.1	4.5	4.9	4.8	3.8	2.9	6.1
	NBRT	0.0	0.6	0.2	0.6	0.3	0.4	0.1	0.2	0.2	0.6	0.3	0.3
	SBLT	4.2	9.0	6.7	5.8	6.6	6.5	6.3	6.1	14.8	6.1	12.9	15.0
	SBTH	4.5	3.9	4.8	7.5	7.6	5.9	6.9	7.5	17.0	26.7	28.3	99.3
	SBRT	0.2	0.3	0.3	0.6	0.6	0.5	0.7	0.8	1.0	0.7	1.1	0.1
	EBLT	3.4	4.1	3.3	6.1	4.6	4.1	3.6	3.3	7.1	5.7	8.3	7.3
	EBTH	0.0	2.2	1.0	1.9	2.0	0.8	1.1	2.1	1.2	1.6	4.8	3.9
	EBRT	0.0	0.4	0.3	0.4	0.7	0.7	0.4	0.2	0.8	1.9	2.1	1.7
	WBLT	0.0	0.7	0.0	0.9	1.2	0.0	1.3	0.0	1.1	0.0	0.9	0.0
	WBTH	1.9	2.1	1.0	0.9	0.0	0.0	1.0	0.0	2.1	1.9	0.9	1.4
WBRT	2.5	2.2	1.1	0.6	1.1	0.4	0.5	0.7	1.0	0.4	0.4	0.7	
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	5.5	10.9	7.1	5.5	4.5	4.2	5.6	5.4	2.5	3.1	7.8	3.3
	NBRT	0.7	2.9	1.2	1.2	1.9	1.4	1.2	0.7	1.3	0.8	1.1	1.2
	SBLT	1.8	9.2	3.4	2.0	2.3	2.5	2.9	3.1	1.9	1.1	1.8	2.2
	SBTH	2.6	4.5	4.0	4.8	8.4	6.8	6.2	8.7	11.2	10.7	14.3	64.2
	SBRT	0.4	0.5	0.6	0.7	1.0	0.6	1.1	0.7	1.1	0.8	0.4	0.3
	EBLT	2.7	3.4	1.6	2.5	1.5	1.4	2.0	2.1	1.7	1.1	2.8	1.3
	EBTH	0.0	2.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	1.3
	EBRT	0.3	0.0	0.0	0.2	0.4	0.2	0.4	0.1	0.3	0.0	0.0	0.3
	WBLT	1.1	4.9	5.9	3.2	2.7	2.2	2.6	2.1	2.2	19.0	8.2	11.1
	WBTH	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	1.3	1.5
WBRT	0.3	2.5	1.1	0.3	0.6	0.7	0.6	0.9	1.0	17.0	3.7	2.6	
HIGH SCHOOL ROAD	NBLT	8.9	296.	163.	14.5	4.2	12.2	5.9	5.6	9.0	9.2	8.1	16.5
	NBTH	40.6	305.	84.7	18.3	14.5	4.7	5.4	10.3	36.8	29.7	30.2	55.3
	NBRT	0.0	6.1	2.2	1.1	0.7	1.0	0.4	0.9	0.5	1.4	0.5	1.4
	SBLT	10.2	16.6	6.7	14.5	34.1	161.	213.	44.8	55.4	36.0	293.	688.
	SBTH	13.8	24.2	6.4	36.2	13.8	14.2	12.5	17.0	24.1	16.3	68.2	207.
	SBRT	1.5	1.3	1.6	0.9	1.7	0.9	2.1	2.2	1.9	2.0	2.7	10.5
	EBLT	9.8	6.8	7.0	10.0	2.5	5.4	64.6	26.9	7.6	8.1	18.6	39.2
	EBTH	5.9	9.4	8.9	4.7	3.6	3.9	36.3	14.3	6.8	9.2	9.6	61.5
	EBRT	4.7	3.9	3.7	2.3	0.7	2.8	17.4	6.3	5.7	6.2	7.3	28.3
	WBLT	5.2	7.1	4.2	4.8	3.9	4.9	7.0	4.0	5.1	12.0	6.6	13.9
	WBTH	9.1	14.6	7.1	10.4	4.1	5.1	6.9	5.0	5.1	7.7	7.2	12.1
WBRT	12.6	31.3	12.5	4.0	3.3	2.3	4.7	3.4	4.0	5.9	4.5	4.9	
JCT I-465 (SOUTH)	NBTH	19.2	161.	22.5	15.2	11.1	8.1	8.1	9.6	24.9	15.8	56.2	101.
	NBRT	5.2	2.6	2.7	1.1	3.3	2.3	1.8	2.6	3.1	4.8	2.5	7.1
	SBLT	7.6	11.7	8.9	9.7	175.	380.	1,10	531.	13.1	14.2	22.7	81.7
	SBTH	1.9	2.0	2.0	1.6	5.3	16.0	12.6	3.2	6.0	13.2	13.7	25.8
	WBLT	12.3	37.9	18.8	50.3	8.0	7.5	6.9	17.0	88.0	17.3	70.7	240.
	WBRT	3.0	15.6	12.7	3.1	3.3	2.1	2.3	2.3	3.4	4.2	6.2	15.6
JCT I-465 (NORTH)	NBTH	3.9	259.	67.6	4.5	3.8	2.2	3.4	2.5	4.6	3.5	7.8	18.7
	NBRT	21.0	320.	142.	7.8	7.9	6.8	2.7	4.8	6.6	3.6	11.4	44.9
	SBLT	11.2	2.8	1.5	9.9	19.2	273.	371.	123.	13.5	23.5	11.9	26.3
	SBTH	0.9	0.8	0.2	1.2	1.8	2.6	1.9	1.7	1.2	2.9	2.4	4.6
	WBLT	12.8	11.1	10.1	17.3	6.4	4.2	11.8	6.5	7.7	9.3	15.3	56.8
	WBRT	1.0	2.3	0.9	1.0	0.6	0.9	1.0	1.1	0.9	0.4	1.2	1.0

Table B-30: Case_4 - Standard Deviation of Delay (V-M) - Traffic Responsive

INT	START END	6:00 AM 7:00 AM	7:00 AM 8:00 AM	8:00 AM 9:00 AM	9:00 AM 10:00 AM	10:00 AM 11:00 AM	11:00 AM 12:00 PM	12:00 PM 1:00 PM
HEATHROW DRIVE / MENDENHALL	NBLT	58.6	199.4	55.7	50.8	37.9	82.9	54.3
	NBTH	75.1	271.7	45.9	50.2	65.8	59.4	67.8
	NBRT	0.0	3.4	1.7	3.5	1.8	1.6	0.7
	SBLT	22.4	152.3	40.0	24.6	25.5	28.3	31.7
	SBTH	35.7	79.3	58.9	68.3	64.0	90.0	98.7
	SBRT	0.3	0.8	1.1	1.2	0.9	1.1	1.8
	EBLT	16.4	21.8	13.7	26.7	47.9	55.4	63.3
	EBTH	0.0	4.3	0.8	1.3	2.8	0.3	3.9
	EBRT	0.0	0.6	0.6	1.3	0.9	1.9	1.6
	WBLT	0.0	0.6	0.0	0.5	0.8	0.0	1.2
	WBTH	2.3	5.4	1.5	0.8	0.0	0.0	0.5
	WBRT	11.9	13.0	3.6	2.6	3.7	1.8	2.3
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	139.8	297.6	80.3	77.9	88.6	77.8	82.1
	NBRT	2.8	22.6	3.4	3.9	3.3	3.0	3.0
	SBLT	6.4	52.7	7.1	6.8	7.9	8.3	7.7
	SBTH	42.7	106.8	84.9	71.5	62.0	91.7	100.9
	SBRT	1.1	1.6	1.5	1.2	1.5	1.4	1.4
	EBLT	12.0	21.9	21.7	10.5	10.0	8.7	9.5
	EBTH	0.0	8.9	0.3	0.0	0.0	0.0	0.0
	EBRT	0.3	0.1	0.0	0.3	0.2	0.2	0.6
	WBLT	2.6	19.8	16.6	11.9	14.3	13.3	14.3
	WBTH	0.0	2.4	0.2	0.0	0.0	0.0	0.0
	WBRT	0.8	19.5	4.8	2.9	2.9	2.3	2.4
HIGH SCHOOL ROAD	NBLT	64.3	525.6	217.9	61.9	46.7	100.2	78.5
	NBTH	450.3	2,458.6	784.0	145.5	156.8	139.3	144.2
	NBRT	0.0	28.5	16.0	5.4	3.4	2.8	1.2
	SBLT	84.4	350.0	165.6	123.5	141.6	155.3	235.7
	SBTH	148.6	362.0	278.9	156.2	142.5	204.3	225.8
	SBRT	5.4	7.4	6.3	11.9	7.6	6.0	18.5
	EBLT	116.2	87.0	80.8	60.1	43.2	50.6	470.0
	EBTH	45.1	72.9	44.7	28.2	36.1	32.6	292.3
	EBRT	8.9	25.8	12.7	6.1	5.7	12.8	118.9
	WBLT	19.8	49.8	39.0	19.0	13.6	20.8	53.9
	WBTH	80.1	94.6	80.0	30.0	12.5	27.5	95.4
	WBRT	146.5	228.7	91.5	24.6	17.1	18.8	44.8
JCT I-465 (SOUTH)	NBTH	318.5	2,037.5	1,956.5	162.5	174.3	152.1	214.7
	NBRT	35.8	44.9	28.7	28.2	24.8	23.7	23.5
	SBLT	59.4	162.8	81.1	41.1	98.0	77.9	103.3
	SBTH	18.3	56.6	29.4	30.7	31.8	38.5	46.2
	WBLT	236.3	501.8	448.6	280.3	272.1	304.0	357.2
	WBRT	22.4	68.7	96.7	12.7	17.7	15.7	15.3
JCT I-465 (NORTH)	NBTH	50.6	768.9	362.0	29.1	32.4	32.6	55.3
	NBRT	334.0	1,993.9	1,194.2	110.5	97.5	78.3	80.3
	SBLT	135.6	749.5	301.5	127.4	57.7	79.2	143.7
	SBTH	4.6	20.4	7.2	9.3	9.4	13.5	15.0
	WBLT	143.8	239.4	175.3	114.3	141.0	113.2	154.8
	WBRT	5.4	21.3	7.0	7.5	2.7	4.4	7.0

Table B-31: Case_5 - Vehicular Delay (V-M) - Time of Day - Part 1 of 2

INT	START END	1:00 PM 2:00 PM	2:00 PM 3:00 PM	3:00 PM 4:00 PM	4:00 PM 5:00 PM	5:00 PM 6:00 PM	TOTALS	CUMM- ULATIVE
HEATHROW DRIVE / MENDENHALL	NBLT	36.1	47.9	37.0	34.1	52.4	747.3	747
	NBTH	70.3	87.5	64.0	74.4	59.9	992.1	1,739
	NBRT	1.3	0.4	2.8	0.8	2.7	20.6	1,760
	SBLT	38.1	110.0	51.1	64.8	42.4	631.2	2,391
	SBTH	104.2	150.3	356.8	443.0	453.8	2,003.0	4,394
	SBRT	1.6	2.1	4.1	4.2	0.1	19.3	4,413
	EBLT	63.6	106.0	152.4	141.7	144.1	853.0	5,266
	EBTH	1.2	1.3	6.2	6.4	4.9	33.4	5,300
	EBRT	0.8	3.3	6.4	8.7	8.0	34.0	5,334
	WBLT	0.0	1.1	0.0	0.7	0.0	4.8	5,339
	WBTH	0.0	2.5	3.8	0.9	2.8	20.6	5,359
	WBRT	3.5	3.3	2.3	1.3	3.7	53.0	5,412
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	5,412
	NBTH	84.7	86.7	76.7	86.5	73.1	1,251.9	6,664
	NBRT	3.3	4.2	5.2	5.4	8.3	68.4	6,732
	SBLT	8.0	24.1	13.7	16.1	8.9	167.7	6,900
	SBTH	107.7	124.5	235.4	292.7	264.0	1,584.9	8,485
	SBRT	2.0	2.0	3.8	6.1	0.2	23.7	8,509
	EBLT	6.5	5.2	6.1	4.9	1.9	119.0	8,628
	EBTH	0.0	0.0	0.0	5.0	0.3	14.5	8,642
	EBRT	0.1	0.2	0.0	0.0	0.2	2.1	8,644
	WBLT	12.9	12.6	69.4	45.9	48.0	281.7	8,926
	WBTH	0.0	0.0	7.4	3.5	1.8	15.2	8,941
	WBRT	3.2	7.0	40.3	26.7	18.8	131.7	9,073
HIGH SCHOOL ROAD	NBLT	42.7	56.9	37.4	43.8	72.9	1,348.8	10,422
	NBTH	152.8	486.9	450.0	516.9	388.0	6,273.3	16,695
	NBRT	3.4	1.9	6.0	1.6	5.4	75.5	16,770
	SBLT	186.9	318.1	343.6	1,295.8	2,840.0	6,240.6	23,011
	SBTH	229.6	174.9	324.7	495.6	1,091.7	3,834.7	26,846
	SBRT	9.1	13.3	14.9	24.5	60.3	185.2	27,031
	EBLT	227.6	91.8	104.1	94.4	145.0	1,570.8	28,602
	EBTH	131.5	55.5	98.5	106.6	191.4	1,135.4	29,737
	EBRT	59.8	33.2	32.8	76.7	83.3	476.7	30,214
	WBLT	40.2	58.2	43.8	72.8	62.5	493.4	30,707
	WBTH	48.0	59.1	63.8	48.9	57.2	697.2	31,405
	WBRT	42.4	55.3	54.4	62.8	41.5	828.6	32,233
JCT I-465 (SOUTH)	NBTH	207.3	305.0	300.0	426.0	362.4	6,616.7	38,850
	NBRT	26.9	33.8	50.0	46.8	30.3	397.1	39,247
	SBLT	66.6	117.2	194.8	251.7	275.4	1,529.4	40,776
	SBTH	43.0	100.0	228.0	310.3	314.6	1,247.4	42,024
	WBLT	370.5	673.6	684.5	869.3	962.2	5,960.4	47,984
	WBRT	18.5	52.4	29.9	53.7	54.5	458.1	48,442
JCT I-465 (NORTH)	NBTH	47.0	70.4	48.0	62.1	57.4	1,615.7	50,058
	NBRT	91.1	119.4	114.9	184.1	137.6	4,535.8	54,594
	SBLT	155.7	180.2	189.4	313.0	192.9	2,625.8	57,220
	SBTH	13.3	19.8	44.8	41.9	47.0	246.1	57,466
	WBLT	121.6	245.1	277.6	340.6	299.6	2,366.3	59,832
	WBRT	6.8	7.2	3.3	3.8	5.4	81.6	59,914

Table B-32: Case_5 - Vehicular Delay (V-M) - Time of Day - Part 2 of 2

INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
HEATHROW DRIVE / MENDENHALL	NBLT	6.2	115.	16.7	10.4	10.0	11.6	6.5	7.3	8.1	3.7	7.7	3.9
	NBTH	3.9	17.6	8.9	3.8	6.5	3.2	6.2	6.7	4.1	3.7	8.9	4.8
	NBRT	0.0	0.8	0.2	0.7	0.4	0.3	0.3	0.4	0.2	0.5	0.4	0.3
	SBLT	5.8	43.0	8.9	4.7	6.6	8.4	9.0	9.4	21.6	5.1	14.1	10.4
	SBTH	5.5	4.4	7.3	5.8	5.8	8.0	3.5	9.8	17.2	10.8	26.2	36.2
	SBRT	0.2	0.5	0.5	0.9	0.3	0.7	0.7	1.0	0.7	0.8	1.3	0.1
	EBLT	2.1	3.8	1.9	4.8	4.7	2.2	4.9	3.4	10.1	11.0	14.9	6.6
	EBTH	0.0	2.6	0.7	1.2	1.9	0.3	1.5	2.1	0.8	2.2	6.0	4.0
	EBRT	0.0	0.4	0.3	0.6	0.3	0.3	0.5	0.3	0.8	2.0	2.0	2.7
	WBLT	0.0	0.9	0.0	1.0	0.7	0.0	2.0	0.0	1.2	0.0	0.9	0.0
	WBTH	1.8	1.8	0.9	0.6	0.0	0.0	0.8	0.0	2.4	2.0	1.0	1.8
WBRT	2.7	1.3	0.8	0.5	0.9	0.7	0.6	0.6	1.3	0.4	0.4	0.6	
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	5.6	14.9	8.2	5.6	3.8	3.6	3.1	6.4	3.3	5.1	5.1	4.6
	NBRT	0.9	1.7	1.3	0.9	2.0	1.3	1.4	0.8	1.4	0.5	1.4	1.1
	SBLT	2.0	7.4	1.5	1.8	2.9	1.4	2.4	3.1	2.4	0.9	3.6	1.6
	SBTH	4.5	4.1	6.9	5.9	6.5	6.2	10.6	10.2	10.4	7.9	11.4	11.1
	SBRT	0.5	0.5	0.4	0.9	1.0	1.0	0.8	0.8	1.1	0.6	0.7	0.2
	EBLT	4.3	2.6	2.1	1.4	1.1	2.2	3.3	3.0	1.4	1.1	1.9	0.4
	EBTH	0.0	1.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.7
	EBRT	0.3	0.1	0.0	0.3	0.1	0.1	0.6	0.1	0.1	0.0	0.0	0.1
	WBLT	1.4	5.1	3.9	3.3	2.7	2.3	1.8	3.1	1.5	25.2	6.6	6.3
	WBTH	0.0	1.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	3.6	1.4	1.7
WBRT	0.2	1.3	0.7	0.9	0.7	0.4	0.5	0.7	1.3	8.5	3.3	3.5	
HIGH SCHOOL ROAD	NBLT	12.1	236.	137.	6.6	3.5	8.0	11.8	3.7	5.9	9.7	4.0	9.3
	NBTH	26.6	973.	387.	10.0	16.5	6.8	6.9	6.2	37.5	39.0	22.1	16.8
	NBRT	0.0	11.8	15.5	1.0	0.9	1.1	0.4	0.9	0.3	1.6	0.4	1.1
	SBLT	10.8	31.6	5.3	10.4	22.1	28.6	45.2	32.6	24.8	29.4	340.	606.
	SBTH	6.6	21.2	13.4	10.2	14.0	10.9	12.9	14.2	7.4	16.7	87.7	909.
	SBRT	1.6	1.9	1.7	1.3	1.5	0.8	2.8	2.4	1.5	2.2	2.8	68.6
	EBLT	8.7	8.9	12.2	5.0	2.6	2.2	69.8	113.	6.9	7.6	13.7	34.7
	EBTH	5.7	5.2	7.3	2.2	5.6	6.1	39.6	48.2	9.3	6.5	6.9	45.6
	EBRT	4.1	3.7	3.7	2.3	1.2	3.0	19.8	34.8	9.2	3.7	5.9	19.8
	WBLT	5.4	8.8	4.6	2.0	2.9	4.4	11.8	5.4	10.6	9.4	10.6	7.5
	WBTH	8.1	12.0	6.9	4.0	2.6	7.0	11.8	7.9	5.1	9.9	5.5	2.9
WBRT	24.7	20.4	18.2	1.5	2.6	2.5	4.6	8.1	8.5	3.6	10.0	4.5	
JCT I-465 (SOUTH)	NBTH	11.2	1.24	1.70	10.7	13.4	7.1	10.7	20.1	12.5	20.7	45.3	13.5
	NBRT	5.2	6.0	5.6	1.8	3.1	3.1	2.4	2.6	3.3	3.7	2.6	3.7
	SBLT	7.5	35.0	20.7	7.3	9.9	16.1	8.0	9.9	10.4	12.5	22.9	46.2
	SBTH	2.2	2.3	2.4	2.8	1.1	1.8	3.9	2.7	2.4	14.2	11.6	49.6
	WBLT	17.3	76.9	13.3	12.5	8.9	5.1	11.6	13.0	9.5	18.3	16.0	329.
	WBRT	3.1	21.3	53.1	1.5	2.0	1.2	2.9	3.1	3.8	2.6	6.2	9.9
JCT I-465 (NORTH)	NBTH	4.6	187.	125.	1.3	7.1	1.4	2.2	2.2	3.0	2.3	5.7	3.3
	NBRT	12.7	332.	382.	7.7	3.9	3.9	4.5	6.6	5.8	6.4	15.1	12.4
	SBLT	16.8	319.	273.	21.0	11.1	6.3	19.2	35.0	7.8	25.4	21.7	22.1
	SBTH	0.6	1.6	0.5	0.9	1.3	1.1	2.4	2.0	1.6	1.6	2.0	2.3
	WBLT	6.0	15.5	10.9	10.0	9.4	7.6	15.3	5.6	13.4	7.1	10.8	6.7
	WBRT	1.2	1.8	0.9	1.3	0.7	1.0	0.3	0.9	1.1	0.9	0.6	1.0

Table B-33: Case_5 - Standard Deviation of Delay (V-M) - Time of Day

INT	START END	6:00 AM 7:00 AM	7:00 AM 8:00 AM	8:00 AM 9:00 AM	9:00 AM 10:00 AM	10:00 AM 11:00 AM	11:00 AM 12:00 PM	12:00 PM 1:00 PM
HEATHROW DRIVE / MENDENHALL	NBLT	53.2	178.5	53.5	52.6	39.6	83.2	56.1
	NBTH	73.6	250.7	47.9	51.3	61.1	56.9	66.2
	NBRT	0.0	3.3	1.8	3.5	1.9	1.6	0.7
	SBLT	21.9	153.0	35.6	23.9	23.3	31.0	31.8
	SBTH	35.1	73.5	60.3	67.4	61.0	88.5	100.3
	SBRT	0.4	0.7	0.9	0.9	1.0	1.0	1.7
	EBLT	13.4	24.3	14.0	28.0	48.6	55.7	65.2
	EBTH	0.0	3.7	0.9	2.5	1.6	0.9	4.0
	EBRT	0.0	0.7	0.7	1.2	0.7	2.2	1.5
	WBLT	0.0	0.5	0.0	0.7	0.6	0.0	1.2
	WBTH	2.4	4.3	1.3	1.3	0.0	0.0	1.0
	WBRT	13.2	13.8	3.8	2.6	4.1	1.6	2.0
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	140.9	301.5	81.5	76.7	87.6	80.7	82.6
	NBRT	2.8	21.7	3.3	3.9	3.3	3.0	3.2
	SBLT	7.0	55.3	7.5	6.9	6.6	8.0	8.0
	SBTH	38.8	105.7	84.6	74.1	60.0	87.7	101.4
	SBRT	0.9	1.9	1.4	1.3	1.5	1.5	1.3
	EBLT	11.3	21.5	19.4	12.3	9.7	7.6	6.4
	EBTH	0.0	8.0	0.8	0.0	0.0	0.0	0.0
	EBRT	0.4	0.1	0.0	0.3	0.2	0.3	0.3
	WBLT	1.8	18.0	16.3	12.6	14.1	13.0	14.0
	WBTH	0.0	2.7	0.4	0.0	0.0	0.0	0.0
	WBRT	0.9	20.5	4.3	3.5	2.8	2.5	2.3
HIGH SCHOOL ROAD	NBLT	61.6	606.8	263.0	64.2	49.6	100.8	78.6
	NBTH	445.1	2,672.2	1,031.5	145.2	163.5	138.6	149.1
	NBRT	0.0	31.8	20.8	5.1	3.5	2.5	1.4
	SBLT	84.5	357.4	168.2	117.5	144.8	152.6	230.9
	SBTH	134.1	373.9	253.5	167.9	139.4	198.2	223.8
	SBRT	5.2	7.2	5.8	11.8	7.5	6.5	18.7
	EBLT	118.7	85.0	83.8	61.0	44.8	48.1	356.6
	EBTH	52.3	73.1	42.9	30.5	33.2	33.3	215.3
	EBRT	11.1	24.8	14.8	6.9	5.5	14.7	82.9
	WBLT	18.9	49.1	39.9	19.3	15.3	20.6	50.4
	WBTH	84.0	85.6	85.0	28.8	12.7	29.6	98.8
	WBRT	146.5	234.9	93.4	25.5	17.6	17.9	45.5
JCT I-465 (SOUTH)	NBTH	334.6	1,811.6	1,600.0	161.4	172.1	150.0	213.8
	NBRT	35.9	41.0	28.4	27.9	25.7	23.5	24.4
	SBLT	56.6	170.3	83.8	46.5	93.0	84.9	110.6
	SBTH	19.5	57.3	26.6	31.7	31.2	38.3	44.4
	WBLT	231.3	524.3	414.8	289.3	273.8	308.8	355.9
	WBRT	24.6	75.9	127.9	13.4	20.5	15.2	15.4
JCT I-465 (NORTH)	NBTH	57.1	936.5	368.6	28.5	28.4	32.6	55.6
	NBRT	345.5	1,908.4	1,203.7	111.1	99.6	75.7	80.4
	SBLT	142.5	739.2	278.2	142.3	56.1	79.8	144.2
	SBTH	5.0	19.9	6.6	9.4	9.3	13.1	14.9
	WBLT	134.0	235.3	170.0	121.2	139.2	112.8	156.5
	WBRT	5.2	20.8	6.1	7.8	2.6	4.5	7.0

Table B-34: Case_5 - Vehicular Delay (V-M) - Traffic Responsive - Part 1 of 2

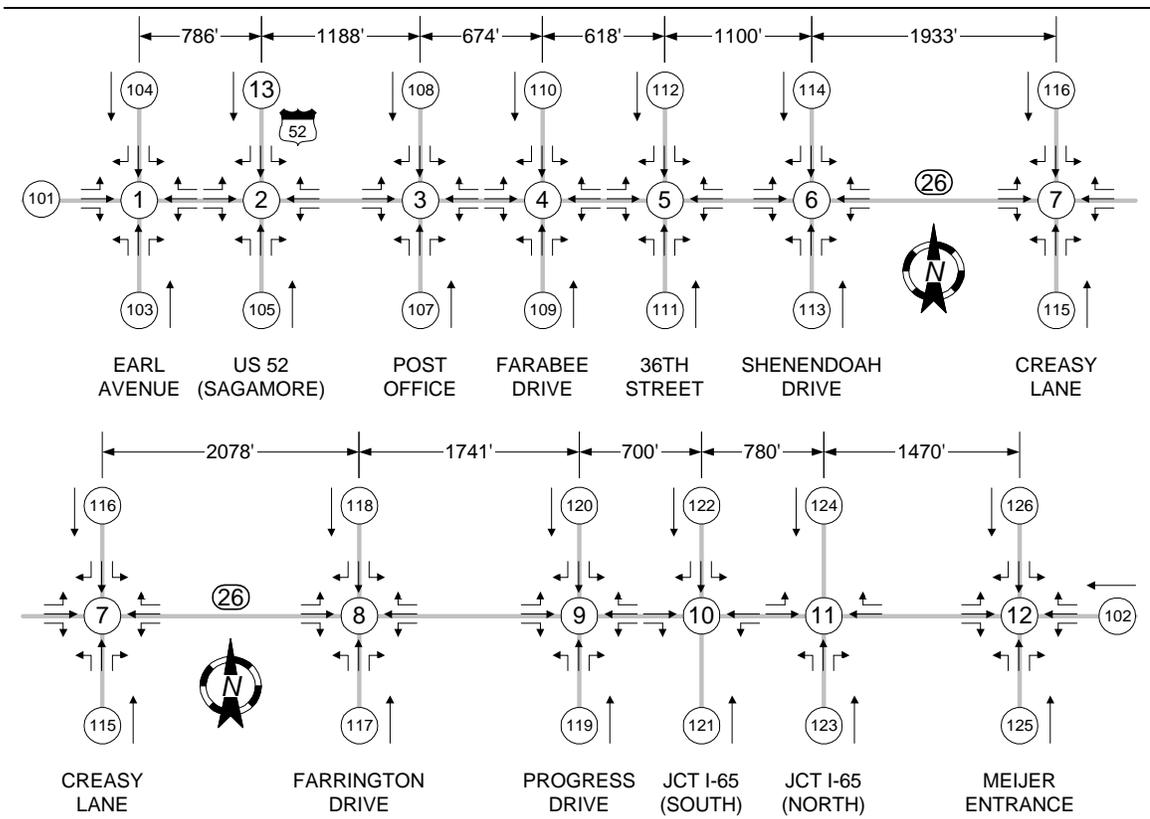
INT	START END	1:00 PM 2:00 PM	2:00 PM 3:00 PM	3:00 PM 4:00 PM	4:00 PM 5:00 PM	5:00 PM 6:00 PM	TOTALS	CUMM- ULATIVE
HEATHROW DRIVE / MENDENHALL	NBLT	37.5	43.5	40.1	34.0	59.8	731.7	732
	NBTH	73.0	88.3	67.5	75.8	56.8	968.9	1,701
	NBRT	1.3	0.4	2.7	0.7	2.7	20.6	1,721
	SBLT	38.4	99.4	51.2	71.2	40.3	621.1	2,342
	SBTH	101.9	156.5	331.6	447.8	440.0	1,964.1	4,306
	SBRT	1.6	1.9	4.2	4.0	0.1	18.5	4,325
	EBLT	64.6	97.4	169.0	144.7	131.3	856.3	5,181
	EBTH	0.7	1.3	6.7	5.3	4.5	32.0	5,213
	EBRT	0.8	3.4	7.3	9.3	8.0	35.9	5,249
	WBLT	0.0	1.2	0.0	0.9	0.0	5.0	5,254
	WBTH	0.0	2.2	3.7	0.7	1.7	18.5	5,273
	WBRT	3.7	2.9	2.0	1.4	3.4	54.4	5,327
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	5,327
	NBTH	85.8	87.7	75.2	84.8	70.3	1,255.2	6,582
	NBRT	3.5	4.3	5.0	5.7	8.1	67.8	6,650
	SBLT	8.5	23.6	13.6	16.4	8.4	169.8	6,820
	SBTH	103.9	137.2	233.8	290.3	255.6	1,573.1	8,393
	SBRT	1.9	2.1	3.7	5.8	0.1	23.4	8,416
	EBLT	5.3	4.7	4.4	4.5	2.5	109.6	8,526
	EBTH	0.0	0.0	0.0	5.4	0.4	14.5	8,540
	EBRT	0.2	0.2	0.0	0.0	0.2	2.3	8,543
	WBLT	12.0	12.4	63.4	44.1	48.8	270.6	8,813
	WBTH	0.0	0.0	8.0	2.2	2.6	16.0	8,829
	WBRT	3.1	7.2	44.2	26.3	19.4	136.8	8,966
HIGH SCHOOL ROAD	NBLT	46.4	56.4	37.4	44.5	84.2	1,493.5	10,460
	NBTH	145.2	473.4	443.9	520.0	403.7	6,731.5	17,191
	NBRT	3.5	1.7	6.0	1.3	5.6	83.3	17,274
	SBLT	184.8	491.2	321.0	1,272.8	2,745.5	6,271.1	23,545
	SBTH	231.5	219.7	325.8	477.9	794.0	3,539.5	27,085
	SBRT	9.3	13.6	15.3	24.3	37.5	162.6	27,247
	EBLT	173.6	90.8	105.0	93.2	141.9	1,402.4	28,650
	EBTH	97.9	56.9	96.7	105.3	193.2	1,030.6	29,680
	EBRT	41.4	38.5	32.2	78.5	85.2	436.6	30,117
	WBLT	41.2	53.6	44.6	72.9	62.1	488.0	30,605
	WBTH	45.7	54.2	66.0	51.2	57.7	699.3	31,304
	WBRT	44.0	55.2	55.9	59.9	39.4	835.9	32,140
JCT I-465 (SOUTH)	NBTH	205.7	320.5	308.9	433.6	354.7	6,066.9	38,207
	NBRT	27.4	32.9	50.1	47.1	30.9	395.1	38,602
	SBLT	75.3	114.4	190.2	255.1	279.2	1,559.8	40,162
	SBTH	41.6	100.0	225.9	302.8	297.1	1,216.4	41,378
	WBLT	369.9	827.6	703.0	869.7	828.4	5,996.7	47,375
	WBRT	18.6	46.7	33.0	51.7	47.2	489.9	47,865
JCT I-465 (NORTH)	NBTH	49.3	73.4	48.4	60.8	56.0	1,795.3	49,660
	NBRT	95.5	125.3	120.2	174.5	133.4	4,473.1	54,133
	SBLT	153.9	191.9	181.7	300.5	208.8	2,619.2	56,752
	SBTH	13.0	20.6	41.2	44.2	46.7	243.8	56,996
	WBLT	124.3	246.3	281.2	331.1	303.4	2,355.2	59,351
	WBRT	6.8	6.4	3.2	4.2	5.0	79.5	59,431

Table B-35: Case_5 - Vehicular Delay (V-M) - Traffic Responsive - Part 2 of 2

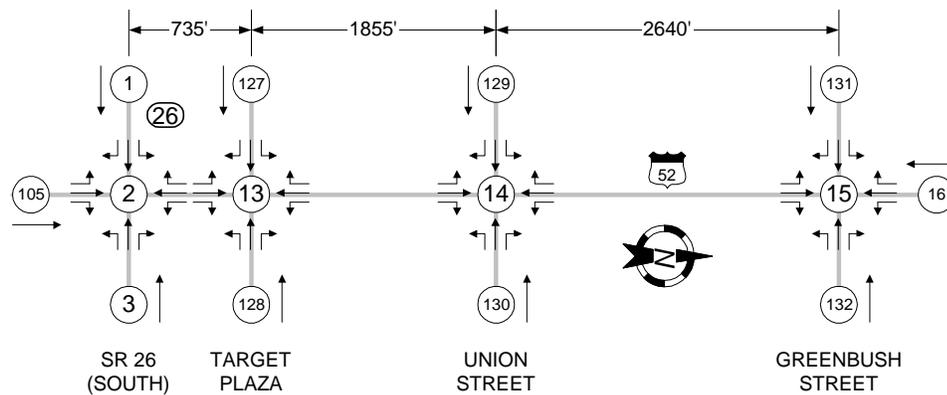
INT	BEG END	6AM 7AM	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM
HEATHROW DRIVE / MENDENHALL	NBLT	5.5	80.8	18.5	9.8	8.2	11.5	5.2	6.8	6.9	6.0	6.4	9.0
	NBTH	3.8	20.9	9.9	3.9	7.8	5.2	4.6	7.6	3.7	4.0	6.5	4.8
	NBRT	0.0	0.8	0.2	0.6	0.3	0.4	0.3	0.4	0.2	0.5	0.3	0.3
	SBLT	5.0	41.6	7.5	4.0	5.7	8.3	7.8	7.8	18.3	8.3	16.8	9.4
	SBTH	4.6	4.8	5.9	6.4	6.7	6.4	3.3	9.4	21.0	19.5	21.8	32.9
	SBRT	0.2	0.5	0.4	0.8	0.3	0.6	0.7	0.9	0.8	1.1	1.3	0.1
	EBLT	3.0	4.0	3.0	3.7	4.6	3.4	3.8	3.4	8.9	14.3	12.8	9.8
	EBTH	0.0	2.2	0.8	1.9	1.7	0.8	1.3	1.6	1.0	2.7	5.0	3.2
	EBRT	0.0	0.4	0.3	0.6	0.3	0.4	0.4	0.2	0.8	1.9	1.7	2.0
	WBLT	0.0	0.9	0.0	1.0	0.7	0.0	2.0	0.0	1.2	0.0	1.0	0.0
	WBTH	1.3	2.0	1.1	0.8	0.0	0.0	0.9	0.0	2.5	1.8	0.9	1.8
WBRT	2.2	1.7	1.0	0.5	1.3	0.6	0.6	0.6	0.9	0.5	0.4	0.6	
STERLING POINT DRIVE	NBLT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NBTH	6.2	11.7	6.7	4.5	3.9	4.4	3.3	7.3	3.2	4.2	6.6	3.9
	NBRT	0.7	3.1	1.2	1.0	1.8	1.2	1.3	0.7	1.4	0.7	1.2	0.9
	SBLT	2.3	10.5	2.2	1.7	2.7	1.1	2.5	3.4	1.9	0.9	3.2	1.2
	SBTH	4.0	5.4	6.8	7.2	6.3	5.8	7.6	8.2	14.1	7.7	8.4	15.1
	SBRT	0.4	0.5	0.3	0.8	0.8	0.9	0.7	0.8	1.1	0.6	0.7	0.2
	EBLT	4.9	2.7	3.2	1.6	1.4	2.3	3.7	2.7	1.3	1.5	2.7	1.2
	EBTH	0.0	2.2	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	0.7
	EBRT	0.3	0.1	0.0	0.3	0.1	0.2	0.4	0.2	0.1	0.0	0.1	0.2
	WBLT	1.5	4.6	4.1	3.9	2.6	2.5	2.0	2.8	1.2	18.6	5.5	7.6
	WBTH	0.0	1.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0	3.7	1.5	1.3
WBRT	0.4	2.3	1.0	0.9	0.6	0.4	0.4	0.8	1.2	8.7	3.3	2.7	
HIGH SCHOOL ROAD	NBLT	10.8	263.	167.	8.2	6.2	13.2	10.5	5.7	9.3	10.2	7.2	11.2
	NBTH	36.1	853.	416.	7.9	17.8	5.4	6.1	7.0	34.3	32.4	29.6	16.4
	NBRT	0.0	9.9	14.7	1.1	0.9	1.0	0.6	0.7	0.4	1.4	0.3	1.2
	SBLT	10.6	30.9	5.6	12.1	19.9	32.3	36.0	30.7	130.	27.5	327.	635.
	SBTH	12.5	21.8	22.1	12.7	13.3	8.5	10.3	12.1	31.0	16.2	68.9	633.
	SBRT	1.6	1.6	1.5	1.1	1.8	1.0	3.0	2.4	1.7	2.1	2.8	48.2
	EBLT	9.4	9.8	8.7	5.3	2.9	5.1	127.	98.3	5.6	7.1	13.1	27.9
	EBTH	7.3	5.5	7.2	3.1	4.9	5.7	81.6	42.5	7.0	6.9	6.4	48.3
	EBRT	3.4	3.6	4.7	1.7	1.1	2.8	37.8	30.2	9.1	4.6	7.4	22.2
	WBLT	4.2	8.1	5.4	2.3	2.9	3.6	11.3	5.8	8.4	8.0	7.9	6.5
	WBTH	11.4	11.0	5.7	4.4	2.4	5.7	13.1	7.0	5.2	7.8	4.5	4.0
WBRT	18.4	21.0	12.3	1.2	2.2	2.4	3.7	9.2	6.4	3.4	8.4	3.8	
JCT I-465 (SOUTH)	NBTH	15.8	1.07	1.44	8.5	13.1	8.6	13.3	17.8	14.0	19.0	54.4	19.8
	NBRT	5.0	5.8	5.4	1.4	2.9	2.6	2.3	2.6	3.1	4.1	2.9	2.9
	SBLT	7.7	33.8	20.8	6.7	12.4	17.3	15.7	12.6	11.1	11.2	23.2	33.6
	SBTH	1.8	2.3	2.9	2.5	1.9	2.0	3.3	2.5	5.0	15.6	10.1	34.5
	WBLT	15.5	83.3	30.4	19.8	7.4	8.0	8.4	12.5	198.	18.3	20.3	231.
	WBRT	4.0	22.6	92.2	1.4	3.9	1.2	2.3	2.9	4.1	4.1	5.6	8.5
JCT I-465 (NORTH)	NBTH	5.3	178.	109.	2.8	5.6	1.8	3.6	2.9	5.6	2.2	4.6	3.5
	NBRT	16.1	268.	339.	8.2	4.7	3.8	5.1	7.8	7.4	7.0	14.7	12.5
	SBLT	13.3	285.	251.	21.9	11.5	9.2	15.7	30.4	17.0	20.5	19.3	18.2
	SBTH	0.7	1.6	0.8	0.8	1.3	1.2	1.8	1.4	1.5	2.8	2.2	2.8
	WBLT	10.0	11.9	10.6	8.6	11.9	6.8	15.5	7.3	14.2	7.3	11.9	6.2
	WBRT	1.0	2.4	1.1	1.2	0.6	0.8	0.7	1.1	1.1	0.6	1.0	0.9

Table B-36: Case_5 - Standard Deviation of Delay (V-M) - Traffic Responsive

APPENDIX C – SR 26 (SOUTH) TRAFFIC RESPONSIVE STUDY NETWORK
AND CONTROLLER PARAMETERS

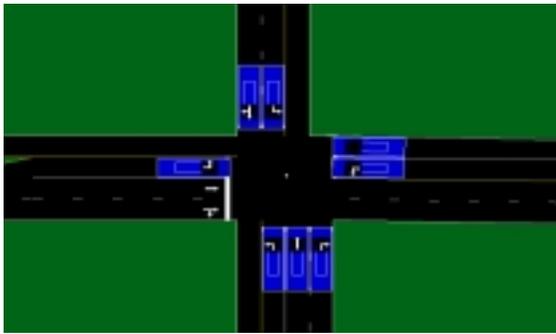


(a) SR 26 (South) Network – Earl Avenue to Meijer Entrance



(b) US 52 (Sagamore) Network – SR 26 (South) to Greenbush Street

Figure C-1: SR 26 (South) & US 52 (Sagamore) – Study Network



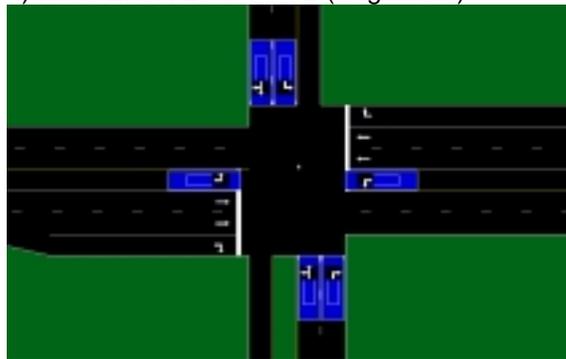
a) Node 1: SR 26 & Earl Avenue



b) Node 2: SR 26 & US 52 (Sagamore)



c) Node 3: SR 26 & Post Office



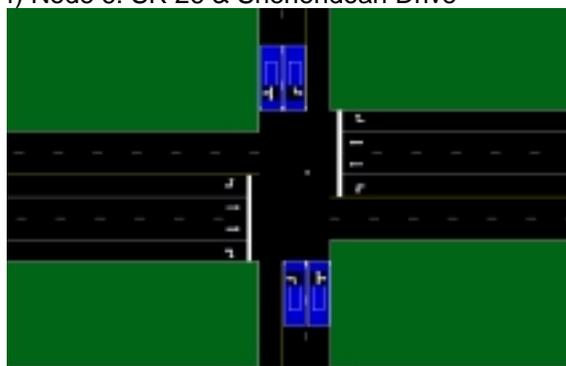
d) Node 4: SR 26 & Farabee Drive

e) Node 5: SR 26 & 36th Street

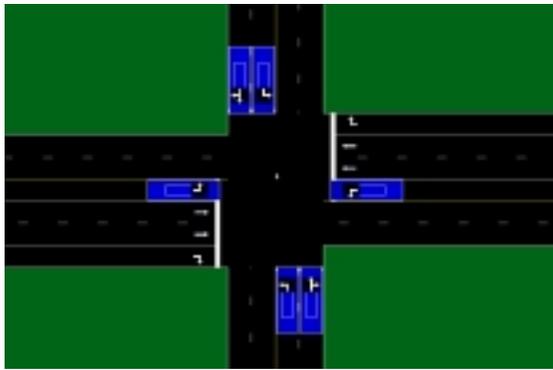
f) Node 6: SR 26 & Shenendoah Drive



g) Node 7: SR 26 & Creasy Lane



h) Node 8: SR 26 & Farrington Drive



i) Node 9: SR 26 & Progress Drive



j) Node 10: SR 26 & JCT I-65 (South)



k) Node 11: SR 26 & JCT I-65 (North)



l) Node 12: SR 26 & Meijer Entrance



m) Node 2: US 52 & SR 26 (South)



n) Node 13: US 52 & Target Plaza

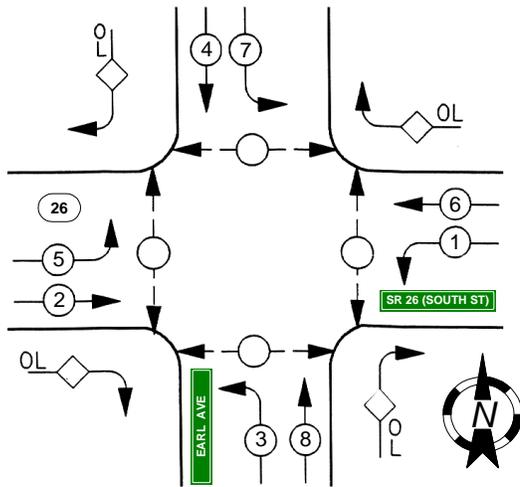


o) Node 14: US 52 & Union Street

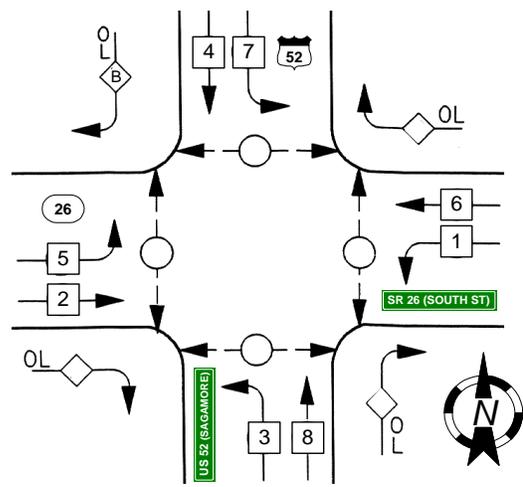


p) Node 15: US 52 & Greenbush Street

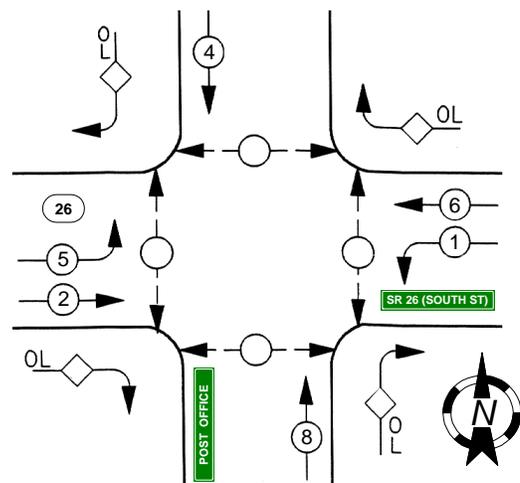
Figure C-2: SR 26 (South) / US 52 (Sagamore) Intersection Geometrics



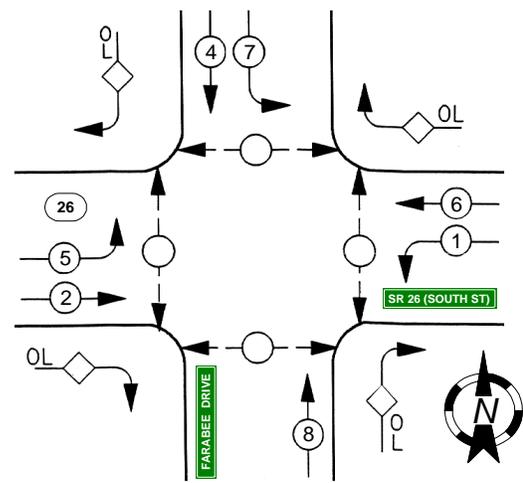
a) Node 1: SR 26 & Earl Avenue



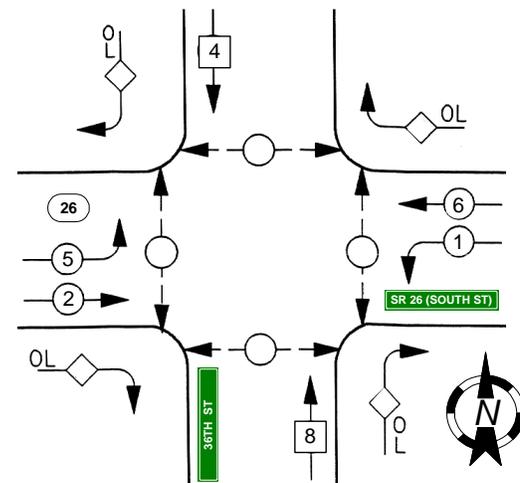
b) Node 2: SR 26 & US 52 (Sagamore)



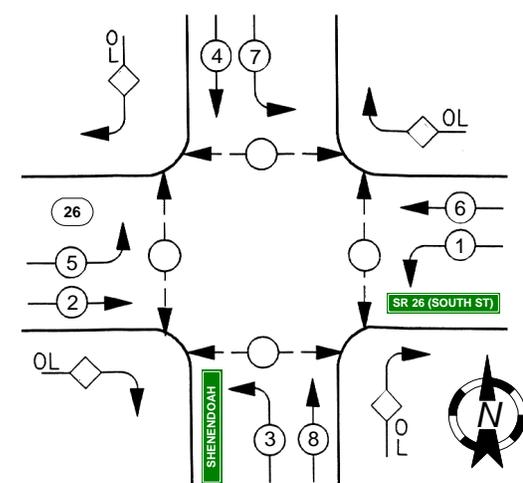
c) Node 3: SR 26 & Post Office



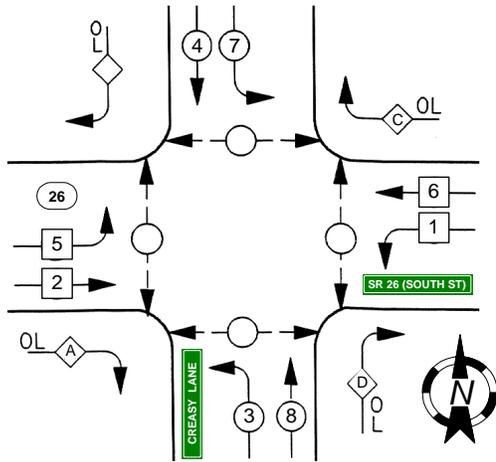
d) Node 4: SR 26 & Farabee Drive



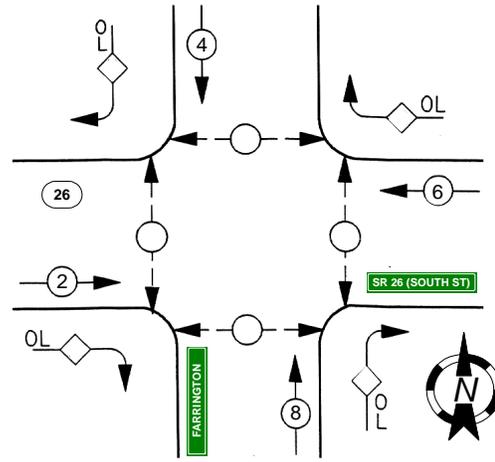
e) Node 5: SR 26 & 36th Street



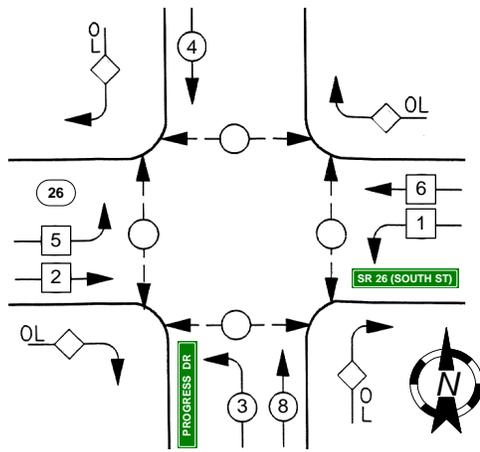
f) Node 6: SR 26 & Shenendoah Drive



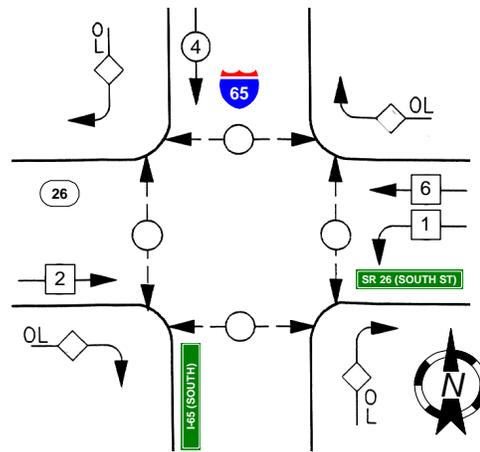
g) Node 7: SR 26 & Creasy Lane



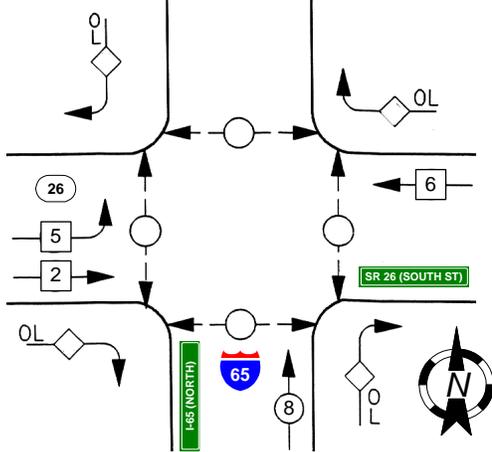
h) Node 8: SR 26 & Farrington Drive



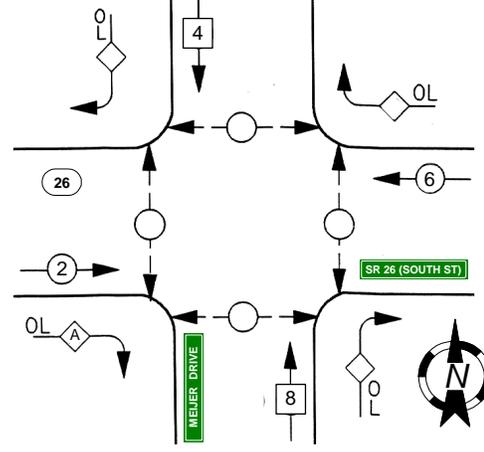
i) Node 9: SR 26 & Progress / Red Cloud



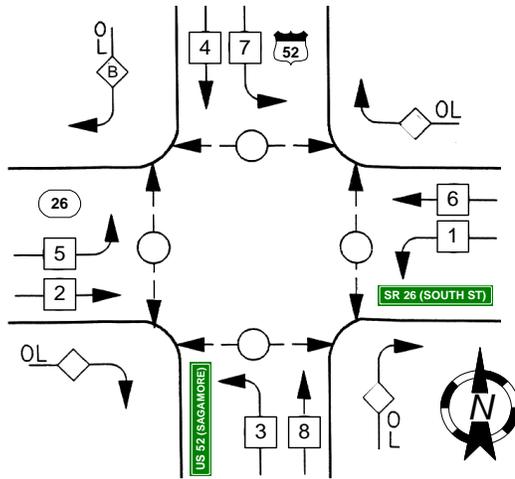
j) Node 10: SR 26 & JCT I-65 (South)



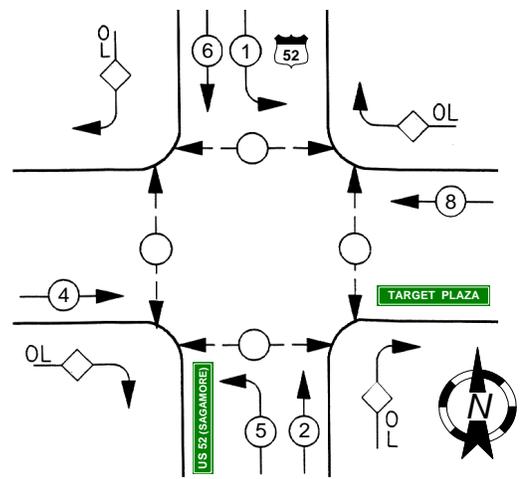
k) Node 11: SR 26 & JCT I-65 (North)



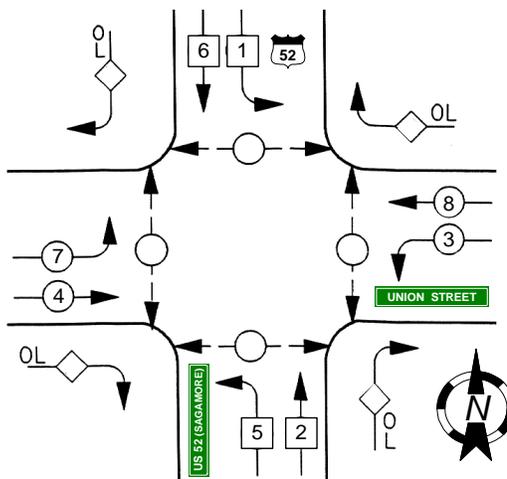
l) Node 12: SR 26 & Meijer Entrance



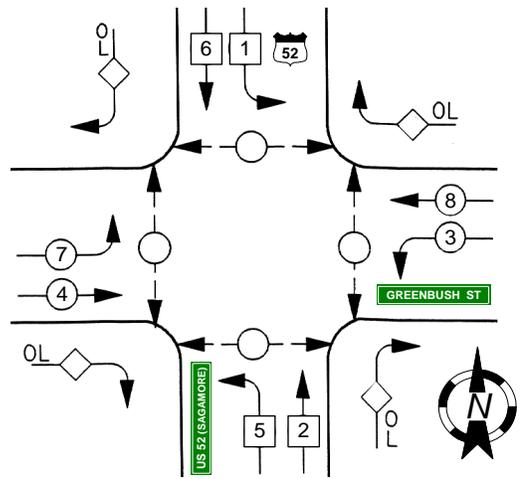
m) Node 2: US 52 & SR 26 (South)



n) Node 13: US 52 & Target Plaza

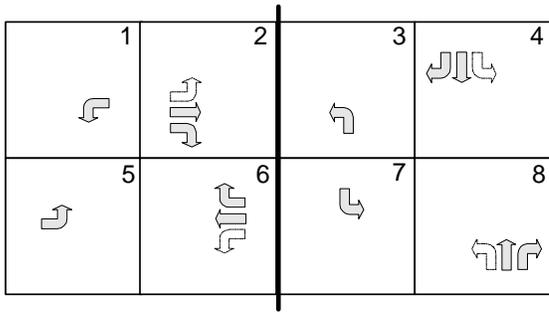


o) Node 14: US 52 & Union Street

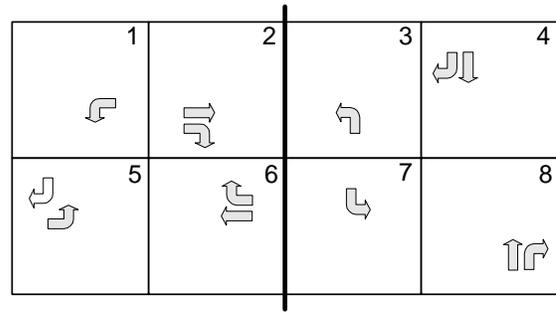


p) Node 15: US 52 & Greenbush Street

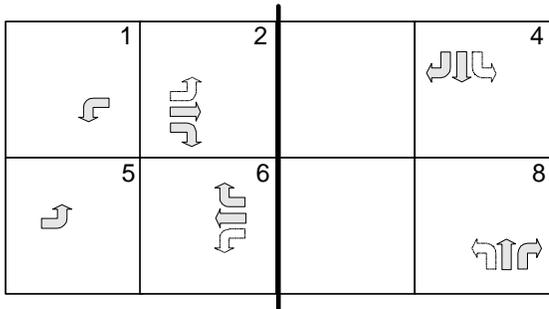
Figure C-3: Phasing Diagrams for Lafayette System (SR 26 & US 52)



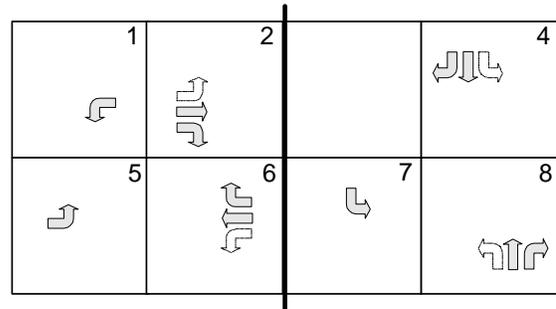
a) Node 1: SR 26 & Earl Avenue



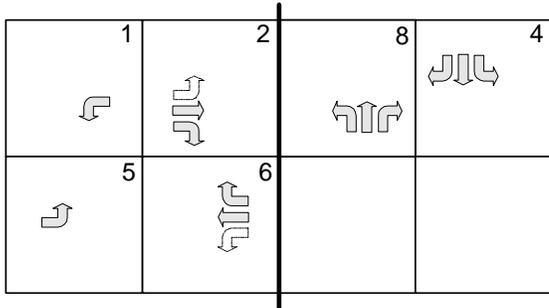
b) Node 2: SR 26 & US 52 (Sagamore)



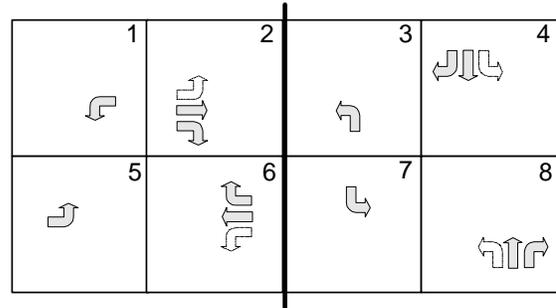
c) Node 3: SR 26 & Post Office



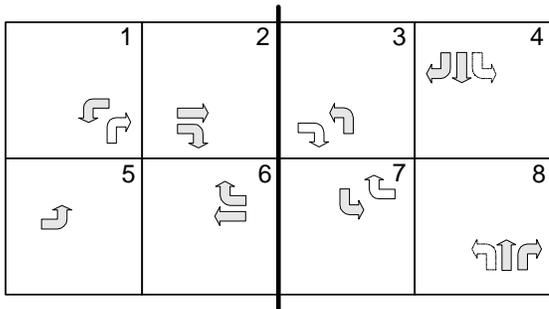
d) Node 4: SR 26 & Farabee Drive



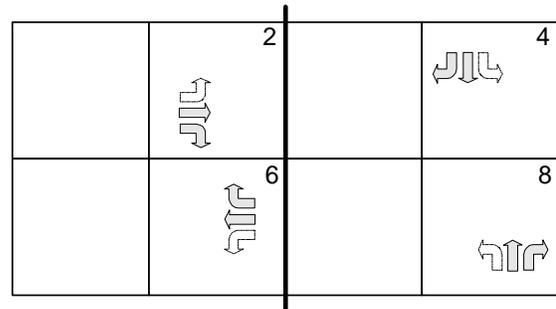
e) Node 5: SR 26 & 36th Street



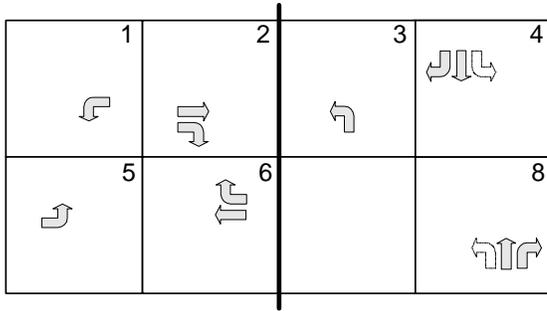
f) Node 6: SR 26 & Shenendoah Drive



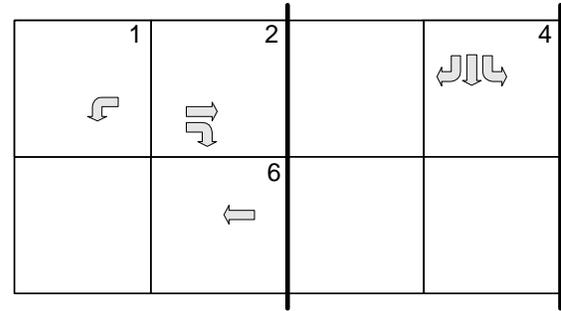
g) Node 7: SR 26 & Creasy Lane



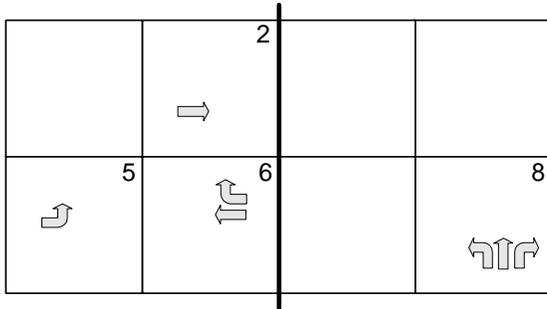
h) Node 8: SR 26 & Farrington Drive



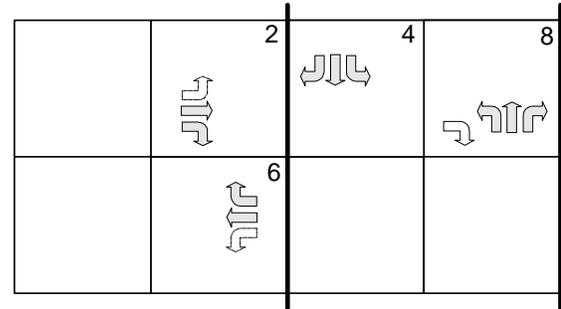
i) Node 9: SR 26 & Progress / Red Cloud



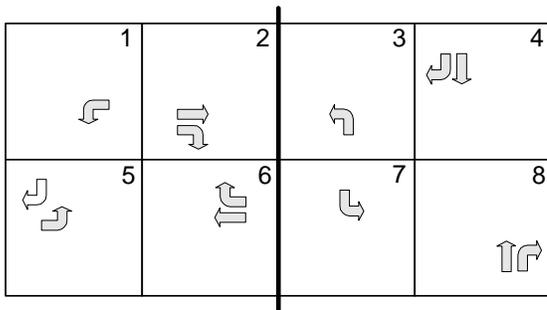
j) Node 10: SR 26 & JCT I-65 (South)



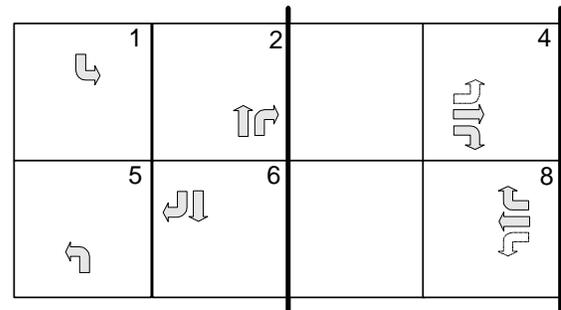
k) Node 11: SR 26 & JCT I-65 (North)



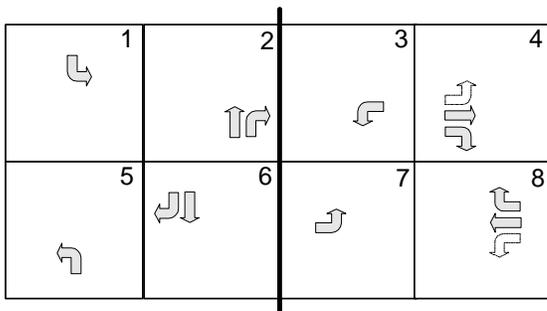
l) Node 12: SR 26 & Meijer Entrance



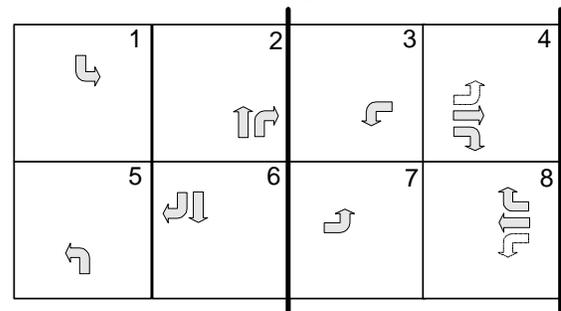
m) Node 2: US 52 & SR 26 (South)



n) Node 13: US 52 & Target Plaza

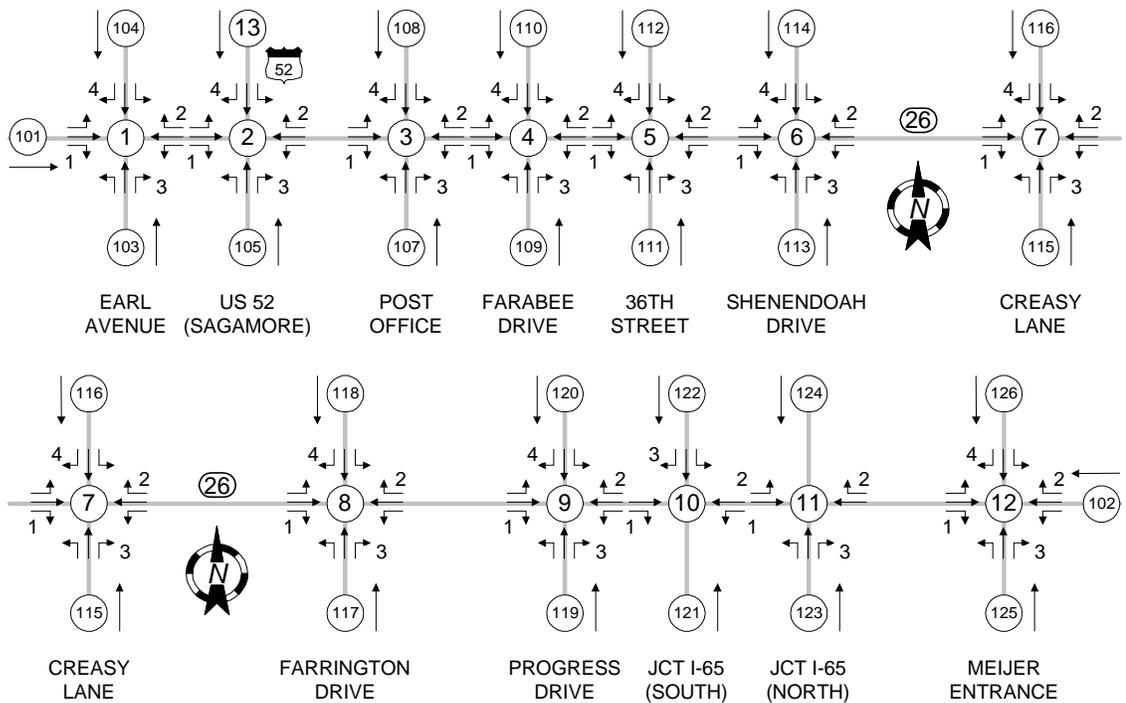


o) Node 14: US 52 & Union Street

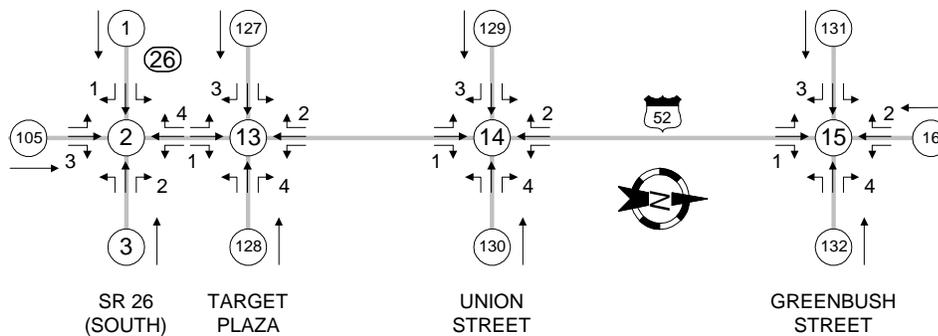


p) Node 15: US 52 & Greenbush Drive

Figure C-4: Intersection Ring Structures (SR 26 & US 52)



(a) SR 26 (South) Approach Labels



(b) US 52 (Sagamore) Approach Labels

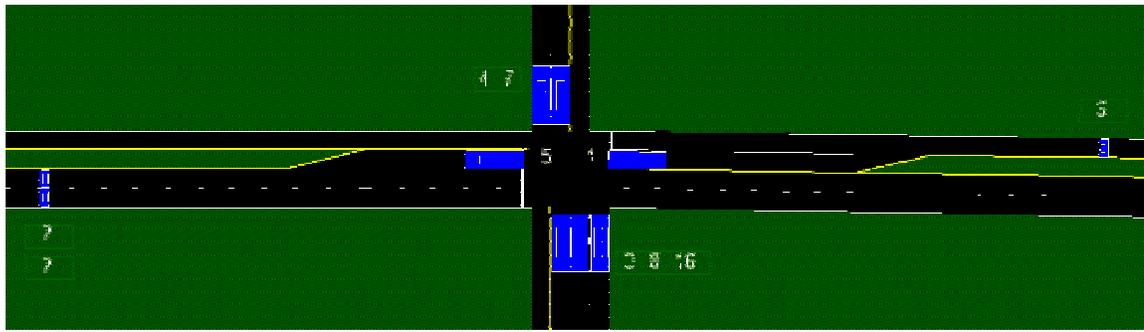
Figure C-5: Intersection Approach Labels (Reference Figure C-6)

```

COM [PortID]
1
CIDdef [CID, Base ID]
1, 1
2, 3
3, 5
4, 7
5, 9
6, 11
7, 13
NodeAssign[Node, CID]
1, 1
2, 2
3, 3
4, 4
5, 5
6, 6
7, 7
Phases [Node, Approach, L/T/R,
Phase#, Pro/Per/PP]
1, 1, L, 5, PP
1, 1, T, 2, Prot
1, 1, R, 2, Prot
1, 2, L, 1, PP
1, 2, T, 6, Prot
1, 2, R, 6, Prot
1, 3, L, 3, PP
1, 3, T, 8, Prot
1, 3, R, 8, Prot
1, 4, L, 7, PP
1, 4, T, 4, Prot
1, 4, R, 4, Prot
2, 1, L, 5, Prot
2, 1, T, 2, Prot
2, 1, R, 2, Prot
2, 2, L, 1, Prot
2, 2, T, 6, Prot
2, 2, R, 6, Prot
2, 3, L, 3, Prot
2, 3, T, 8, Prot
2, 3, R, 8, Prot
2, 4, L, 7, Prot
2, 4, T, 4, Prot
2, 4, R, 4, Prot
3, 1, L, 5, PP
3, 1, T, 2, Prot
3, 1, R, 2, Prot
3, 2, L, 1, PP
3, 2, T, 6, Prot
3, 2, R, 6, Prot
3, 3, L, 3, PP
3, 3, T, 8, Prot
3, 3, R, 8, Prot
3, 4, L, 7, PP
3, 4, T, 4, Prot
3, 4, R, 4, Prot
4, 1, L, 5, PP
4, 1, T, 2, Prot
4, 1, R, 2, Prot
4, 2, L, 1, PP
4, 2, T, 6, Prot
4, 2, R, 6, Prot
4, 3, L, 3, PP
4, 3, T, 8, Prot
4, 3, R, 8, Prot
4, 4, L, 7, PP
4, 4, T, 4, Prot
4, 4, R, 4, Prot
5, 1, L, 5, PP
5, 1, T, 2, Prot
5, 1, R, 2, Prot
5, 2, L, 1, PP
5, 2, T, 6, Prot
5, 2, R, 6, Prot
5, 3, L, 8, Prot
5, 3, T, 8, Prot
5, 3, R, 8, Prot
5, 4, L, 4, Prot
5, 4, T, 4, Prot
5, 4, R, 4, Prot
6, 1, L, 5, PP
6, 1, T, 2, Prot
6, 1, R, 2, Prot
6, 2, L, 1, PP
6, 2, T, 6, Prot
6, 2, R, 6, Prot
6, 3, L, 3, PP
6, 3, T, 8, Prot
6, 3, R, 8, Prot
6, 4, L, 7, PP
6, 4, T, 4, Prot
6, 4, R, 4, Prot
7, 1, L, 5, Prot
7, 1, T, 2, Prot
7, 1, R, 9, Prot
7, 2, L, 1, Prot
7, 2, T, 6, Prot
7, 2, R, 11, Prot
7, 3, L, 3, PP
7, 3, T, 8, Prot
7, 3, R, 12, Prot
7, 4, L, 7, PP
7, 4, T, 4, Prot
7, 4, R, 4, Prot

```

Figure C-6: External Control File (CID) for Phasing (Reference Figure C-5)



a) Node 1: SR 26 & Earl Avenue (CID_1)



b) Node 2: SR 26 & JCT I-65 (South) (CID_2)



c) Node 3: SR 26 & Post Office (CID_3)



d) Node 4: SR 26 & Farabee Drive (CID_4)

Figure C-7: Intersection Detector Locations and Numbering

101	1	7		121	360			42
101	1	8	3000	118	60			42
	1	2	7	205	360			42
	1	2	8	3000	202	60		42
	2	1	7		117	360		42
	2	1	1	3000	122	60		42
	2	3	7		305	360		42
	2	3	8	3000	302	60		42
	2	3	2	10500	210	60	1	[SYSTEM DETECTOR] 42
	2	3	1	10500	212	60	1	[SYSTEM DETECTOR] 42
	3	2	7		201	360		42
	3	2	2	3000	206	60		42
	3	2	1	3000	214	60		42
	3	4	7		405	360		42
	3	4	8	3000	402	60		42
	4	3	7		301	360		42
	4	3	8	3000	306	60		42
	4	5	7		505	360		42
	4	5	8	3000	502	60		42
	5	4	7		401	360		42
	5	4	8	3000	406	60		42
	5	6	7		605	360		42
	5	6	8	3000	602	60		42
	5	6	2	10000	509	60		[SYSTEM DETECTOR] 42
	5	6	1	10000	511	60		[SYSTEM DETECTOR] 42
	6	5	7		501	360		42
	6	5	8	3000	506	60		42
	6	7	7		705	360		42
	6	7	8	3000	702	60		42
	7	6	7		601	360		42
	7	6	8	3000	606	60		42
	7	6	2	18000	709	60	1	[SYSTEM DETECTOR] 42
	7	6	1	18000	711	60	1	[SYSTEM DETECTOR] 42
	8	7	7		701	360		42
	8	7	8	3000	706	60		42
	8	7	2	19780	713	60	1	[SYSTEM DETECTOR] 42
	8	7	1	19780	715	60	1	[SYSTEM DETECTOR] 42
	8	9	2	16410	717	60		[SYSTEM DETECTOR] 42
	8	9	1	16410	719	60		[SYSTEM DETECTOR] 42
	12	11	9	13700	712	60		[SYSTEM DETECTOR] 42
103	1	7		119	360			42
103	1	2		124	360			42
103	1	1		132	360			42
104	1	2		123	360			42
104	1	1		120	360			42
105	2	7		203	360			42
105	2	8	3000	208	60			42
	2	13	2	6150	217	60	1	[SYSTEM DETECTOR] 42
	2	13	1	6150	219	60	1	[SYSTEM DETECTOR] 42
	13	2	7		207	360		42
	13	2	8	3000	204	60		42
	13	2	2	6150	213	60		[SYSTEM DETECTOR] 42
	13	2	1	6150	215	60		[SYSTEM DETECTOR] 42
107	3	2		308	360			42

107	3	1			316	360			42
108	3	2			304	360			42
108	3	1			312	360			42
109	4	2			408	360			42
109	4	1			416	360			42
110	4	2			407	360			42
110	4	1			404	360			42
111	5	1			508	360			42
111	5	7			516	360			42
112	5	2			504	360			42
112	5	1			512	360			42
113	6	2			603	360			42
113	6	1			608	360			42
114	6	2			607	360			42
114	6	1			604	360			42
115	7	7			703	360			42
115	7	8	3000		708	60			42
116	7	7			707	360			42
116	7	8	3000		704	60			42
123	11	2	3800		710	60		[SYSTEM DETECTOR]	42
14	13	2	17250		209	60	1	[SYSTEM DETECTOR]	42
14	13	1	17250		211	60	1	[SYSTEM DETECTOR]	42
1	101	1	2	1	103	1	104	1	2 43
2	1	2	3	2	105	2	13	2	2 43
3	2	3	4	3	107	3	108	3	2 43
4	3	4	5	4	109	4	110	4	2 43
5	4	5	6	5	111	5	112	5	2 43
6	5	6	7	6	113	6	114	6	2 43
7	6	7	8	7	115	7	116	7	2 43
8	7	8	9	8	117	8	118	8	43
9	8	9	10	9	119	9	120	9	43
10	9	10	11	10	122	10			43
11	10	11	12	11	123	11			43
12	11	12	102	12	125	12	126	12	43
13	2	13	14	13	127	13	128	13	43
14	13	14	15	14	129	14	130	14	43
15	14	15	16	15	131	15	132	15	43

Figure C-8: Sample External Detector File (Reference Figure C-7)

INT	BEG END	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM	6PM 7PM
1	EB	311	342	460	530	654	674	563	706	813	705	709	575
1	NB	406	334	388	351	478	457	382	506	713	433	536	316
1	SB	292	341	453	429	538	565	437	544	608	552	515	356
2	NB	735	600	676	817	1060	1134	1057	1254	1228	1117	1251	883
3	NB	11	6	20	10	40	120	66	40	12	28	49	31
3	SB	180	191	186	203	219	207	205	216	155	232	274	220
4	NB	197	215	212	237	336	304	247	258	381	348	367	231
4	SB	49	53	106	133	158	194	176	186	130	180	186	174
5	NB	49	30	18	26	32	24	25	77	102	61	28	23
5	SB	71	169	91	104	141	165	142	107	147	191	174	102
6	NB	59	23	11	8	24	18	22	116	177	72	51	21
6	SB	86	55	72	80	73	111	126	122	114	111	125	114
7	NB	635	600	514	572	759	606	830	1180	1220	1555	1423	1179
7	SB	715	641	572	575	799	622	712	726	707	994	1094	898
8	NB	53	51	61	61	75	76	47	60	60	58	60	49
8	SB	17	12	12	11	12	22	33	22	9	12	35	51
9	NB	121	104	125	121	158	161	145	130	121	117	123	154
9	SB	179	201	206	198	232	286	184	152	138	95	145	146
10	SB	314	551	541	457	375	424	441	446	429	501	485	595
11	NB	247	264	268	293	318	279	193	183	207	206	241	199
12	WB	772	564	452	378	398	444	335	343	400	446	483	540
12	NB	173	166	194	245	275	315	297	307	311	433	334	385
12	SB	2	3	1	1	2	2	2	2	2	1	1	1
13	EB	1	14	19	11	13	9	10	18	10	10	21	13
13	WB	37	48	168	245	373	466	268	306	308	257	330	373
14	EB	398	441	470	541	681	693	742	806	962	1139	1186	683
14	WB	732	546	368	337	412	406	401	441	513	513	552	416
15	EB	255	297	333	406	467	516	477	465	508	599	677	391
15	WB	656	537	374	390	421	407	465	404	472	521	504	349
15	SB	843	726	725	668	861	900	863	950	926	968	1053	654

Table C-1: Entry Volumes per Period (VPH) – (Regular Volumes – Case_1)

INT	BEG END	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM	6PM 7PM
1	EB	311	342	460	530	596	574	563	706	813	705	751	885
1	NB	406	334	388	351	440	474	382	506	713	433	329	270
1	SB	292	341	453	429	502	477	437	544	608	552	262	357
2	NB	735	600	676	817	990	991	1057	1254	1228	1117	1114	892
3	NB	11	6	20	10	120	66	66	40	12	28	49	31
3	SB	180	191	186	203	270	205	205	216	155	232	274	220
4	NB	197	215	212	237	304	247	247	258	381	348	367	321
4	SB	49	53	106	133	194	176	176	186	130	180	186	174
5	NB	49	30	18	26	24	25	25	77	102	61	28	23
5	SB	71	169	91	104	165	142	142	107	147	191	174	103
6	NB	59	23	11	8	18	22	22	116	177	72	51	21
6	SB	86	55	72	80	111	126	126	122	114	111	125	114
7	NB	635	600	514	572	953	931	830	1180	1220	1555	817	736
7	SB	715	641	572	575	914	751	712	726	707	994	593	915
8	NB	53	51	61	61	76	47	47	60	60	58	60	49
8	SB	17	12	12	11	22	33	33	22	9	12	35	51
9	NB	121	104	125	121	156	133	145	130	121	117	123	154
9	SB	179	201	206	198	286	184	184	152	138	95	145	146
10	SB	314	551	541	457	664	544	441	446	429	501	559	594
11	NB	247	264	268	293	544	566	193	183	207	206	387	379
12	WB	772	564	452	378	1083	1108	335	343	400	446	847	840
12	NB	173	166	194	245	315	297	297	307	311	433	334	385
12	SB	2	3	1	1	1	1	2	2	2	1	1	1
13	EB	1	14	19	11	10	10	10	18	10	10	21	13
13	WB	37	48	168	245	467	269	268	306	308	257	329	373
14	EB	398	441	470	541	723	611	742	806	962	1139	1155	1312
14	WB	732	546	368	337	514	499	401	441	513	513	501	509
15	EB	255	297	333	406	560	466	477	465	508	599	439	431
15	WB	656	537	374	390	418	410	465	404	472	521	504	349
15	SB	843	726	725	668	1011	988	863	950	926	968	2298	2444

Table C-2: Entry Volumes per Period (VPH) – (Event Volumes – Case_2)

INT	BEG END	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM	6PM 7PM
EARL AVENUE	EBLT	13	11	10	10	6	10	9	7	7	5	6	5
	EBTH	81	82	82	82	85	83	83	84	85	90	87	92
	EBRT	6	7	8	8	9	7	8	9	8	5	7	3
	WBLT	13	14	12	14	15	18	14	15	16	16	17	19
	WBTH	70	68	73	68	67	65	68	69	71	68	70	72
	WBRT	17	18	15	18	18	17	18	16	13	16	13	9
	NBLT	5	5	15	10	6	7	7	7	9	6	6	7
	NBTH	69	73	66	66	69	70	71	67	68	71	69	69
	NBRT	26	22	19	24	25	23	22	26	23	23	25	24
	SBLT	23	30	29	34	35	34	27	33	32	31	31	31
	SBTH	72	65	60	60	60	62	67	59	64	64	65	59
SBRT	5	5	11	6	5	4	6	8	4	5	4	10	
US 52 (SAGAMORE)	EBLT	19	20	18	16	18	18	19	18	19	16	16	14
	EBTH	70	67	68	65	62	62	60	62	62	64	69	67
	EBRT	11	13	14	19	20	20	21	20	19	20	15	19
	WBLT	20	24	22	27	27	27	26	28	27	24	24	28
	WBTH	57	54	55	49	48	48	51	50	47	51	55	51
	WBRT	23	22	23	24	25	25	23	22	26	25	21	21
	NBLT	9	11	12	12	13	13	15	14	12	13	11	12
	NBTH	72	65	68	69	63	62	62	66	69	67	67	63
	NBRT	19	24	20	19	24	25	23	20	19	20	22	25
	SBLT	20	20	22	20	27	25	25	22	22	22	25	27
	SBTH	63	66	66	67	60	62	65	67	69	68	65	64
SBRT	17	14	12	13	13	13	10	11	9	10	10	9	
POST OFFICE	EBLT	19	14	10	11	9	11	15	14	15	14	13	10
	EBTH	80	85	88	87	84	82	83	83	83	83	84	87
	EBRT	1	1	2	2	7	7	2	3	2	3	3	3
	WBLT	1	1	1	1	6	5	2	1	0	2	3	5
	WBTH	85	88	87	89	83	85	82	85	84	79	81	80
	WBRT	14	11	12	10	11	10	16	14	16	19	16	15
	NBLT	55	17	35	80	60	48	42	38	33	32	45	13
	NBTH	9	0	10	0	0	4	2	4	9	4	10	3
	NBRT	36	83	55	20	40	48	56	58	58	64	45	84
	SBLT	30	35	31	34	25	33	43	42	50	47	44	55
	SBTH	0	0	0	1	1	2	3	0	1	0	1	2
SBRT	70	65	69	65	74	65	54	58	49	53	55	43	
FARABEE DRIVE	EBLT	3	6	8	8	9	9	8	9	9	7	5	7
	EBTH	86	85	84	85	85	85	85	85	84	87	90	89
	EBRT	11	9	8	7	6	6	7	6	7	6	5	4
	WBLT	18	14	11	12	12	12	13	13	17	12	13	9
	WBTH	81	82	84	81	81	83	81	81	78	80	80	85
	WBRT	1	4	5	7	7	5	6	6	5	8	7	6
	NBLT	17	15	21	17	17	19	23	20	13	19	18	16
	NBTH	7	8	10	15	12	13	11	18	9	11	8	15
	NBRT	76	77	69	68	71	68	66	62	78	70	74	69
	SBLT	4	17	16	29	25	35	29	26	31	31	26	35
	SBTH	53	34	22	21	16	17	19	18	17	19	28	13
SBRT	43	49	62	50	29	48	52	56	52	50	46	52	

Table C-3: Turning Movements (Percentages – Case_1) – Table 1 of 4

INT	BEG END	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM	6PM 7PM
36TH STTRET	EBLT	13	8	9	7	6	6	6	6	7	6	5	5
	EBTH	86	90	90	92	94	93	93	94	93	93	94	95
	EBRT	1	2	1	1	0	1	1	0	0	1	1	0
	WBLT	1	1	1	1	1	1	1	1	1	0	0	0
	WBTH	90	89	94	92	93	91	92	92	92	93	93	95
	WBRT	9	10	5	7	6	8	7	7	7	7	7	5
	NBLT	90	63	44	65	66	63	56	69	61	69	54	39
	NBTH	2	17	6	16	6	20	4	13	20	8	25	4
	NBRT	8	20	50	19	28	17	40	18	19	23	21	57
	SBLT	48	42	35	35	45	55	39	53	45	51	63	56
	SBTH	1	2	2	0	1	1	2	2	1	1	0	0
SBRT	51	56	63	65	54	44	59	45	54	48	37	44	
SHENENDOAH DRIVE	EBLT	4	4	5	6	5	6	5	5	5	6	6	7
	EBTH	96	95	94	94	95	93	94	95	95	94	94	93
	EBRT	0	1	1	0	0	1	1	0	0	0	0	0
	WBLT	10	3	2	1	2	1	1	2	5	1	1	0
	WBTH	89	94	94	94	94	94	94	94	91	95	93	92
	WBRT	1	3	4	5	4	5	5	4	4	4	6	8
	NBLT	7	22	18	38	13	17	23	9	7	7	12	10
	NBTH	10	8	9	12	16	16	13	9	6	10	12	9
	NBRT	83	70	73	50	71	67	64	82	87	83	76	81
	SBLT	15	20	32	33	27	37	33	25	38	45	49	49
	SBTH	16	7	1	1	0	2	1	1	1	2	1	0
SBRT	69	73	67	66	73	61	66	74	61	53	50	51	
CREASY LANE	EBLT	6	8	9	8	7	9	8	8	7	9	7	9
	EBTH	69	70	63	63	63	61	63	64	67	62	67	65
	EBRT	25	22	28	29	30	30	29	28	26	29	26	26
	WBLT	14	13	19	18	21	19	20	20	17	18	18	20
	WBTH	65	61	59	57	56	59	54	55	57	54	52	51
	WBRT	21	26	22	25	23	22	26	25	26	28	30	29
	NBLT	25	35	36	36	35	38	35	30	25	28	24	27
	NBTH	56	48	46	48	46	51	47	50	55	54	56	52
	NBRT	19	17	18	16	19	11	18	20	20	18	20	21
	SBLT	35	40	38	34	42	42	41	37	45	42	43	45
	SBTH	58	51	51	57	49	49	50	54	48	52	52	49
SBRT	7	9	11	9	9	9	9	9	7	6	5	6	
FARRINGTON DRIVE	EBLT	1	2	1	2	2	2	2	1	1	1	3	4
	EBTH	98	96	96	95	96	95	96	97	97	98	95	94
	EBRT	1	2	3	3	2	3	2	2	2	1	2	2
	WBLT	1	1	1	2	2	2	2	1	2	2	2	2
	WBTH	99	99	98	91	97	97	97	98	98	97	96	96
	WBRT	0	0	1	1	1	1	1	1	0	1	2	2
	NBLT	72	73	69	67	61	50	81	72	63	57	68	61
	NBTH	0	0	0	0	2	1	0	0	0	0	2	8
	NBRT	28	27	31	33	37	49	19	28	37	43	30	31
	SBLT	6	25	8	27	42	32	42	41	33	50	26	49
	SBTH	0	8	9	9	8	4	0	4	0	0	3	0
SBRT	94	67	83	64	50	64	58	55	67	50	71	51	

Table C-4: Turning Movements (Percentages – Case_1) – Table 2 of 4

INT	BEG END	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM	6PM 7PM
PROGRESS DRIVE / RED CLOUD	EBLT	9	11	12	9	6	7	4	4	2	4	5	4
	EBTH	80	80	79	82	85	84	88	89	91	89	88	85
	EBRT	11	9	9	9	9	9	8	7	7	7	7	11
	WBLT	4	4	4	4	4	3	4	4	5	7	5	5
	WBTH	86	82	84	83	82	86	86	87	87	87	85	86
	WBRT	11	14	12	13	14	11	10	9	8	6	10	9
	NBLT	35	39	36	29	27	30	45	46	40	32	36	42
	NBTH	6	2	3	2	5	5	2	0	1	2	3	1
	NBRT	59	59	61	69	68	65	53	54	59	66	61	57
	SBLT	55	62	57	44	67	72	74	65	67	74	72	56
	SBTH	8	3	4	6	3	3	0	5	1	0	2	4
SBRT	37	35	39	50	30	25	26	30	32	26	26	40	
JCT I-65 (SOUTH)	EBTH	72	72	76	63	72	72	76	80	77	79	81	74
	EBRT	28	28	24	37	28	28	24	20	23	21	19	26
	WBLT	4	6	3	6	0	6	3	4	5	5	4	4
	WBTH	96	94	97	94	100	94	97	96	95	95	96	96
	SBLT	32	30	22	26	30	33	36	29	31	41	48	51
	SBTH	0	0	0	0	0	0	0	0	2	0	1	0
	SBRT	68	70	78	74	70	67	64	71	67	59	51	49
JCT I-65 (NORTH)	EBLT	27	28	26	22	22	20	28	30	26	29	22	34
	EBTH	73	72	74	78	78	80	72	70	74	71	78	66
	WBTH	82	86	88	85	82	83	85	86	83	82	76	87
	WBRT	18	14	12	15	18	17	15	14	17	18	24	13
	NBLT	79	86	71	17	71	73	77	74	73	68	71	72
	NBTH	0	0	0	1	0	0	5	1	2	1	0	1
	NBRT	21	14	29	22	29	27	18	25	25	31	29	27
MEIJER ENTRANCE	EBLT	0	0	0	0	0	0	0	0	0	0	0	0
	EBTH	65	59	52	50	53	52	53	53	60	58	66	61
	EBRT	35	41	48	50	47	48	47	47	40	42	34	39
	WBLT	3	4	6	4	7	6	6	3	4	5	5	6
	WBTH	97	96	94	96	93	94	93	97	95	95	95	94
	WBRT	0	0	0	0	0	0	1	0	1	0	0	0
	NBLT	95	93	94	97	94	96	95	96	94	97	96	96
	NBTH	0	0	1	1	1	1	0	0	1	0	1	0
	NBRT	5	7	5	2	5	3	5	4	5	3	3	4
	SBLT	0	0	0	0	0	50	0	0	0	0	0	0
	SBTH	50	33	100	100	50	50	50	50	50	100	100	100
SBRT	50	67	0	0	50	0	50	50	50	0	0	0	

Table C-5: Turning Movements (Percentages – Case_1) – Table 3 of 4

INT	BEG END	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM	6PM 7PM
TARGET PLAZA	NBLT	1	1	1	1	1	1	1	2	1	1	1	1
	NBTH	94	93	86	84	81	81	84	85	86	85	85	84
	NBRT	5	6	13	15	18	18	15	13	13	14	14	15
	SBLT	4	8	10	12	15	15	9	12	12	15	12	13
	SBTH	95	90	89	87	84	84	90	88	87	85	87	86
	SBRT	1	2	1	1	1	1	1	0	1	0	1	1
	EBLT	0	43	21	45	23	33	30	33	20	0	33	23
	EBTH	0	7	5	10	15	0	0	0	20	10	5	15
	EBRT	100	50	74	45	62	67	70	67	60	90	62	62
	WBLT	49	50	53	55	53	49	52	55	49	38	54	53
	WBTH	0	4	0	1	0	0	0	1	0	0	0	0
WBRT	51	46	47	44	47	51	48	44	51	62	46	47	
UNION STREET	NBLT	15	20	20	21	23	21	17	18	16	17	16	20
	NBTH	79	70	71	69	66	66	72	73	75	73	73	72
	NBRT	6	10	9	10	11	13	11	9	9	10	11	8
	SBLT	15	14	9	9	9	9	9	10	11	14	16	13
	SBTH	65	66	72	74	75	76	73	74	71	69	72	72
	SBRT	20	20	19	17	16	15	18	16	18	17	12	15
	EBLT	26	27	23	22	23	27	26	28	28	23	23	24
	EBTH	58	50	49	48	48	46	47	48	52	58	59	51
	EBRT	16	23	28	30	29	27	27	24	20	19	18	25
	WBLT	21	14	15	14	19	21	19	13	18	14	18	17
	WBTH	62	70	67	66	62	59	63	64	58	59	59	63
WBRT	17	16	18	20	19	20	18	23	24	27	23	20	
GREENBUSH STREET	NBLT	17	17	18	21	19	21	17	17	14	13	13	10
	NBTH	77	75	73	69	71	69	73	75	75	77	74	81
	NBRT	6	8	9	10	10	10	10	8	11	10	13	9
	SBLT	13	12	14	14	14	14	13	14	17	19	20	19
	SBTH	79	76	75	76	76	75	78	79	75	74	71	72
	SBRT	8	10	11	10	10	11	9	7	8	7	9	9
	EBLT	23	23	16	18	18	18	21	17	18	20	16	11
	EBTH	47	48	44	47	47	45	41	47	55	54	58	67
	EBRT	30	29	40	35	35	37	38	36	27	26	26	22
	WBLT	20	14	27	17	18	18	22	19	15	15	18	12
	WBTH	63	65	52	59	56	56	55	53	54	52	50	59
WBRT	17	21	21	24	26	26	23	28	31	33	32	29	

Table C-6: Turning Movements (Percentages – Case_1) – Table 4 of 4

INT	BEG END	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM	6PM 7PM
EARL AVENUE	EBLT	13	11	10	10	9	8	9	7	7	5	8	9
	EBTH	81	82	82	82	82	83	83	84	85	90	83	82
	EBRT	6	7	8	8	9	9	8	9	8	5	9	9
	WBLT	13	14	12	14	13	13	14	15	16	16	14	14
	WBTH	70	68	73	68	72	72	68	69	71	68	70	71
	WBRT	17	18	15	18	15	15	18	16	13	16	16	15
	NBLT	5	5	15	10	8	8	7	7	9	6	8	8
	NBTH	69	73	66	66	69	69	71	67	68	71	69	69
	NBRT	26	22	19	24	23	23	22	26	23	23	23	23
	SBLT	23	30	29	34	32	32	27	33	32	31	32	32
	SBTH	72	65	60	60	61	61	67	59	64	64	61	61
SBRT	5	5	11	6	7	7	6	8	4	5	7	7	
US 52 (SAGAMORE)	EBLT	19	20	18	16	18	18	19	18	19	16	12	8
	EBTH	70	67	68	65	63	63	60	62	62	64	69	72
	EBRT	11	13	14	19	19	19	21	20	19	20	19	20
	WBLT	20	24	22	27	23	23	26	28	27	24	29	34
	WBTH	57	54	55	49	52	52	51	50	47	51	48	45
	WBRT	23	22	23	24	25	25	23	22	26	25	23	21
	NBLT	9	11	12	12	16	16	15	14	12	13	12	13
	NBTH	72	65	68	69	65	67	62	66	69	67	67	65
	NBRT	19	24	20	19	19	17	23	20	19	20	21	22
	SBLT	20	20	22	20	26	29	25	22	22	22	33	35
	SBTH	63	66	66	67	62	60	65	67	69	68	59	58
SBRT	17	14	12	13	12	11	10	11	9	10	8	7	
POST OFFICE	EBLT	19	14	10	11	12	12	15	14	15	14	12	12
	EBTH	80	85	88	87	84	84	83	83	83	83	84	84
	EBRT	1	1	2	2	4	4	2	3	2	3	4	4
	WBLT	1	1	1	1	3	3	2	1	0	2	3	3
	WBTH	85	88	87	89	85	85	82	85	84	79	85	85
	WBRT	14	11	12	10	12	12	16	14	16	19	12	12
	NBLT	55	17	35	80	48	42	42	38	33	32	45	13
	NBTH	9	0	10	0	4	2	2	4	9	4	10	3
	NBRT	36	83	55	20	48	56	56	58	58	64	45	84
	SBLT	30	35	31	34	33	43	43	42	50	47	44	55
	SBTH	0	0	0	1	2	3	3	0	1	0	1	2
SBRT	70	65	69	65	65	54	54	58	49	53	55	43	
FARABEE DRIVE	EBLT	3	6	8	8	8	6	8	9	9	7	7	7
	EBTH	86	85	84	85	86	86	85	85	84	87	87	87
	EBRT	11	9	8	7	6	8	7	6	7	6	6	6
	WBLT	18	14	11	12	12	12	13	13	17	12	14	14
	WBTH	81	82	84	81	82	82	81	81	78	80	79	79
	WBRT	1	4	5	7	6	6	6	6	5	8	7	7
	NBLT	17	15	21	17	19	23	23	20	13	19	18	16
	NBTH	7	8	10	15	13	11	11	18	9	11	8	15
	NBRT	76	77	69	68	68	66	66	62	78	70	74	69
	SBLT	4	17	16	29	35	29	29	26	31	31	26	35
	SBTH	53	34	22	21	17	19	19	18	17	19	28	13
SBRT	43	49	62	50	48	52	52	56	52	50	46	52	

Table C-7: Turning Movements (Percentages – Case_2) – Table 1 of 4

INT	BEG END	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM	6PM 7PM
36TH STTRET	EBLT	13	8	9	7	6	6	6	6	7	6	6	6
	EBTH	86	90	90	92	93	93	93	94	93	93	93	93
	EBRT	1	2	1	1	1	1	1	0	0	1	1	1
	WBLT	1	1	1	1	1	1	1	1	1	0	1	1
	WBTH	90	89	94	92	92	92	92	92	92	93	92	92
	WBRT	9	10	5	7	7	7	7	7	7	7	7	7
	NBLT	90	63	44	65	63	56	56	69	61	69	54	39
	NBTH	2	17	6	16	20	4	4	13	20	8	25	4
	NBRT	8	20	50	19	17	40	40	18	19	23	21	57
	SBLT	48	42	35	35	55	39	39	53	45	51	63	55
	SBTH	1	2	2	0	1	2	2	2	1	1	0	1
SBRT	51	56	63	65	44	59	59	45	54	48	37	44	
SHENENDOAH DRIVE	EBLT	4	4	5	6	5	5	5	5	5	6	5	5
	EBTH	96	95	94	94	95	95	94	95	95	94	95	95
	EBRT	0	1	1	0	0	0	1	0	0	0	0	0
	WBLT	10	3	2	1	2	2	1	2	5	1	2	2
	WBTH	89	94	94	94	93	93	94	94	91	95	93	93
	WBRT	1	3	4	5	5	5	5	4	4	4	5	5
	NBLT	7	22	18	38	17	23	23	9	7	7	12	10
	NBTH	10	8	9	12	16	13	13	9	6	10	12	9
	NBRT	83	70	73	50	67	64	64	82	87	83	76	81
	SBLT	15	20	32	33	37	33	33	25	38	45	49	49
	SBTH	16	7	1	1	2	1	1	1	1	2	1	0
SBRT	69	73	67	66	61	66	66	74	61	53	50	51	
CREASY LANE	EBLT	6	8	9	8	7	8	8	8	7	9	8	8
	EBTH	69	70	63	63	64	63	63	64	67	62	65	65
	EBRT	25	22	28	29	29	29	29	28	26	29	27	27
	WBLT	14	13	19	18	16	16	20	20	17	18	18	23
	WBTH	65	61	59	57	60	60	54	55	57	54	58	54
	WBRT	21	26	22	25	24	24	26	25	26	28	24	23
	NBLT	25	35	36	36	34	34	35	30	25	28	26	26
	NBTH	56	48	46	48	48	48	47	50	55	54	55	55
	NBRT	19	17	18	16	18	18	18	20	20	18	19	19
	SBLT	35	40	38	34	39	39	41	37	45	42	43	43
	SBTH	58	51	51	57	52	52	50	54	48	52	51	51
SBRT	7	9	11	9	9	9	9	9	7	6	6	6	
FARRINGTON DRIVE	EBLT	1	2	1	2	2	2	2	1	1	1	2	2
	EBTH	98	96	96	95	96	96	96	97	97	98	96	96
	EBRT	1	2	3	3	2	2	2	2	2	1	2	2
	WBLT	1	1	1	2	2	2	2	1	2	2	2	2
	WBTH	99	99	98	91	97	97	97	98	98	97	97	97
	WBRT	0	0	1	1	1	1	1	1	0	1	1	1
	NBLT	72	73	69	67	50	81	81	72	63	57	68	61
	NBTH	0	0	0	0	1	0	0	0	0	0	2	8
	NBRT	28	27	31	33	49	19	19	28	37	43	30	31
	SBLT	6	25	8	27	32	42	42	41	33	50	26	49
	SBTH	0	8	9	9	4	0	0	4	0	0	3	0
SBRT	94	67	83	64	64	58	58	55	67	50	71	51	

Table C-8: Turning Movements (Percentages – Case_2) – Table 2 of 4

INT	BEG END	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM	6PM 7PM
PROGRESS DRIVE / RED CLOUD	EBLT	9	11	12	9	2	2	4	4	2	4	2	2
	EBTH	80	80	79	82	96	96	88	89	91	89	96	96
	EBRT	11	9	9	9	2	2	8	7	7	7	2	2
	WBLT	4	4	4	4	4	4	4	4	5	7	6	6
	WBTH	86	82	84	83	84	84	86	87	87	87	86	86
	WBRT	11	14	12	13	12	12	10	9	8	6	8	8
	NBLT	35	39	36	29	27	37	45	46	40	32	36	42
	NBTH	6	2	3	2	6	5	2	0	1	2	3	1
	NBRT	59	59	61	69	67	58	53	54	59	66	61	57
	SBLT	55	62	57	44	72	74	74	65	67	74	72	56
	SBTH	8	3	4	6	3	0	0	5	1	0	2	4
SBRT	37	35	39	50	25	26	26	30	32	26	26	40	
JCT I-65 (SOUTH)	EBTH	72	72	76	63	74	74	76	80	77	79	79	79
	EBRT	28	28	24	37	26	26	24	20	23	21	21	21
	WBLT	4	6	3	6	4	4	3	4	5	5	5	5
	WBTH	96	94	97	94	96	96	97	96	95	95	95	95
	SBLT	32	30	22	26	32	33	36	29	31	41	39	42
	SBTH	0	0	0	0	0	0	0	0	2	0	0	0
	SBRT	68	70	78	74	68	67	64	71	67	59	61	58
JCT I-65 (NORTH)	EBLT	27	28	26	22	24	21	28	30	26	29	25	24
	EBTH	73	72	74	78	76	79	72	70	74	71	75	76
	WBTH	82	86	88	85	85	85	85	86	83	82	80	80
	WBRT	18	14	12	15	15	15	15	14	17	18	20	20
	NBLT	79	86	71	17	86	94	77	74	73	68	82	86
	NBTH	0	0	0	1	0	0	5	1	2	1	0	0
	NBRT	21	14	29	22	14	6	18	25	25	31	18	14
MEIJER ENTRANCE	EBLT	0	0	0	0	0	0	0	0	0	0	0	0
	EBTH	65	59	52	50	71	73	53	53	60	58	70	74
	EBRT	35	41	48	50	29	27	47	47	40	42	30	26
	WBLT	3	4	6	4	2	3	6	3	4	5	3	3
	WBTH	97	96	94	96	98	97	93	97	95	95	97	97
	WBRT	0	0	0	0	0	0	1	0	1	0	0	0
	NBLT	95	93	94	97	96	95	95	96	94	97	96	96
	NBTH	0	0	1	1	1	0	0	0	1	0	1	0
	NBRT	5	7	5	2	3	5	5	4	5	3	3	4
	SBLT	0	0	0	0	0	0	0	0	0	0	0	0
	SBTH	50	33	100	100	100	100	50	50	50	100	100	100
SBRT	50	67	0	0	0	0	50	50	50	0	0	0	

Table C-9: Turning Movements (Percentages – Case_2) – Table 3 of 4

INT	BEG END	7AM 8AM	8AM 9AM	9AM 10A	10A 11A	11A 12P	12P 1PM	1PM 2PM	2PM 3PM	3PM 4PM	4PM 5PM	5PM 6PM	6PM 7PM
TARGET PLAZA	NBLT	1	1	1	1	1	1	1	2	1	1	1	1
	NBTH	94	93	86	84	84	84	84	85	86	85	86	86
	NBRT	5	6	13	15	15	15	15	13	13	14	13	13
	SBLT	4	8	10	12	13	13	9	12	12	15	13	13
	SBTH	95	90	89	87	86	86	90	88	87	85	86	86
	SBRT	1	2	1	1	1	1	1	0	1	0	1	1
	EBLT	0	43	21	45	30	30	30	33	20	0	33	23
	EBTH	0	7	5	10	10	0	0	0	20	10	5	15
	EBRT	100	50	74	45	60	70	70	67	60	90	62	62
	WBLT	49	50	53	55	49	52	52	55	49	38	54	53
	WBTH	0	4	0	1	0	0	0	1	0	0	0	0
WBRT	51	46	47	44	51	48	48	44	51	62	46	47	
UNION STREET	NBLT	15	20	20	21	23	22	17	18	16	17	16	18
	NBTH	79	70	71	69	67	68	72	73	75	73	74	72
	NBRT	6	10	9	10	10	10	11	9	9	10	10	10
	SBLT	15	14	9	9	10	10	9	10	11	14	12	10
	SBTH	65	66	72	74	74	74	73	74	71	69	72	74
	SBRT	20	20	19	17	16	16	18	16	18	17	16	16
	EBLT	26	27	23	22	25	25	26	28	28	23	25	25
	EBTH	58	50	49	48	48	48	47	48	52	58	56	56
	EBRT	16	23	28	30	27	27	27	24	20	19	19	19
	WBLT	21	14	15	14	15	17	19	13	18	14	14	20
	WBTH	62	70	67	66	69	68	63	64	58	59	61	64
WBRT	17	16	18	20	16	15	18	23	24	27	25	16	
GREENBUSH STREET	NBLT	17	17	18	21	18	18	17	17	14	13	13	13
	NBTH	77	75	73	69	73	73	73	75	75	77	75	75
	NBRT	6	8	9	10	9	9	10	8	11	10	12	12
	SBLT	13	12	14	14	15	15	13	14	17	19	8	10
	SBTH	79	76	75	76	75	75	78	79	75	74	84	82
	SBRT	8	10	11	10	10	10	9	7	8	7	8	8
	EBLT	23	23	16	18	17	17	21	17	18	20	18	18
	EBTH	47	48	44	47	48	48	41	47	55	54	56	56
	EBRT	30	29	40	35	35	35	38	36	27	26	26	26
	WBLT	20	14	27	17	18	18	22	19	15	15	18	12
	WBTH	63	65	52	59	57	56	55	53	54	52	50	59
WBRT	17	21	21	24	25	26	23	28	31	33	32	29	

Table C-10: Turning Movements (Percentages – Case_2) – Table 4 of 4

SR 26 (SOUTH ST)		POCKET LENGTHS (FT)		STOP BAR DETECTOR LENGTHS (FT)			RACEWAY DETECTORS (FT)	
INT	MOVE	LEFT	RIGHT	LEFT	THRU	RIGHT	THRU	DIST
1	EB	100	--	36	--	--	6	300
1	WB	150	--	36	36	--	6	300
1	NB	70	--	36	36	36	--	--
1	SB	--	--	36	36	--	--	--
2	EB	205	--	36	--	--	6	300
2	WB	550	--	36	--	--	6	300
2	NB	390	305	36	--	--	6	300
2	SB	380	275	36	--	--	6	300
3	EB	315	55	36	--	--	6	300
3	WB	200	140	36	--	--	6	300
3	NB	--	--	--	36	--	--	--
3	SB	--	--	--	36	--	--	--
4	EB	180	95	36	--	--	6	300
4	WB	200	140	36	--	--	6	300
4	NB	--	--	--	36	36	--	--
4	SB	--	--	36	36	--	--	--
5	EB	140	--	36	--	--	6	300
5	WB	110	--	36	--	--	6	300
5	NB	50	--	--	36	36	--	--
5	SB	--	--	--	36	--	--	--
6	EB	200	--	36	--	--	6	300
6	WB	250	200	36	--	--	6	300
6	NB	--	--	36	36	--	--	--
6	SB	--	--	36	36	--	--	--
7	EB	200	170	36	--	--	6	300
7	WB	180	160	36	--	--	6	300
7	NB	350	190	36	--	--	--	--
7	SB	500	--	36	--	--	--	--
8	EB	200	200	--	--	--	6	300
8	WB	200	200	--	--	--	6	300
8	NB	--	--	--	36	--	--	--
8	SB	--	--	--	36	--	--	--
9	EB	165	60	36	--	--	6	300
9	WB	140	140	36	--	--	6	300
9	NB	--	--	36	36	--	--	--
9	SB	--	--	--	36	--	--	--
10	EB	--	175	--	--	--	6	300
10	WB	130	--	36	--	--	6	300
10	SB	--	--	36	--	36	--	--
11	EB	180	--	36	--	--	6	300
11	WB	--	100	--	--	--	6	300
11	NB	--	--	36	--	36	--	--
12	EB	105	PREV	--	--	--	6	300
12	WB	--	--	--	--	--	6	300
12	NB	--	--	36	--	36	--	--
12	SB	--	--	--	36	--	--	--
13	NB	200	200	36	--	--	6	300
13	SB	200	200	36	--	--	6	300
13	EB	--	--	--	36	--	--	--
13	WB	--	--	--	36	--	--	--

14	NB	250	250	36	--	--	6	300
14	SB	250	250	36	--	--	6	300
14	EB	500	--	36	36	--	--	--
14	WB	500	--	36	36	36	--	--
15	NB	250	250	36	--	--	6	300
15	SB	250	250	36	--	--	6	300
15	EB	500	--	36	36	--	--	--
15	WB	500	--	36	36	--	--	--

NOTE: "PREV" DENOTES THAT THE TURNING BAY BEGINS AT THE PREVIOUS INTERSECTION.

Table C-11: Intersection Pocket Lengths and Detector Locations

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
1	EBLT	5	121	PRS
1	EBTH	2	118	PRS
1	WBLT	1	117	PRS
1	WBTH	6	122	PRS
1	NBLT	3	119	PRS
1	NBTH	8	124	PRS
1	NBRT	16	132	PRS
1	SBTH	7	123	PRS
1	SBTH	4	120	PRS

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
2	EBLT	5	205	PRS
2	EBTH	2	202	PRS
2	WBLT	1	201	PRS
2	WBTH	6	206	PRS
2	WBRT	14	214	PRS
2	NBLT	3	203	PRS
2	NBTH	8	208	PRS
2	SBLT	7	207	PRS
2	SBTH	4	204	PRS

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
3	EBLT	5	305	PRS
3	EBTH	2	302	PRS
3	WBLT	1	301	PRS
3	WBTH	6	306	PRS
3	NBTH	8	308	PRS
3	NBTH	16	316	PRS
3	SBTH	4	304	PRS
3	SBTH	12	312	PRS

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
4	EBLT	5	405	PRS
4	EBTH	2	402	PRS
4	WBLT	1	401	PRS
4	WBTH	6	406	PRS
4	NBTH	8	408	PRS
4	NBRT	16	416	PRS
4	SBLT	7	407	PRS
4	SBTH	4	404	PRS

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
5	EBLT	5	505	PRS
5	EBTH	2	502	PRS
5	WBLT	1	501	PRS
5	WBTH	6	506	PRS
5	NBTH	8	508	PRS
5	NBRT	16	516	PRS
5	SBTH	4	504	PRS
5	SBTH	12	512	PRS

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
6	EBLT	5	605	PRS
6	EBTH	2	602	PRS
6	WBLT	1	601	PRS
6	WBTH	6	606	PRS
6	NBLT	3	603	PRS
6	NBTH	8	608	PRS
6	SBLT	7	607	PRS
6	SBTH	4	604	PRS

INT	MOVE- MENT	DET NUM	STAT ID	PUL PRS
7	EBLT	5	705	PRS
7	EBTH	2	702	PRS
7	WBLT	1	701	PRS
7	WBTH	6	706	PRS
7	NBLT	3	703	PRS
7	NBTH	8	708	PRS
7	SBLT	7	707	PRS
7	SBTH	4	704	PRS

Table C-12: Intersection Detector Configuration (CID Logic Only)

INT	MOVE- MENT	DET NUM	LOCK / N-LCK	DELAY (SEC)	CALL PHASE	DETECTOR TYPE
1	EBLT	5	N-LCK	--	5	STANDARD (NORMAL)
1	EBTH	2	LOCK	--	2	STANDARD (NORMAL)
1	WBLT	1	N-LCK	--	1	STANDARD (NORMAL)
1	WBTH	6	LOCK	--	6	STANDARD (NORMAL)
1	NBLT	3	N-LCK	--	3	STANDARD (NORMAL)
1	NBTH	8	N-LCK	--	8	STANDARD (NORMAL)
1	NBRT	16	N-LCK	20	8	EXTEND / DELAY (T-1)
1	SBTH	7	N-LCK	--	7	STANDARD (NORMAL)
1	SBTH	4	N-LCK	10	4	EXTEND / DELAY (T-1)
2	EBLT	5	N-LCK	--	5	STANDARD (NORMAL)
2	EBTH	2	LOCK	--	2	STANDARD (NORMAL)
2	WBLT	1	N-LCK	--	1	STANDARD (NORMAL)
2	WBTH	6	LOCK	--	6	STANDARD (NORMAL)
2	WBRT	14	N-LCK	--	6	STANDARD (NORMAL)
2	NBLT	3	N-LCK	--	3	STANDARD (NORMAL)
2	NBTH	8	LOCK	--	8	STANDARD (NORMAL)
2	SBLT	7	N-LCK	--	7	STANDARD (NORMAL)
2	SBTH	4	LOCK	--	4	STANDARD (NORMAL)
3	EBLT	5	N-LCK	--	5	STANDARD (NORMAL)
3	EBTH	2	LOCK	--	2	STANDARD (NORMAL)
3	WBLT	1	N-LCK	--	1	STANDARD (NORMAL)
3	WBTH	6	LOCK	--	6	STANDARD (NORMAL)
3	NBTH	8	N-LCK	--	8	STANDARD (NORMAL)
3	NBTH	16	N-LCK	10	8	EXTEND / DELAY (T-1)
3	SBTH	4	N-LCK	--	4	STANDARD (NORMAL)
3	SBTH	12	N-LCK	10	4	EXTEND / DELAY (T-1)
4	EBLT	5	N-LCK	--	5	STANDARD (NORMAL)
4	EBTH	2	LOCK	--	2	STANDARD (NORMAL)
4	WBLT	1	N-LCK	--	1	STANDARD (NORMAL)
4	WBTH	6	LOCK	--	6	STANDARD (NORMAL)
4	NBTH	8	N-LCK	--	8	STANDARD (NORMAL)
4	NBRT	16	N-LCK	20	8	EXTEND / DELAY (T-1)
4	SBLT	7	N-LCK	--	7	STANDARD (NORMAL)
4	SBTH	4	N-LCK	10	4	EXTEND / DELAY (T-1)
5	EBLT	5	N-LCK	--	5	STANDARD (NORMAL)
5	EBTH	2	LOCK	--	2	STANDARD (NORMAL)
5	WBLT	1	N-LCK	--	1	STANDARD (NORMAL)
5	WBTH	6	LOCK	--	6	STANDARD (NORMAL)
5	NBTH	8	N-LCK	--	8	STANDARD (NORMAL)
5	NBRT	16	N-LCK	20	8	EXTEND / DELAY (T-1)
5	SBTH	4	N-LCK	--	4	STANDARD (NORMAL)
5	SBTH	12	N-LCK	10	4	EXTEND / DELAY (T-1)
6	EBLT	5	N-LCK	--	5	STANDARD (NORMAL)
6	EBTH	2	LOCK	--	2	STANDARD (NORMAL)
6	WBLT	1	N-LCK	--	1	STANDARD (NORMAL)
6	WBTH	6	LOCK	--	6	STANDARD (NORMAL)
6	NBLT	3	N-LCK	--	3	STANDARD (NORMAL)
6	NBTH	8	N-LCK	10	8	EXTEND / DELAY (T-1)
6	SBLT	7	N-LCK	--	7	STANDARD (NORMAL)
6	SBTH	4	N-LCK	10	4	EXTEND / DELAY (T-1)

7	EBLT	5	N-LCK	--	5	STANDARD (NORMAL)
7	EBTH	2	LOCK	--	2	STANDARD (NORMAL)
7	WBLT	1	N-LCK	--	1	STANDARD (NORMAL)
7	WBTH	6	LOCK	--	6	STANDARD (NORMAL)
7	NBLT	3	N-LCK	--	3	STANDARD (NORMAL)
7	NBTH	8	LOCK	--	8	STANDARD (NORMAL)
7	SBLT	7	N-LCK	--	7	STANDARD (NORMAL)
7	SBTH	4	LOCK	--	4	STANDARD (NORMAL)

Table C-13: Intersection Detector Configuration (Controller)

INT	MOVE- MENT	DETECTORS		DET NUM	STAT ID	LOC TLM	TLM ADD	SYS NUM	PUL PRS
		THRU	DIST						
14	SBTH	6	1725	9	209	2*	SDA1	1	PUL
14	SBTH	6	1725	11	211	2*	SDA2	2	PUL
13	SBTH	6	615	13	213	2*	SDB1	3	PRS
13	SBTH	6	615	15	215	2*	SDB2	4	PRS
2	NBTH	6	615	17	217	2	SDC1	5	PUL
2	NBTH	6	615	19	219	2	SDC2	6	PUL
2	EBTH	6	1050	10	210	2	SDD1	7	PUL
2	EBTH	6	1050	12	212	2	SDD2	8	PUL
5	EBTH	6	1000	9	509	5	SDA1	9	PRS
5	EBTH	6	1000	11	511	5	SDA2	10	PRS
7	WBTH	6	1800	9	709	7	SDA1	11	PUL
7	WBTH	6	1800	11	711	7	SDA2	12	PUL
8	WBTH	6	1978	13	713	7*	SDB1	13	PRS
8	WBTH	6	1978	15	715	7*	SDB2	14	PRS
8	EBTH	6	1641	17	717	7*	SDC1	15	PRS
8	EBTH	6	1641	19	719	7*	SDC2	16	PRS
11	NBTH	6	-380	10	710	7*	SDD1	17	PRS
12	WBTH	6	1370	12	712	7*	SDD2	18	PRS

NOTE: A "*" REPRESENTS THAT AN ALTERNATE ADDRESS WAS USED DUE TO HARDWARE.
NOTE: ALL DISTANCES WITHOUT A "-" ARE MEASURED FROM THE UPSTREAM INTERSECTION.

Table C-14: System Detector Configuration (CID Logic Only)

INT	DESCRIPTION (SEC)	1	2	3	4	5	6	7	8
1	MINIMUM GREEN	3	15	3	7	3	15	3	7
1	VEHICLE EXTENSION	2.5	5.0	2.5	3.0	2.5	5.0	2.5	3.0
1	MAXIMUM GREEN	25	120	25	55	25	120	25	55
1	YELLOW CLEARANCE	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
1	RED CLEARANCE	1.0	2.0	1.0	1.5	1.0	2.0	1.0	1.5
1	MINIMUM GAP TIME	2.5	3.0	2.5	3.0	2.5	3.0	2.5	3.0
2	MINIMUM GREEN	3	15	3	15	3	15	3	15
2	VEHICLE EXTENSION	2.5	5.0	2.5	5.0	2.5	5.0	2.5	5.0
2	MAXIMUM GREEN	35	85	35	85	35	85	35	85
2	YELLOW CLEARANCE	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
2	RED CLEARANCE	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0
2	MINIMUM GAP TIME	2.5	3.0	2.5	3.0	2.5	3.0	2.5	3.0
3	MINIMUM GREEN	3	15	--	7	3	15	--	7
3	VEHICLE EXTENSION	2.5	5.0	--	3.0	2.5	5.0	--	3.0
3	MAXIMUM GREEN	20	80	--	35	20	80	--	35
3	YELLOW CLEARANCE	3.5	3.5	--	3.5	3.5	3.5	--	3.5
3	RED CLEARANCE	1.0	2.0	--	1.5	1.0	2.0	--	1.5
3	MINIMUM GAP TIME	2.5	3.0	--	3.0	2.5	3.0	--	3.0
4	MINIMUM GREEN	3	15	--	7	3	15	3	7
4	VEHICLE EXTENSION	2.5	5.0	--	3.0	2.5	5.0	2.5	3.0
4	MAXIMUM GREEN	25	80	--	45	25	80	25	45
4	YELLOW CLEARANCE	3.5	3.5	--	3.5	3.5	3.5	3.5	3.5
4	RED CLEARANCE	1.0	2.0	--	1.5	1.0	2.0	1.0	1.5
4	MINIMUM GAP TIME	2.5	3.0	--	3.0	2.5	3.0	2.5	3.0
5	MINIMUM GREEN	3	15	--	3	3	15	--	3
5	VEHICLE EXTENSION	2.5	5.0	--	3.0	2.5	5.0	--	3.0
5	MAXIMUM GREEN	25	80	--	25	25	80	--	25
5	YELLOW CLEARANCE	3.5	3.5	--	3.5	3.5	3.5	--	3.5
5	RED CLEARANCE	1.0	2.0	--	1.5	1.0	2.0	--	1.5
5	MINIMUM GAP TIME	2.5	3.0	--	3.0	2.5	3.0	--	3.0
6	MINIMUM GREEN	3	15	3	7	3	15	3	7
6	VEHICLE EXTENSION	2.5	5.0	2.5	3.0	2.5	5.0	2.5	3.0
6	MAXIMUM GREEN	25	80	20	35	25	80	20	35
6	YELLOW CLEARANCE	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
6	RED CLEARANCE	1.0	2.0	1.0	1.5	1.0	2.0	1.0	1.5
6	MINIMUM GAP TIME	2.5	3.0	2.5	3.0	2.5	3.0	2.5	3.0
7	MINIMUM GREEN	3	15	3	7	3	15	3	7
7	VEHICLE EXTENSION	2.5	5.0	2.5	5.0	2.5	5.0	2.5	5.0
7	MAXIMUM GREEN	35	80	35	45	35	80	35	45
7	YELLOW CLEARANCE	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
7	RED CLEARANCE	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0
7	MINIMUM GAP TIME	2.5	3.0	2.5	3.0	2.5	3.0	2.5	3.0
8	MINIMUM GREEN	--	15	--	7	--	15	--	7
8	VEHICLE EXTENSION	--	5.0	--	3.0	--	5.0	--	3.0
8	MAXIMUM GREEN	--	80	--	25	--	80	--	25
8	YELLOW CLEARANCE	--	3.5	--	3.5	--	3.5	--	3.5
8	RED CLEARANCE	--	2.0	--	1.5	--	2.0	--	1.5
8	MINIMUM GAP TIME	--	3.0	--	3.0	--	3.0	--	3.0
9	MINIMUM GREEN	3	15	3	7	3	15	--	3
9	VEHICLE EXTENSION	2.5	5.0	2.5	3.0	2.5	5.0	--	3.0

9	MAXIMUM GREEN	25	80	25	35	25	80	--	35
9	YELLOW CLEARANCE	3.5	3.5	3.5	3.5	3.5	3.5	--	3.5
9	RED CLEARANCE	1.0	2.0	1.0	1.5	1.0	2.0	--	1.5
9	MINIMUM GAP TIME	2.5	3.0	2.5	3.0	2.5	3.0	--	3.0
10	MINIMUM GREEN	3	15	--	7	--	15	--	--
10	VEHICLE EXTENSION	2.5	5.0	--	3.0	--	5.0	--	--
10	MAXIMUM GREEN	25	80	--	45	--	80	--	--
10	YELLOW CLEARANCE	3.5	3.5	--	3.5	--	3.5	--	--
10	RED CLEARANCE	1.0	2.0	--	1.5	--	2.0	--	--
10	MINIMUM GAP TIME	2.5	3.0	--	3.0	--	3.0	--	--
11	MINIMUM GREEN	--	15	--	--	3	15	--	7
11	VEHICLE EXTENSION	--	5.0	--	--	2.5	5.0	--	3.0
11	MAXIMUM GREEN	--	80	--	--	55	80	--	45
11	YELLOW CLEARANCE	--	3.5	--	--	3.5	3.5	--	3.5
11	RED CLEARANCE	--	2.0	--	--	1.0	2.0	--	1.5
11	MINIMUM GAP TIME	--	3.0	--	--	2.5	3.0	--	3.0
12	MINIMUM GREEN	--	15	--	3	--	15	--	7
12	VEHICLE EXTENSION	--	5.0	--	3.0	--	5.0	--	3.0
12	MAXIMUM GREEN	--	80	--	12	--	80	--	35
12	YELLOW CLEARANCE	--	3.5	--	3.5	--	3.5	--	3.5
12	RED CLEARANCE	--	2.0	--	1.5	--	2.0	--	1.5
12	MINIMUM GAP TIME	--	3.0	--	3.0	--	3.0	--	3.0
13	MINIMUM GREEN	3	15	--	7	3	15	--	7
13	VEHICLE EXTENSION	2.5	5.0	--	3.0	2.5	5.0	--	3.0
13	MAXIMUM GREEN	25	80	--	35	25	80	--	35
13	YELLOW CLEARANCE	3.5	3.5	--	3.5	3.5	3.5	--	3.5
13	RED CLEARANCE	1.0	2.0	--	1.5	1.0	2.0	--	1.5
13	MINIMUM GAP TIME	2.5	3.0	--	3.0	2.5	3.0	--	3.0
14	MINIMUM GREEN	3	15	3	7	3	15	3	7
14	VEHICLE EXTENSION	2.5	5.0	2.5	3.0	2.5	5.0	2.5	3.0
14	MAXIMUM GREEN	45	120	45	55	45	120	45	55
14	YELLOW CLEARANCE	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
14	RED CLEARANCE	1.0	2.0	1.0	1.5	1.0	2.0	1.0	1.5
14	MINIMUM GAP TIME	2.5	3.0	2.5	3.0	2.5	3.0	2.5	3.0
15	MINIMUM GREEN	3	15	3	7	3	15	3	7
15	VEHICLE EXTENSION	2.5	5.0	2.5	3.0	2.5	5.0	2.5	3.0
15	MAXIMUM GREEN	35	120	35	65	35	120	35	65
15	YELLOW CLEARANCE	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
15	RED CLEARANCE	1.0	2.0	1.0	1.5	1.0	2.0	1.0	1.5
15	MINIMUM GAP TIME	2.5	3.0	2.5	3.0	2.5	3.0	2.5	3.0

NOTE: THE MAXIMUM GREEN TIMINGS SHOWN IN THIS TABLE ARE INHIBITED UNDER COORDINATION.

Table C-15: General Phase Parameters (SR 26 – South)

INT	COS	CYC	OFF	1	2	3	4	5	6	7	8	LAG
1	111	140	0	12	80	12	36	12	80	17	31	
1	211	100	0	12	54	12	22	12	54	12	22	
1	311	150	0	14	72	12	52	12	74	19	45	
1	411	160	0	15	91	12	42	12	94	19	35	
1	511	160	0	13	108	12	27	12	109	13	26	
2	111	140	18	30	36	18	56	18	48	35	39	
2	211	100	4	18	42	18	22	18	42	18	22	
2	311	150	6	28	47	18	57	19	56	33	42	
2	411	160	5	31	60	18	51	18	73	35	34	
2	511	160	19	29	48	18	65	18	59	47	36	1,3
3	111	140	120	12	106	--	22	12	106	--	22	
3	211	100	30	12	66	--	22	12	66	--	22	
3	311	150	144	12	116	--	22	16	112	--	22	
3	411	160	147	12	126	--	22	16	122	--	22	
3	511	160	117	12	126	--	22	20	118	--	22	
4	111	140	132	13	93	--	34	12	94	12	22	
4	211	100	44	12	54	--	34	12	54	12	22	
4	311	150	147	15	101	--	34	12	104	12	22	
4	411	160	153	18	108	--	34	12	114	12	22	
4	511	160	142	14	112	--	34	12	114	12	22	
5	111	140	13	12	84	--	22	12	84	--	22	
5	211	100	56	12	44	--	22	12	44	--	22	
5	311	150	148	12	94	--	22	12	94	--	22	
5	411	160	9	12	104	--	22	12	104	--	22	
5	511	160	159	12	104	--	22	12	104	--	22	
6	111	140	76	12	94	12	22	12	94	12	22	
6	211	100	46	12	54	12	22	12	54	12	22	
6	311	150	63	12	104	12	22	12	104	12	22	
6	411	160	73	12	114	12	22	12	114	12	22	
6	511	160	85	12	114	12	22	12	114	12	22	
7	111	140	74	21	62	26	31	18	65	27	30	
7	211	100	96	18	40	15	27	18	40	20	22	
7	311	150	83	19	53	34	44	18	54	38	40	
7	411	160	85	33	58	36	33	18	73	37	32	
7	511	160	83	29	64	25	42	18	75	39	28	1
8	111	140	49	--	118	--	22	--	118	--	22	
8	211	100	24	--	78	--	22	--	78	--	22	
8	311	150	36	--	128	--	22	--	128	--	22	
8	411	160	49	--	138	--	22	--	138	--	22	
8	511	160	67	--	138	--	22	--	138	--	22	
9	111	140	0	18	88	12	22	18	88	--	34	
9	211	100	64	18	48	12	22	18	48	--	34	
9	311	150	138	18	98	12	22	18	98	--	34	
9	411	160	2	18	108	12	22	18	108	--	34	
9	511	160	11	18	108	12	22	18	108	--	34	
10	111	140	113	18	100	--	22	--	118	--	--	
10	211	100	32	18	60	--	22	--	78	--	--	
10	311	150	105	18	110	--	22	--	128	--	--	
10	411	160	123	18	119	--	23	--	137	--	--	
10	511	160	139	18	115	--	27	--	133	--	--	

11	111	140	121	--	116	--	--	30	86	--	24	
11	211	100	88	--	78	--	--	19	59	--	22	
11	311	150	117	--	128	--	--	45	83	--	22	
11	411	160	149	--	99	--	--	42	57	--	61	
11	511	160	142	--	117	--	--	59	58	--	43	
12	111	140	134	--	106	--	12	--	106	--	22	
12	211	100	0	--	66	--	12	--	66	--	22	
12	311	150	142	--	115	--	12	--	115	--	23	
12	411	160	157	--	126	--	12	--	126	--	22	
12	511	160	159	--	123	--	12	--	123	--	25	
13	111	140	14	20	94	--	26	18	96	--	26	
13	211	100	89	18	60	--	22	18	60	--	22	
13	311	150	149	14	114	--	22	12	116	--	22	
13	411	160	117	19	110	--	31	12	117	--	31	
13	511	160	122	24	112	--	24	12	124	--	24	
14	111	140	61	18	77	12	33	22	73	18	27	
14	211	100	46	18	39	12	31	18	39	12	31	
14	311	150	63	21	67	12	50	22	66	29	33	
14	411	160	64	18	84	12	46	36	66	20	38	
14	511	160	79	24	66	12	58	19	71	35	35	1
15	111	140	84	18	65	12	45	20	63	12	45	
15	211	100	12	18	33	12	37	18	33	12	37	
15	311	150	91	23	56	12	59	19	60	13	58	
15	411	160	68	19	77	12	52	25	71	12	52	
15	511	160	73	36	66	12	46	18	84	12	46	

NOTE: OFFSETS ARE REFERENCED FROM THE BEGINNING OF THE FIRST COORDINATED PHASE.

Table C-16: SR 26 (South) Coordination Plans and Splits

STP	PRG	DAY	TIME	COS	SF1	SF2	SF3	SF4	TRP	OVR
1	1	M-F	0600	211	OFF	OFF	OFF	OFF	YES	NO
2	1	M-F	0900	111	OFF	OFF	OFF	OFF	YES	NO
3	1	M-F	1500	311	OFF	OFF	OFF	OFF	YES	NO
4	1	M-F	1800	111	OFF	OFF	OFF	OFF	YES	NO
5	1	M-F	2300	FREE	OFF	OFF	OFF	OFF	YES	NO
6	2	SAT	0730	111	OFF	OFF	OFF	OFF	YES	NO
7	2	SAT	2200	FREE	OFF	OFF	OFF	OFF	YES	NO
8	3	SUN	0900	111	OFF	OFF	OFF	OFF	YES	NO
9	3	SUN	2000	FREE	OFF	OFF	OFF	OFF	YES	NO

NOTE: TRP AS "YES" ENABLES THE TRAFFIC RESPONSIVE (TRP) PLAN AS "PLAN-IN-EFFECT".
NOTE: OVR AS "YES" ALLOWS TRP TO OVERRIDE TOD IF THE CYCLE COMMAND IS GREATER.

Table C-17: Time of Day Programming Chart (SR 26 – South)

TLM ADD	CTR 1-24	SDA1 1-32	SDA2 1-32	SDB1 1-32	SDB2 1-32	SDC1 1-32	SDC2 1-32	SDD1 1-32	SDD2 1-32
1	1	0	0	0	0	0	0	0	0
2	2	1	2	3	4	5	6	7	8
3	3	0	0	0	0	0	0	0	0
4	4	0	0	0	0	0	0	0	0
5	5	9	10	0	0	0	0	0	0
6	6	0	0	0	0	0	0	0	0
7	7	11	12	13	14	15	16	17	18

NOTE: SYSTEM DETECTORS ARE WIRED TO THE NEAREST LOCAL CONTROLLER.
NOTE: THE NUMBERS ABOVE ARE THE ACTUAL MASTER SYSTEM DETECTOR NUMBERS.

Table C-18: System Detector Mapping Table (Master Controller)

GROUP SETTINGS	1	2	3	4	5	6	7	8
ASSIGN SD TO LANE 1	1	5	7	11	17	0	0	0
ASSIGN SD TO LANE 2	2	6	8	12	18	0	0	0
ASSIGN SD TO LANE 3	3	9	15	13	0	0	0	0
ASSIGN SD TO LANE 4	4	10	16	14	0	0	0	0
DETECTORS REQUIRED	3	3	3	3	2	N/A	N/A	N/A
ASSIGN TO LEVEL	N/A	N/A	2	2	N/A	N/A	N/A	N/A
ASSIGN TO DIRECTION 1	N/A	2	2	N/A	N/A	N/A	N/A	N/A
ASSIGN TO DIRECTION 2	N/A	N/A	N/A	2	2	N/A	N/A	N/A
ASSIGN TO SPLIT A	N/A	N/A	AV	AV	N/A	N/A	N/A	N/A
ASSIGN TO SPLIT B	AV	N/A						
ASSIGN TO ARTERIAL	N/A	N/A	2	2	N/A	N/A	N/A	N/A
ASSIGN TO NON-ARTERIAL	2	N/A						

NOTE: SYSTEM DETECTORS ONLY FUNCTION DURING TRAFFIC RESPONSIVE (TRP) OPERATION.

Table C-19: Traffic Responsive Programming (System Detectors)

FUNCTION COMPUTATIONS	LEV	DR1	DR2	SPA	SPB	ART	NRT
TRAFFIC PARAMETER	CON						
VALUE OF THE GROUPS	1	1	1	2	2	AV	AV
SMOOTHING FACTOR (%)	30	30	30	30	30	30	30
UPDATE THRESHOLD (%)	20	40	40	20	20	20	20

NOTE: SAMPLE PERIODS FOR THIS STUDY WAS ONCE PER CYCLE (TRAFFIC RESPONSIVE).
NOTE: CON = CONCENTRATION WHICH INCLUDES BOTH VOLUME AND OCCUPANCY FUNCTIONS.

Table C-20: System Detector Function Computations (SR 26 – South)

LEVEL (0-101%)		OFFSET (0-100%)		SPLIT (0-101%)		NRT-ART (0-100%)	
2>1	12	1>AV	5	2>1	10	NRT>ART	15
1>2	25	AV>1	10	1>2	20	ART>NRT	35
3>2	45	2>AV	5	3>2	20		
2>3	55	AV>2	10	2>3	30		
4>3	101			4>3	30		
3>4	101			3>4	40		
5>4	101						
4>5	101						

NOTE: LEVEL AND SPLITS ARE OMITTED BY ENTERING A PERCENTAGE GREATER THAN 100%.

Table C-21: System Thresholds for Plan Selection (SR 26 – South)

LEVEL	DESCRIPTION	CLR	COS	SF1	SF2	SF3	SF4
LEVEL 1	DIRECTION 1 (DR1)	NO	FREE	OFF	OFF	OFF	OFF
LEVEL 1	DIRECTION 2 (DR2)	NO	FREE	OFF	OFF	OFF	OFF
LEVEL 1	AVERAGE (AV)	NO	FREE	OFF	OFF	OFF	OFF
LEVEL 1	NRT-ART (NRT/ART)	NO	FREE	OFF	OFF	OFF	OFF
LEVEL 2	DIRECTION 1 (DR1)	NO	311	OFF	OFF	OFF	OFF
LEVEL 2	DIRECTION 2 (DR2)	NO	211	OFF	OFF	OFF	OFF
LEVEL 2	AVERAGE (AV)	NO	111	OFF	OFF	OFF	OFF
LEVEL 2	NRT-ART (NRT/ART)	NO	511	OFF	OFF	OFF	OFF
LEVEL 3	DIRECTION 1 (DR1)	NO	311	OFF	OFF	OFF	OFF
LEVEL 3	DIRECTION 2 (DR2)	NO	411	OFF	OFF	OFF	OFF
LEVEL 3	AVERAGE (AV)	NO	511	OFF	OFF	OFF	OFF
LEVEL 3	NRT-ART (NRT/ART)	NO	511	OFF	OFF	OFF	OFF
LEVEL 4	DIRECTION 1 (DR1)	YES	CLR	OFF	OFF	OFF	OFF
LEVEL 4	DIRECTION 2 (DR2)	YES	CLR	OFF	OFF	OFF	OFF
LEVEL 4	AVERAGE (AV)	YES	CLR	OFF	OFF	OFF	OFF
LEVEL 4	NRT-ART (NRT/ART)	YES	CLR	OFF	OFF	OFF	OFF
LEVEL 5	DIRECTION 1 (DR1)	YES	CLR	OFF	OFF	OFF	OFF
LEVEL 5	DIRECTION 2 (DR2)	YES	CLR	OFF	OFF	OFF	OFF
LEVEL 5	AVERAGE (AV)	YES	CLR	OFF	OFF	OFF	OFF
LEVEL 5	NRT-ART (NRT/ART)	YES	CLR	OFF	OFF	OFF	OFF

NOTE: SYSTEM DETECTORS ONLY FUNCTION DURING TRAFFIC RESPONSIVE (TRP) OPERATION.

Table C-22: Traffic Responsive Plan Selection Chart (SR 26 – South)

NODE	NODE_1		NODE_2		NODE_3		NODE_4		NODE_5		NODE_7	
	TOD	TRP										
8:00	111	411	111	411	111	411	111	411	111	411	111	411
8:05	111	411	111	411	111	411	111	411	111	411	111	411
8:10	111	411	111	411	111	411	111	411	111	411	111	411
8:15	111	TRN										
8:20	111	TRN										
8:25	111	111	111	111	111	111	111	111	111	TRN	111	TRN
8:30	111	111	111	111	111	111	111	111	111	111	111	111
8:35	111	111	111	111	111	111	111	111	111	111	111	111
8:40	111	111	111	111	111	111	111	111	111	111	111	111
8:45	111	111	111	111	111	111	111	111	111	111	111	111
8:50	111	111	111	111	111	111	111	111	111	111	111	111
8:55	111	111	111	111	111	111	111	111	111	111	111	111
9:00	111	111	111	111	111	111	111	111	111	111	111	111
9:05	111	111	111	111	111	111	111	111	111	111	111	111
9:10	111	111	111	111	111	111	111	111	111	111	111	111
9:15	111	111	111	111	111	111	111	111	111	111	111	111
9:20	111	111	111	111	111	111	111	111	111	111	111	111
9:25	111	111	111	111	111	111	111	111	111	111	111	111
9:30	111	111	111	111	111	111	111	111	111	111	111	111
9:35	111	111	111	111	111	111	111	111	111	111	111	111
9:40	111	111	111	111	111	111	111	111	111	111	111	111
9:45	111	111	111	111	111	111	111	111	111	111	111	111
9:50	TRN	TRN	311	TRN	TRN	TRN	TRN	TRN	311	111	311	111
9:55	311	TRN										
10:00	311	111	311	111	311	TRN	311	TRN	311	TRN	311	TRN
10:05	311	TRN										
10:10	311	TRN	311	TRN	311	311	311	TRN	311	TRN	311	TRN
10:15	311	311	311	311	311	311	311	311	311	311	311	311
10:20	311	311	311	311	311	311	311	311	311	311	311	311
10:25	311	311	311	311	311	311	311	311	311	311	311	311
10:30	311	311	311	311	311	311	311	311	311	311	311	311
10:35	311	311	311	311	311	311	311	311	311	311	311	311
10:40	311	311	311	311	311	311	311	311	311	311	311	311
10:45	TRN	311	311	311	TRN	311	TRN	311	TRN	311	TRN	311
10:50	TRN	311	TRN	311	111	311	TRN	311	TRN	311	TRN	311
10:55	111	TRN										
11:00	111	TRN	111	111	111	111	111	111	111	111	111	111
SYNC	89%	76%	92%	76%	89%	80%	89%	73%	89%	72%	93%	79%

Table C-23: SR 26 (South) / US 52 – Pattern Table – Typical Day (Run_1)

NODE	NODE_1		NODE_2		NODE_3		NODE_4		NODE_5		NODE_7	
	TOD	TRP										
8:00	111	411	111	411	111	411	111	411	111	411	111	411
8:05	111	411	111	411	111	411	111	411	111	411	111	411
8:10	111	TRN	111	TRN	111	411	111	411	111	411	111	TRN
8:15	111	211	111	211	111	211	111	211	111	TRN	111	211
8:20	111	TRN										
8:25	111	TRN										
8:30	111	TRN										
8:35	111	411	111	TRN								
8:40	111	411	111	411	111	411	111	411	111	411	111	411
8:45	111	411	111	411	111	411	111	411	111	411	111	411
8:50	111	411	111	411	111	411	111	411	111	411	111	411
8:55	111	411	111	411	111	411	111	411	111	411	111	411
9:00	111	411	111	411	111	411	111	411	111	411	111	411
9:05	111	411	111	411	111	411	111	411	111	411	111	411
9:10	111	411	111	411	111	411	111	411	111	411	111	411
9:15	111	411	111	411	111	411	111	411	111	411	111	411
9:20	111	411	111	TRN								
9:25	111	TRN										
9:30	111	111	111	TRN	111	111	111	111	111	111	111	111
9:35	111	111	111	111	111	111	111	111	111	111	111	111
9:40	111	111	111	111	111	111	111	111	111	111	111	111
9:45	111	111	111	111	111	111	111	111	111	111	TRN	111
9:50	TRN	111	311	111	TRN	111	TRN	111	311	111	311	111
9:55	311	111	311	111	311	111	311	111	311	111	311	111
10:00	311	TRN	311	111								
10:05	311	TRN	311	311	311	311	311	TRN	311	TRN	311	TRN
10:10	311	311	311	311	311	311	311	311	311	311	311	311
10:15	311	311	311	311	311	311	311	311	311	311	311	311
10:20	311	311	311	TRN	311	311	311	311	311	311	311	311
10:25	311	TRN										
10:30	311	511	311	511	311	511	311	511	311	511	311	TRN
10:35	311	511	311	511	311	511	311	511	311	511	311	511
10:40	311	511	311	511	311	511	311	511	311	511	311	511
10:45	311	511	311	511	TRN	511	TRN	511	TRN	511	TRN	511
10:50	TRN	511	TRN	511	111	511	TRN	511	TRN	511	111	511
10:55	111	511	111	511	111	511	111	511	111	511	111	511
11:00	111	511	111	511	111	511	111	511	111	511	111	511
SYNC	90%	73%	92%	67%	91%	73%	89%	66%	86%	67%	93%	67%

Table C-24: SR 26 (South) / US 52 – Pattern Table – Event Day (Run_1)

NODE NUMBER	NODE_1		NODE_2		NODE_3	
OPERATION	TOD	TRP	TOD	TRP	TOD	TRP
TYPICAL	89	76	92	76	89	80
EVENT DAY	90	73	92	67	91	73

NODE NUMBER	NODE_4		NODE_5		NODE_7	
OPERATION	TOD	TRP	TOD	TRP	TOD	TRP
TYPICAL	89	73	89	72	93	79
EVENT DAY	89	66	86	67	93	67

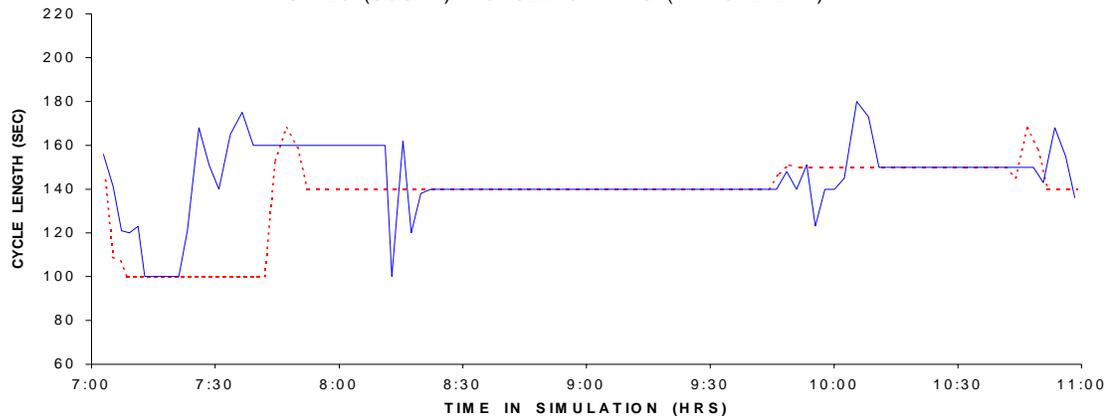
Table C-25: SR 26 (South) US 52 – Percent In-Sync (%) Table – Run_1

TIME-OF-DAY	NODE_1		NODE_2		NODE_3	
TYPICAL / EVENT	TYP	EVT	TYP	EVT	TYP	EVT
RUN_1 (TOD)	89	90	92	92	89	91
RUN_2 (TOD)	89	91	92	93	92	91
RUN_3 (TOD)	91	92	92	89	91	89
RUN_4 (TOD)	91	91	91	90	91	91
RUN_5 (TOD)	91	91	91	90	91	91

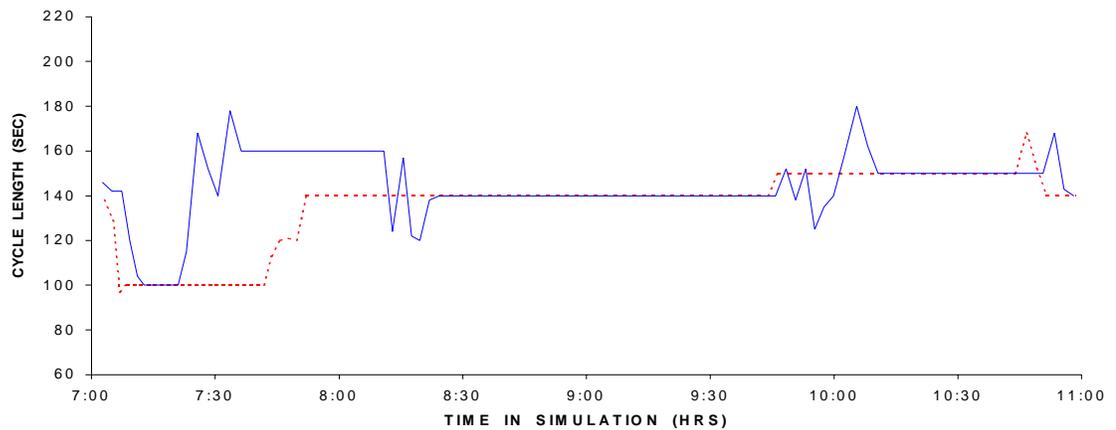
TIME-OF-DAY	NODE_4		NODE_5		NODE_7	
TYPICAL / EVENT	TYP	EVT	TYP	EVT	TYP	EVT
RUN_1 (TOD)	89	89	89	86	93	93
RUN_2 (TOD)	88	90	80	86	92	94
RUN_3 (TOD)	89	89	93	94	94	93
RUN_4 (TOD)	87	86	85	82	95	94
RUN_5 (TOD)	88	91	90	94	94	93

Table C-26: SR 26 (South) US 52 – Percent In-Sync (%) Table – All Runs

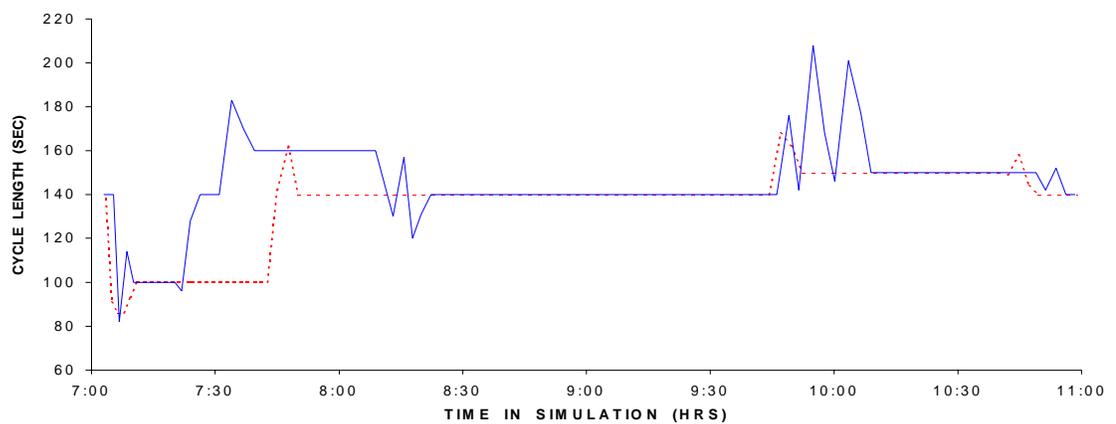
COMPARISON OF TRANSITIONING ALGORITHMS (RUN_1)
 SR 26 (SOUTH) - CYCLE GRAPHS (TYPICAL DAY)



a) Node 1: SR 26 & Earl Avenue



b) Node 2: SR 26 & US 52 (Sagamore)

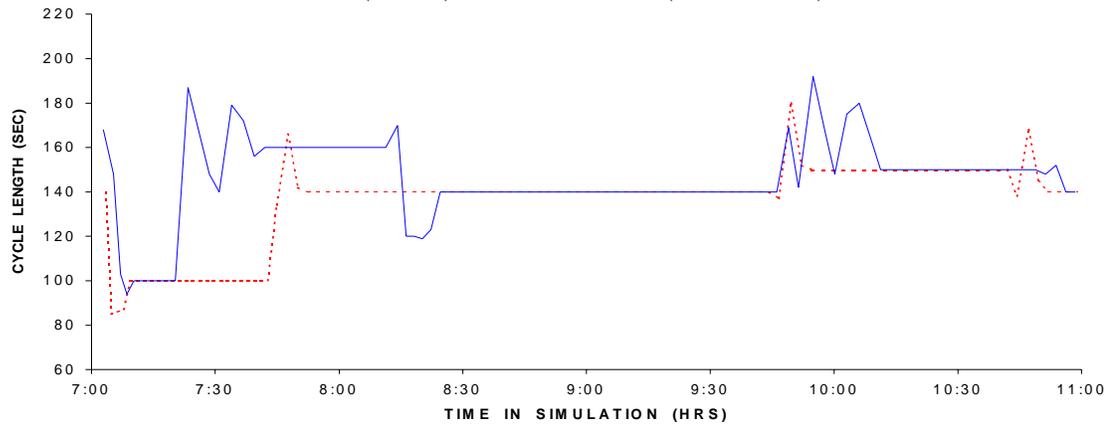


--- TIME OF DAY (TOD) — TRAFFIC RESPONSIVE (TRP)

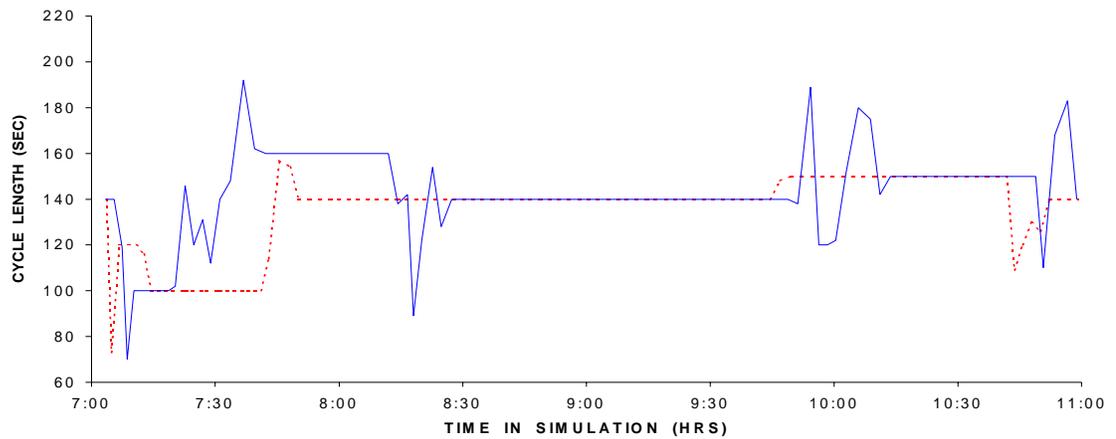
c) Node 3: SR 26 & Post Office

Figure C-9: SR 26 (South) System Cycle Graphs – Typical Day

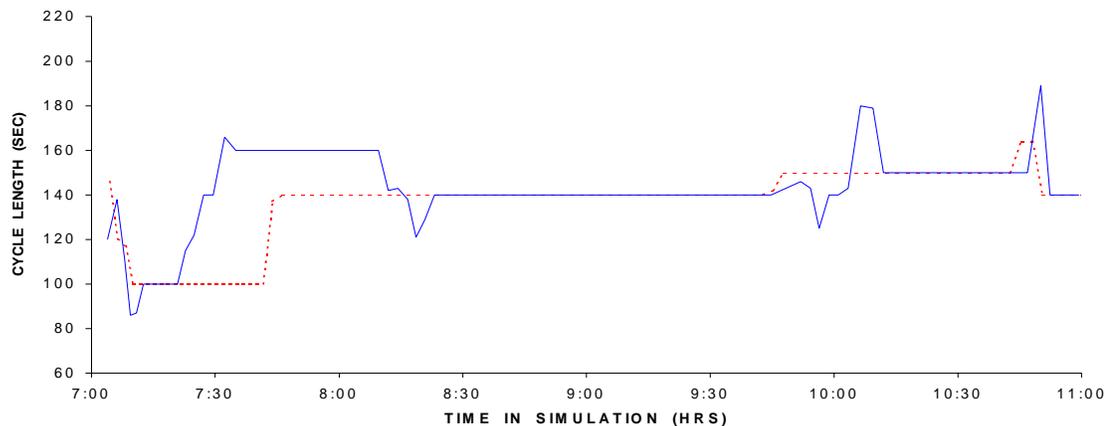
COMPARISON OF TRANSITIONING ALGORITHMS (RUN_1)
 SR 26 (SOUTH) - CYCLE GRAPHS (TYPICAL DAY)



a) Node 4: SR 26 & Farabee Drive



b) Node 5: SR 26 & 36th Street

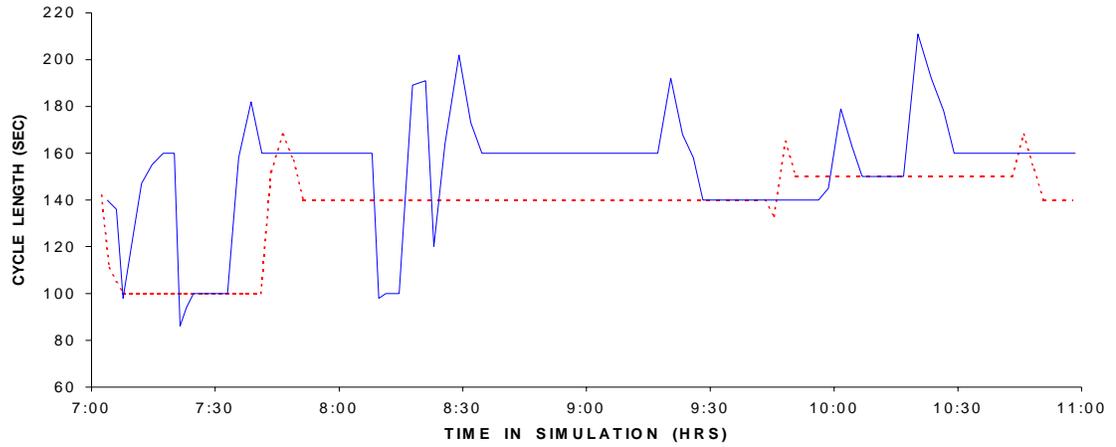


--- TIME OF DAY (TOD) — TRAFFIC RESPONSIVE (TRP)

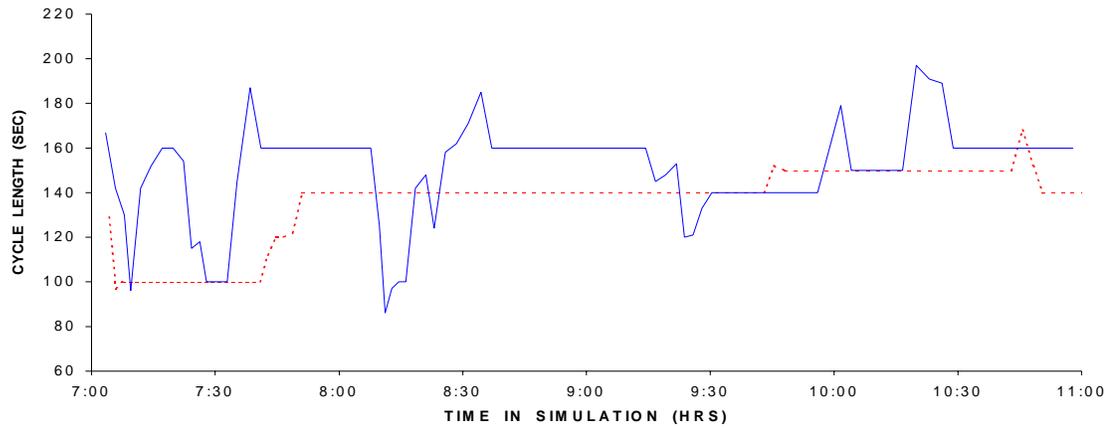
c) Node 7: SR 26 & Creasy Lane

Figure C-10: SR 26 (South) System Cycle Graphs – Typical Day

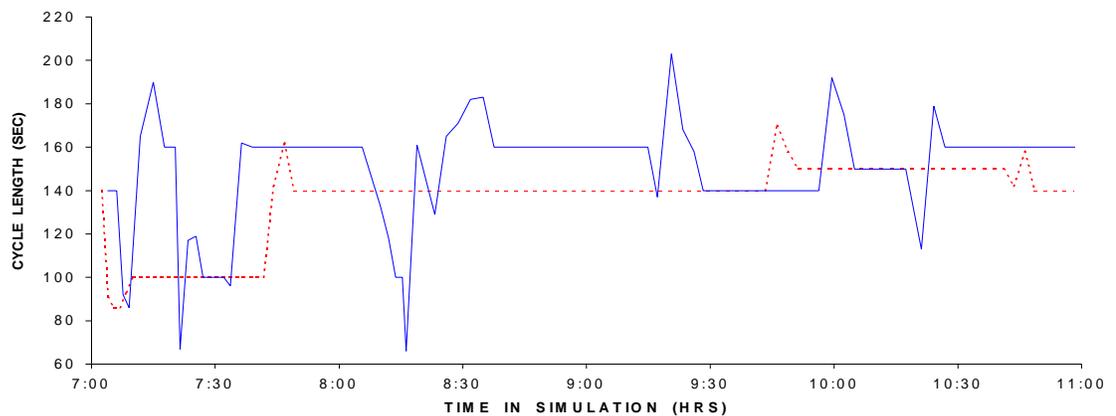
COMPARISON OF TRANSITIONING ALGORITHMS (RUN_1)
SR 26 (SOUTH) - CYCLE GRAPHS (EVENT DAY)



a) Node 1: SR 26 & Earl Avenue



b) Node 2: SR 26 & US 52 (Sagamore)

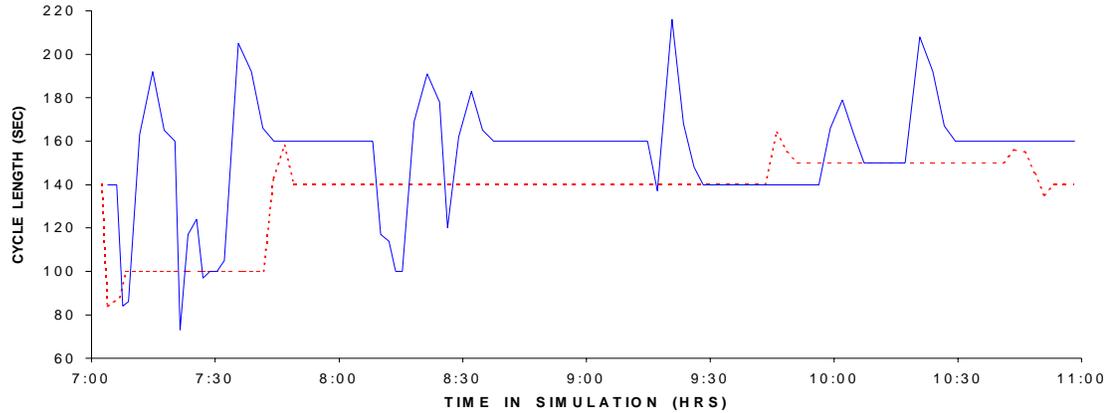


--- TIME OF DAY (TOD) — TRAFFIC RESPONSIVE (TRP)

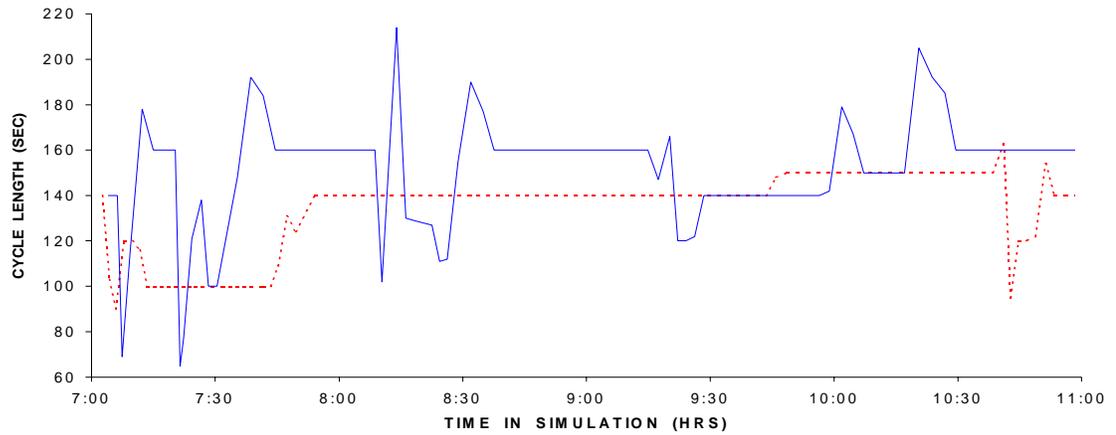
c) Node 3: SR 26 & Post Office

Figure C-11: SR 26 (South) System Cycle Graphs – Event Day

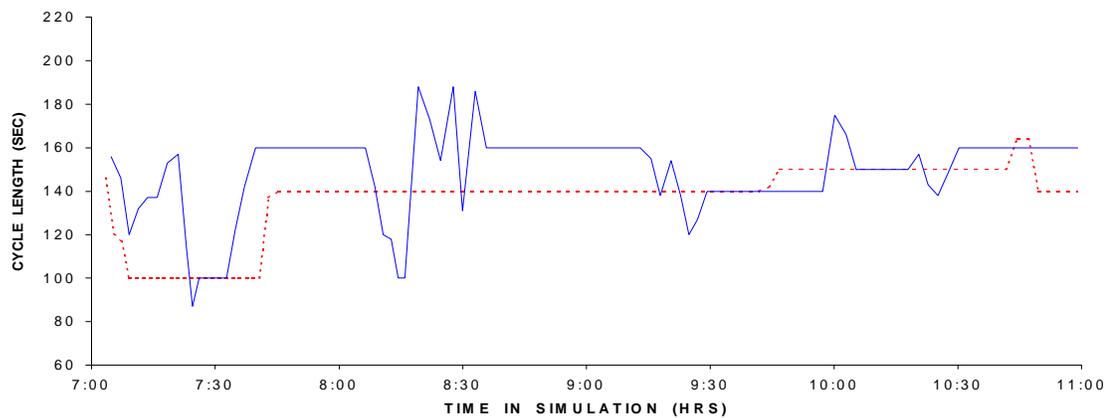
COMPARISON OF TRANSITIONING ALGORITHMS (RUN_1)
 SR 26 (SOUTH) - CYCLE GRAPHS (EVENT DAY)



a) Node 4: SR 26 & Farabee Drive



b) Node 5: SR 26 & 36th Street



--- TIME OF DAY (TOD) — TRAFFIC RESPONSIVE (TRP)

c) Node 7: SR 26 & Creasy Lane

Figure C-12: SR 26 (South) System Cycle Graphs – Event Day