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Automatic Turning Movements Identification System: Intersection Error Analysis

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Automatic Turning Movements Identification System

Intersection Error Analysis

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Final Report

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Automatic Turning Movements Identification System

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ABSTRACT

To lessen congestion at intersections, traffic identification systems are placed at roadway intersections in order to collect vehicle data. These traffic identification systems include various types of detectors that can identify the presence of vehicles in real-time. However, these detectors can only detect their presence and not their turning movements. To fix this issue, The University of Akron has developed a program that can automatically identify vehicle turning movements and is called the Automatic Turning Movement Identification System, or ATMIS. ATMIS uses mathematical algorithms to compute the vehicle's turning movements based on a sink and feed detector paring. During traffic simulations while using ATMIS, it was found that it could not adequately compute certain vehicle behaviors and turning movements resulting in output errors. To determine the specific traffic events that are causing the output errors in ATMIS, traffic simulations were conducted on two different geometric intersections in Traffic in Cities Simulation Model, VISSIM, software. The turning movements accurately calculated by ATMIS and also the turning movement output errors were recorded and analyzed for both intersection simulations. Once all ATMIS errors were identified in the output, the simulations were conducted once again for a further in depth analysis of each error. Simulations were altered to a slower rate in order to analyze and visually capture each individual turning movement error. The error information was documented and organized in such a way to recommend possible solutions to increase the accuracy of the ATMIS software.

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NOMENCLATURE

- ATMIS – Automatic Turning Movement Identification System
- TMI – Turning Movements Identification
- EB – Eastbound
- ER – Eastbound Right Turn
- EL – Eastbound Left Turn
- ET – Eastbound Thru
- SB – Southbound
- SR – Southbound Right Turn
- SL – Southbound Left Turn
- ST – Southbound Thru
- NB – Northbound
- NR – Northbound Right Turn
- NL – Northbound Left Turn
- NT – Northbound Thru
- WB – Westbound
- WR – Westbound Right Turn
- WL – Westbound Left Turn
- WT – Westbound Thru
- VIP – Video Image Processors
- LOS – Level of Service

DATA TABLE COLOR LENGEND

Table Color Legend						
Accident	Lane Change	Loop Time Expiration	Turning Conflict	Ran Red Signal	Right Turn	Unknown

1.0 INTRODUCTION

1.1 Traffic Identification Systems

Congestion is a major concern for traffic engineers. The basic mobility problem that many municipalities face is that current roads do not have enough capacity to handle peak hour traffic without forcing the commuters into congestion. Some of the ways congestion can be alleviated are by building new roads, ramp metering, creating more HOV lanes, utilizing more public transportation, and implementing intelligent transportation devices (Downs, 2004). Most of these methods can be very costly, which is why it is important for municipalities to choose the appropriate methods accordingly. One way to do this is to implement traffic identification systems. By using traffic identification systems, signalized intersection efficiency can be increased and vehicle crashes can be reduced. Dead-time traffic can also be reduced and real time traffic data can be obtained by using traffic identification systems.

An intersection with a traffic identification system is known as an intelligent intersection, or an intersection that has a detector structure that senses an oncoming vehicle into the interchange and tells the signal's controller about the vehicle's presence in order to change the signal from red to green (Muench, 2006). There are several types of devices/applications used to classify an intersection as an intelligent intersection, each of which have their own advantages and disadvantages when compared to each other.

1.1.1 Inductive Loop Detectors

There are many different types of detectors that are currently in use today. One of the most common types is the inductive loop detection system, which can provide information such as volume, speed, headway, and gaps (VDC, 2000). A simple schematic diagram can be seen in *Figure 1*. When a vehicle crosses over the detector, which is buried under the roadway pavement, the loop detector loses its inductance. This occurs because the vehicle induces eddy currents in the wires in the loop (FHWA, 2006). The lower inductance in the loop triggers the electronic output relay to send an electronic pulse to the controller to signal the presence of a vehicle (FHWA, 2006).

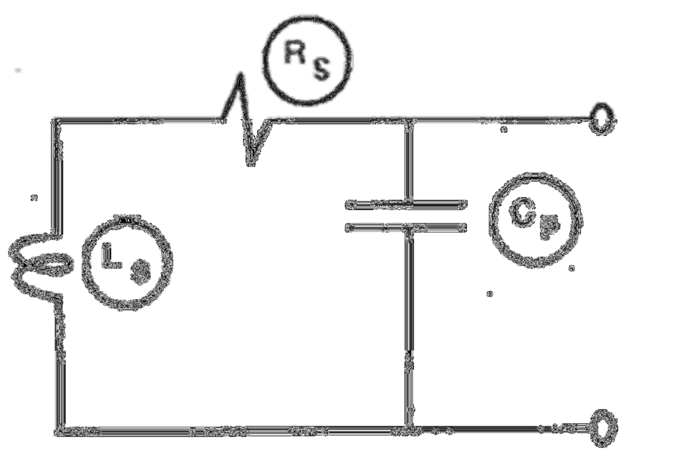

Figure 1: Schematic Diagram of an Inductive Loop Detector (Muench, 2006)

To install a loop detector, multiple pavement cuts are required (VDC, 2000). As shown in *Figure 2*, the sawcut plan is a box like shape that contains separate cuts to round out each of the corners. A trench leading to an electrical pullbox must accompany each inductive loop in order to feed the signal to the controller cabinet.

After being installed, the pavement life in and around each loop detector has been found to decrease over time (VDC, 2000). Installation and maintenance of each loop detector also requires lane closures, which can cause traffic delays at busy intersections, and the wires within the loop detectors can become weathered under extreme temperatures (VDC, 2000). This method requires each traffic lane to have its own loop detector in order for the controller cabinet to identify the presence of all vehicles in the intersection.

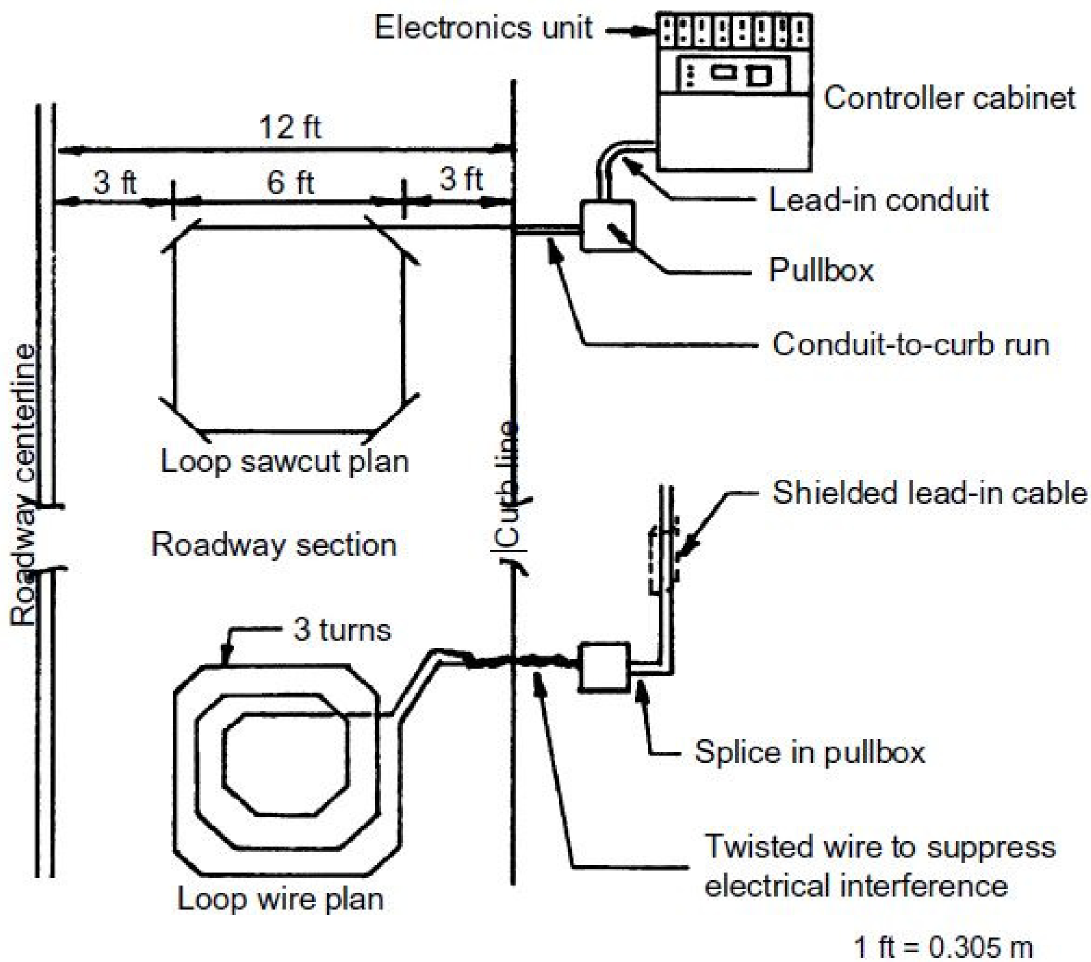

Figure 2: Inductive Loop Detector Sawcut Plan (VDC, 2000)

1.1.2 Magnetic Detectors

Magnetometers and magnetic inductions can also be used at signalized intersections. Currently the Federal Highway Administration, FHWA, allows two types of magnetic field sensors, the two-axis fluxgate magnetometer and the search coil magnetometer (FHWA, 2006). The difference between these two magnetic induction sensors are that the two-axis fluxgate magnetometer has the capability to detect stopped and moving vehicles, while the search coil magnetometer only detects moving vehicles (FHWA, 2006). These magnetic sensors indicate the presence of a metallic object by detecting the perturbation, or energy shift, in the Earth's magnetic field that was caused by the metallic object (VDC, 2000).

Figure 3 displays how the magnetic detector interacts when a vehicle is on the detector. The vector addition of the dipole magnetic fields of a metallic object, the vehicle, with the Earth's magnetic field produces a perturbation effect, or an energy shift (VDC, 2000).

These detectors have longer life spans compared to loop detectors and can be placed in locations such as bridge decks where loop detectors cannot (VDC, 2000). However, magnetic detectors require pavement cuts which shorten pavement similarly to inductive loop detectors. Because these detectors are constructed underneath the pavement, lane closures are needed for placement and maintenance of these detectors.

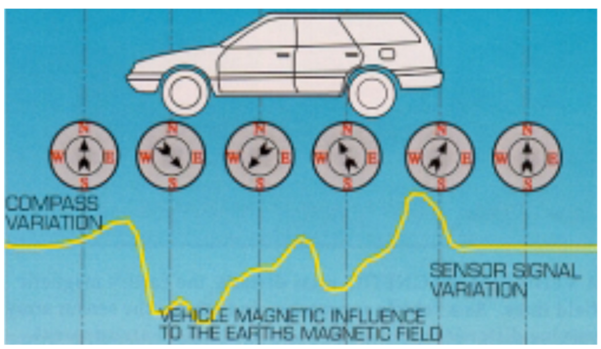

Figure 3: Vehicle's Reaction to Magnetic Detectors (VDC, 2000)

1.1.3 Video Image Processors

Video Image Processors, or VIPs, were developed as an alternative to inductive and magnetic detectors (VDC, 2000). VIPs are cameras attached above ground to the signal pole, meaning these systems do not interfere with an intersection's pavement. A VIP usually consists of three components: cameras set up to observe the traffic, a microprocessor computer to digitize the images from the camera, and software that converts the images to usable traffic data (VDC, 2000). VIPs detect the changes between consecutive frames in the camera images based on built-in algorithms that analyze the color imagery. This is how a VIP can differentiate between pavement and a vehicle (VDC, 2000). The user determines the placement of detection zones that are within the view of the camera (FHWA, 2006). *Figure 4* shows what a VIP looks like and the image that a VIP produces. In *Figure 4*, the red boxes are the user created detector zones where the VIP is sensing the presence of a vehicle.

Figure 4: Video Image Processors (Muench, 2006)

VIPs can detect vehicles in multiple lanes and provide lots of data such as speed, presence and classification (VDC, 2000). However, VIPs can be very costly, and their results can be greatly affected by the weather (FHWA, 2006). Snow, ice, and shadows caused by sunsets and sunrises and greatly affect the accuracy of VIP systems. Also, the placement of VIPs can affect the efficiency of the unit. When placed high atop signal poles, wind can become an issue and cause blurred images that the microprocessor cannot interpret. The direction in which the cameras aim can also change the results. When a VIP camera is pointed upstream to traffic, traffic incidents are not blocked by traffic queues, but tall trucks and buses can block the camera's sight (FHWA, 2006). Headlight beams in other travel lanes can also be accidentally detected when the road section is on a curve and can cause processing errors (FHWA, 2006).

1.1.4 Microwave, Ultrasonic Wave, and Thermal Detection

Another type of system that can be used to implement traffic identification systems uses microwave, infrared, or ultrasonic waves. These systems are attached above ground to the signal poles and can have better performance in varying weather compared to VIPs (VDC, 2000).

Microwave detection uses Doppler radar sensors to determine a vehicle's presence. The microwave radar projects a microwave beam toward the roadway and the reflector waves are measured based on their speed and angle to determine the vehicle's position and speed when crossing the microwave projection area (Smartmicro, 2015). Because of the necessity for the radar to measure the speed and angle change of the reflection waves for each vehicle, it is difficult for a microwave detector to detect stopped vehicles (VDC, 2000). *Figure 5* shows a microwave detector unit. The unit head can be attached atop a signal pole or atop an overhead sign to obtain traffic counts, presence detection, speeds, or queuing lengths.

Figure 5: Microwave Detection Unit (Smartmicro, 2015)

Ultrasonic detectors work similarly to microwave detectors. Ultrasonic detectors identify vehicles by the arrival time difference between waves being reflected off the roadway back to the detector unit and off a vehicle and back to the detector unit (Sumitomo Electric Group, 2012). This process is shown in *Figure* 6. The ultrasonic waves take a longer time to bounce off the pavement and back to the unit as opposed to bouncing off a vehicle.

Ultrasonic detectors can have difficulty at low visibilities such as during a snowstorm or fog, are sensitive to changes in temperatures, and have difficulty effectively measuring vehicles traffic at high speeds (VDC, 2000). Ultrasonic detectors are used for presence detection for both moving and stopped vehicles.

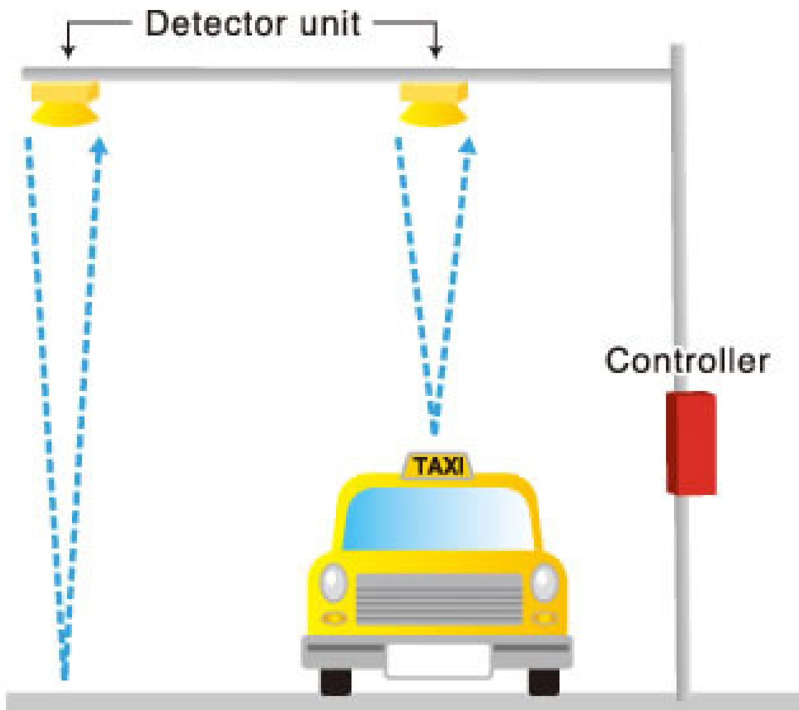

Figure 6: Ultrasonic Detectors (Sumitomo Electric Group, 2012)

Infrared or thermal traffic sensors are installed just like VPIs. Instead of sending photo imaging to the processor, the thermal traffic sensors send thermal images to the processor which then relays the message of a vehicle presence to the traffic controller cabinet (FLIR, 2013). A thermal image that these detectors create is shown in *Figure 7*. The detector zones that are highlighted in a white hue in *Figure 7* are the detector zones that are currently activated. The detectors that have a black hue are the detectors that are not activated.

Figure 7: Thermal Traffic Sensors Image (FLIR, 2013)

These units are placed atop of a traffic signal pole in a similar fashion to a VPI unit. A thermal traffic sensor camera is shown in *Figure 8*. These detectors are not affected by sunlight glare, darkness, headlights, or varying weather conditions and can distinguish the difference between a vehicle, bicycle, and even an animal (FLIR, 2013).

Figure 8: Thermal Traffic Sensor Camera (FLIR, 2013)

1.1.5 Bluetooth Detection

Newer technologies such as bluetooth vehicle tracking have begun to be introduced to the market. One of the newest detector technologies is Trafficast's Bluetooth Travel-time Origination and Destination, or BlueTOAD, detector. BlueTOAD collects the Media Access Control, or MAC, addresses from Bluetooth enabled devices such as cell phones, headsets, navigation devices while the vehicle travels past these detectors (Trafficast, 2012). Once the Bluetooth device is detected by another BlueTOAD detector, the MAC address is sent to a server that matches that specific MAC address from the first BlueTOAD detector the vehicle had driven past (Trafficast, 2012). *Figure 9* shows the installation of a BlueTOAD detector on a sign post. These detectors can be installed on sign posts, light poles, or other poles along the roadway.

Figure 9: Trafficast's BlueTOAD Installation (Trafficast, 2012)

The average speeds across the road segments are derived from the two time stamps of the two different BlueTOAD detectors. The speeds are then plotted on a map to update the user of real time travel times as part of the Intelligent Transportation System, ITS (Trafficast, 2012). The BlueTOAD detectors are also useful when determining a roadway's Level of Service, also known as LOS.

1.2 Problem Description

Most of the applications mentioned above can give real time data to a signal controller about the presence of a vehicle at a signalized intersection. However, these detector systems do not give real time turning movement information. Currently, turning movement data at intersections are obtained manually with handheld devices like the one shown in *Figure 10.* They can be collected either in the field or by video imaging produced by various types of detectors. Whether counted in the field or via video imaging, manual turning movement counts are tedious, labor intensive, time consuming, and expensive (Mao, 2009).

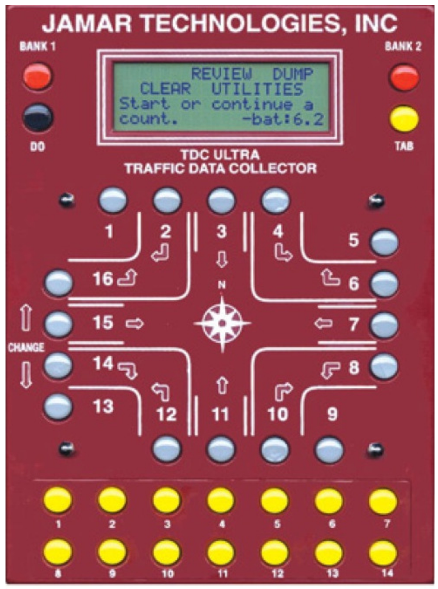

Figure 10: Handheld Traffic Counter (JAMAR Technologies, 2010)

In order to bridge the gap between real time information that the detectors provide and the inability to obtain accurate real time turning movement data, The University of Akron has developed a system called Automatic Turning Movement Identification System, or ATMIS. ATMIS, which provides real time turning movement data regardless of geometric layout, can take video feed detection from a signalized intersection and distinguish various turning movements within the intersection (Mao, 2009). Although the ATMIS software has proven it can detect and count vehicle turning movements, it has been found that results have had accuracy issues and cannot be analyzed unless volume data from existing detectors are present.

While running several traffic simulations of different geometric layouts in VISIM software, ATMIS recorded turning movements of the vehicles passing through the intersection. During the simulation, many errors occurred in ATMIS’s output. Up to this point, there has been no further examination of the errors outputted by ATMIS. In order to increase the accuracy of the ATMIS software, the errors must be evaluated. If the errors can be found and examined, there is a chance the software’s programming can be altered to correct such errors.

2.0 OBJECTIVE

The primary objective of this project is to identify and analyze output errors that occurred during simulations. Once the ATMIS output errors are identified, the specific turning movements and traffic events are examined thoroughly. After documented, proper recommendations can be made in an effort to correct any errors and increase traffic count accuracy. All results will be reported to the traffic department staff and the attempt to fix such errors can proceed accordingly.

3.0 APPLICATIONS

3.1 Automatic Turning Movements Identification System

ATMIS, developed by the Transportation Laboratory of The University of Akron, is a program that identifies vehicle turning movements automatically in different geometric and traffic control conditions (The University of Akron, 2014). The system, which is designed to be independent of the geometric layout of the intersection, “includes shared lanes and irregular intersection configurations, and is calibrated to tolerate a certain level of detections error” (Yi, Shao, & Mao, 2010). By developing a real-time system, which can automatically collect movement information at signalized intersections and determine its exact movements, the need of manual traffic counting becomes limited (The University of Akron, 2014). Analyzing data via computer software will help produce quicker and more efficient information.

3.1.1 ATMIS Algorithm

ATMIS uses a mathematical algorithm to track the turning movements of vehicles. To get a better understanding of how the algorithm and ATMIS software correlate with each other, a general setup of a four way intersection is shown in *Figure 11.* Detector boxes 1, 2, 3, and 4 are all inbound feed detectors. When a vehicle crosses one of these four detectors, the loop opens and it remains open until the vehicle crosses an outbound sink detector. Outbound detectors are the gray boxes number 5, 6, 7, and 8. For example, when looking at detector 4, a feed detector, there are three legal turning movements the vehicle can make. The three movements are thru, left, or right. As long as the vehicle makes a legal turning movement, the algorithm will be able to match detector 4 to detectors 5, 6, or 7. If the vehicle were to make a thru movement and pass over detector 6, then the algorithm will output a matched turning movement of ET. This process is repeated for every vehicle that makes a legal turning movement and its data is put into an output in a Microsoft Excel file. If a vehicle does not make a legal turning movement, an error will occur and the output will entail a time stamp when the detector was interrupted.

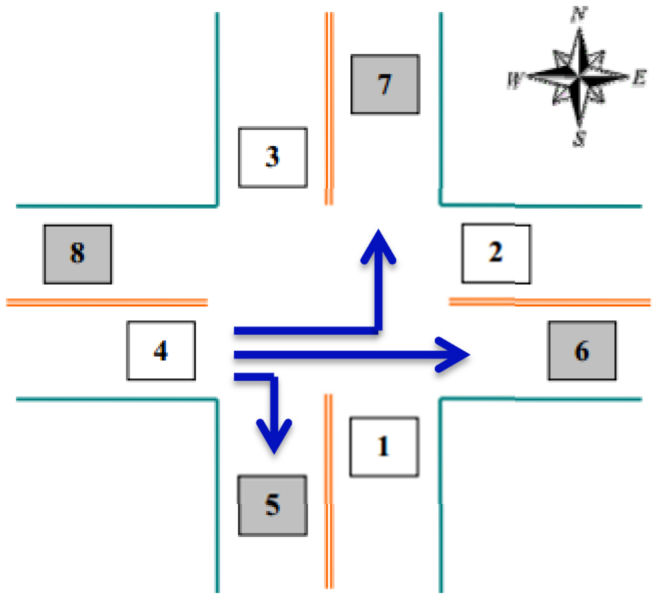

Figure 11: Detector Configuration for a Four-Leg One-Lane Intersection (Yi, 2010)

3.1.2 ATMIS Detection Flowchart

When detectors are placed at each inbound and outbound lane at an existing intersection, ATMIS software can track the turning movements based on a mathematical algorithm (Mao, 2009). When a vehicle approaches an intersection, the incoming detector is activated and attempts to create a match to the vehicle's appropriate outgoing lane detector. After a vehicle makes a complete turning movement (right turning movement, left turning movement, or thru movement), the data is then processed through the algorithm. By cycling through a series of questions, the turning movement data continues through the cycle until it finds the correct match. A flow chart that the turning movement data uses to find its correct movement match is shown in *Figure 12*.

The algorithm can produce three outcomes: output matched movement, no output, and multiple matches process (Mao, 2009). The desired output from the flow chart is a matched movement, which signifies the program recorded a successful turning movement and has outputted it correctly (Mao, 2009). If the time limit is reached and the movement is still not matched, the algorithm produces an error and no output is determined (Mao, 2009). In certain situations, the algorithm may get confused and may find multiple turning movement matches (Mao, 2009). In this case, the algorithm again outputs an error and the detection is not recorded (Mao, 2009).

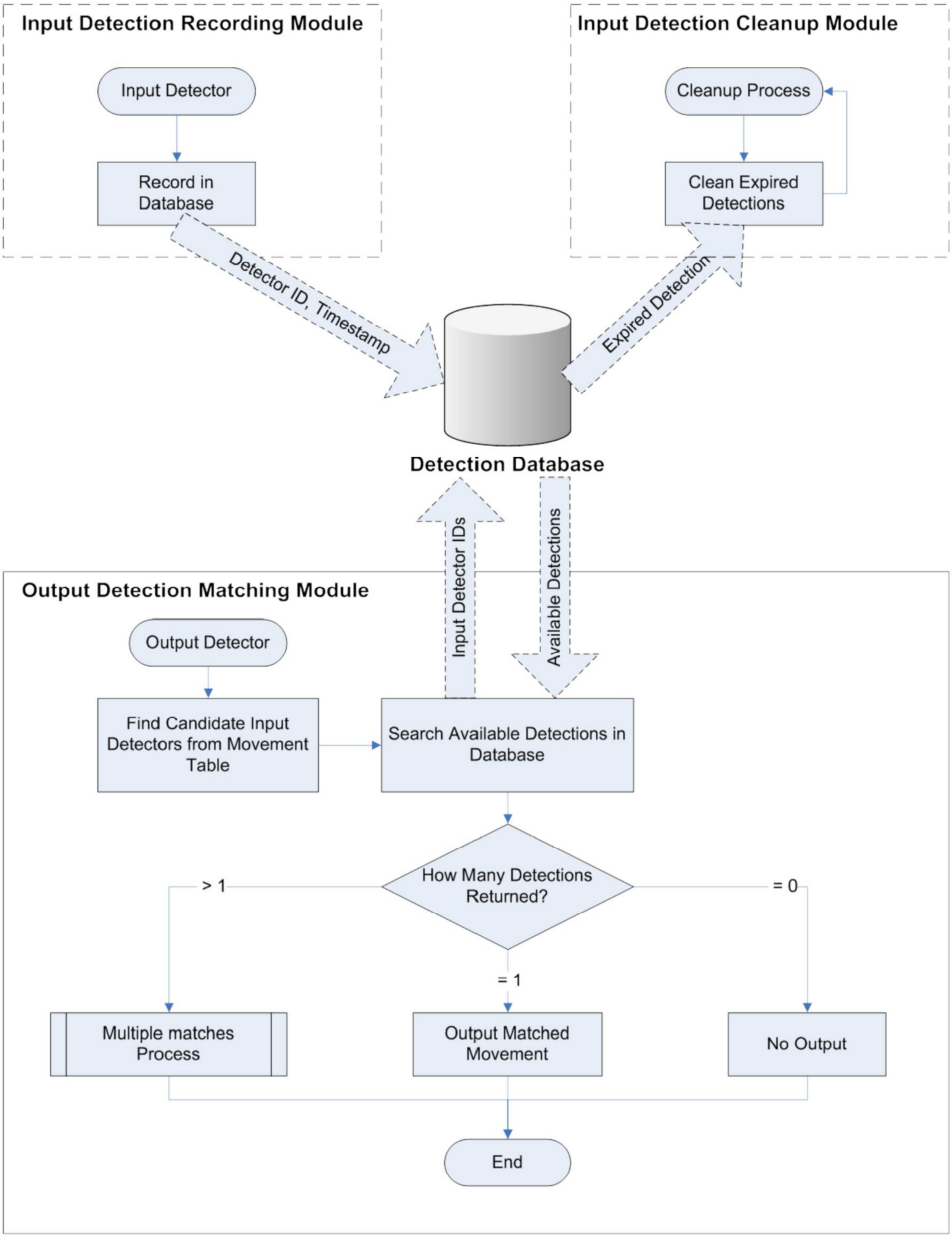

Figure 12: ATMIS Algorithm Flowchart (Mao, 2009)

3.1 VISSIM

VISSIM software was released in the year of 1992 and was developed for traffic management and control (Doina, 2007). It is a “microscopic, time step, and behavior based simulation model developed to model urban traffic and public transit operations” (Doina, 2007). VISSIM can be used for several tasks such as junction geometry, motorway traffic, simulations of public transport, emissions modeling, active traffic management, and multimodal systems (PTV Group, 2015). For this particular project, VISSIM was used to simulate vehicle traffic through an intersection. By adding timed traffic signals within the intersection, simulations could be developed to impersonate real time traffic movements. VISSIM intersection geometric arrangements can be found in Section 6.0 Simulations & Results.

4.0 ASSUMPTIONS

Many assumptions were made for the test simulations analyzed on the Turning Movement software. First and foremost, it was assumed that some errors detected were made by vehicle driving errors. When the simulations were created, they were programmed to take into account that drivers do not always obey the law and sometimes make illegal turning movements. Another assumption made was that the simulations would produce sufficient errors within time durations of 1800 seconds (30 minutes) with a traffic flow of nearly 1200 vehicles. A time period of thirty minutes was assumed to be adequate time to collect sufficient turning movement errors in a dense intersection. The traffic density allowed the simulation to establish a queue at each approach way and allowed for an analysis that demonstrated real life situations. Applying a high flow rate such as 1200 vehicles allowed for vehicles to make several turning movements and detect many errors in a short amount of time. It can also be noted that conditions such as weather were assumed to be in dry weather environments and did not play a factor in any of the errors detected.

5.0 APPROACH

Like any other project, background information was needed first in order to analyze the data efficiently and for the project to be fully understood. The first task accomplished consisted of understanding the ATMIS software programming. Created at the University of Akron, the programming applies the algorithm, which identifies the various turning movements. The C++ programming was viewed and some of the coding was depicted in order to get introduced to the VISSIM software. VISSIM was used to run traffic simulations and allow the turning movement program to collect all vehicle movement data. Several days were spent learning the VISSIM software and how it would be applied to our research project. Learning the features and tools VISSIM provided allowed for proper examination of the error outputs calculated by ATMIS.

Once the background information was fully understood, the simulations were then run. Simulations were run on VISSIM software while displaying the vehicle turning movements within the intersection. Once the simulations were completed, all the data collected by the turning movement program was converted into a Microsoft Excel spreadsheet. All errors were separated and filed into separate spreadsheets. For each error detected, the detector at which the error occurred and the time at which the error occurred were recorded. Each error was analyzed individually and was observed at the appropriate time again in the VISSIM software. At the specific times at which the errors occurred, the speed of the simulation was slowed to a tenth of a second in order to obtain screen shots to get a better understanding of the vehicle movements. Each error was observed in order to get a full understanding of why errors were being detected.

6.0 SIMULATIONS & RESULTS

6.1 Laboratory Simulations

6.1.1 Intersection #1 – 4-Way Intersection with Designated Turning Lanes

The first intersection simulation in the VISSIM software was a 4-way intersection, as shown in *Figures 13 and 14*. The green arrows in *Figure 13* represent the traffic coming into the intersection and the red arrows represent the traffic leaving the intersection. *Figure 14* shows the intersection design and permitted movements of the intersection. In *Figure 14*, the detectors in green identify the traffic going into the intersection and the detectors in red identify the traffic leaving the intersection. Detector 1 measures the SB traffic turning right. The only allowable feed/sink detector combination for Detector 1 is a 1 to 14 movement, representing SR turning movements. Detectors 2 and 3 measure the SB traffic conducting a ST movement. Detectors 2 and 3's feed/sink detector pairings are Detectors 12 and 13, respectfully. Detector 4 is in a left turn only lane for SB traffic. It measures a 4 to 11 SL turning movement. Detector 5 counts all traffic going WB into the intersection. A 5 to 9 movement measures a WR turning movement. A 5 to 14 movement measures a WT movement, and a 5 to 12 detector combination measures a WL turning movement. Detector 6 measures NB traffic either making a thru and right movement. A feed/sink detector combination of 6 to 11 measures a NR movement, and a 6 to 9 movement processes a NT movement. Detector 7 only permitted a legal movement of 7 to 14, which computes the NB turning movements. Detector 8 computes all EB traffic going into the intersection. An 8 to 12 feed/sink detector combination measures ER turning movements, 8 to 11 combination measures ET movements, and 8 to 10 movements computes EL turning movements. No other feed/sink detector combinations are measurable in ATMIS in this simulation.

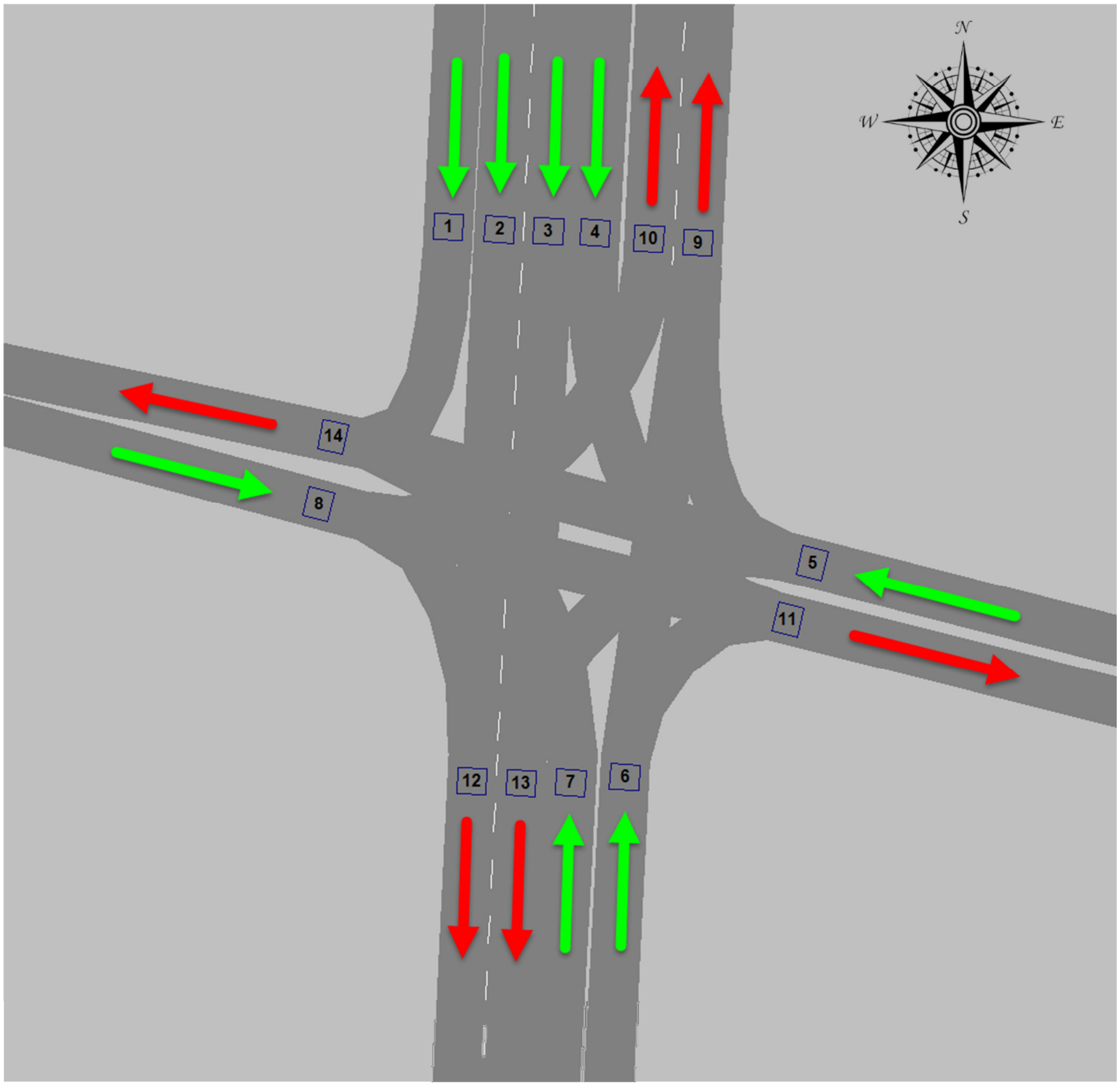

Figure 13: Intersection #1 Aerial Layout

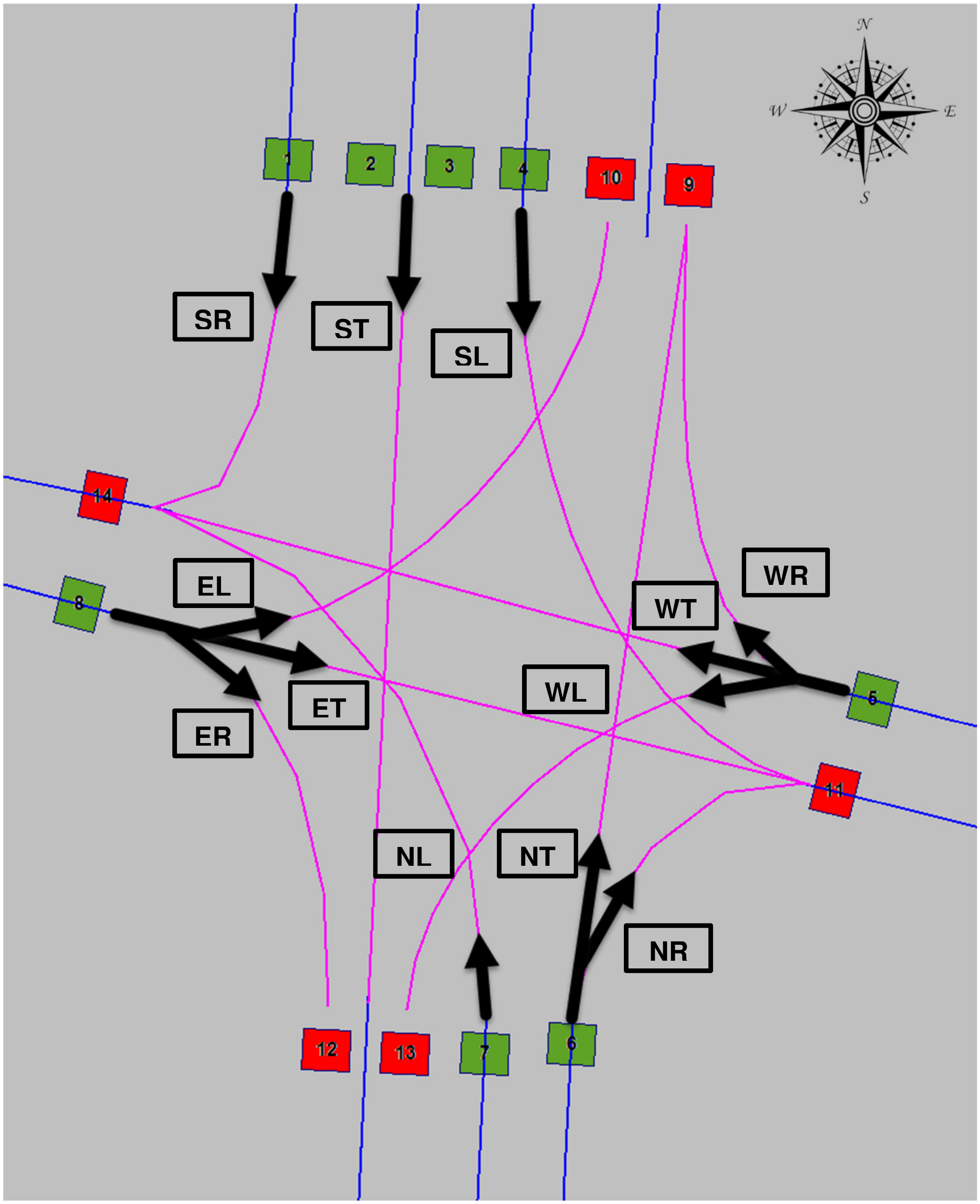

Figure 14: Intersection #1 Detector and Turning Design

6.1.2 Intersection #2 – 4-Way Intersection without Turning Lanes

The second intersection simulation in the VISSIM software is a 4-way intersection shown in *Figures 15 and 16*. The green arrows in *Figure 15* represent the traffic coming into the intersection and the red arrows represent the traffic leaving the intersection. In this intersection, there are no dedicated turning lanes. *Figure 16* shows the intersection design and permitted movements of the intersection. In *Figure 16*, the detectors in green identify the traffic going into the intersection and the detectors in red identify the traffic leaving the intersection. Detector 1 has two possible turning movement outcomes. A 1 to 12 feed/sink combination represents a NR movement while a 1 to 10 movement represents a NT movement. Detector 2 also has two possible turning movement outcomes. Vehicles entering detector 2 can either have a 2 to 6 feed/sink detector combination representing a NL movement or a 2 to 9 combination signifying a NT movement. Detector 11 measures all WB traffic going into the intersection. An 11 to 10 feed/sink detector combination signifies a WR movement. An 11 to 6 combination represents WT, and an 11 to 3 feed/sink combination represents a WL turning movement. Vehicles entering Detector 8 have two possible outcomes. An 8 to 12 feed/sink combination signifies a SL movement and an 8 to 3 combination represents a ST turning movement. At Detector 7, a 7 to 6 combination measures a SR movement, and a 7 to 4 detector combination represents a ST turning movement. All traffic going EB into the intersection passes through Detector 5. At Detector 5, a 5 to 9 feed/sink combination represents an EL movement, a 5 to 12 pairing signifies an ET movement, and a 5 to 4 combination measures ER turning movements.

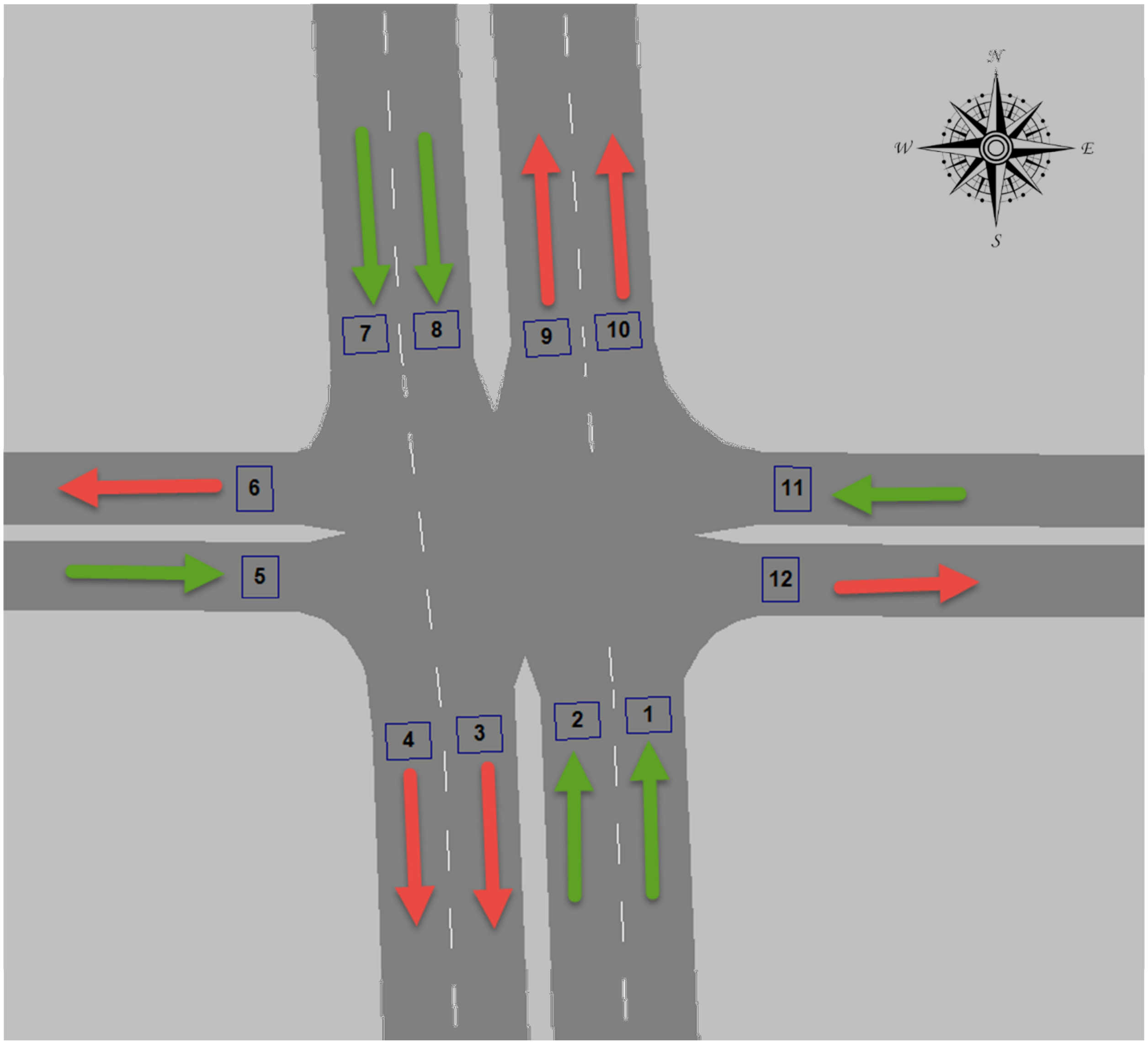

Figure 15: Intersection #2 Aerial Layout

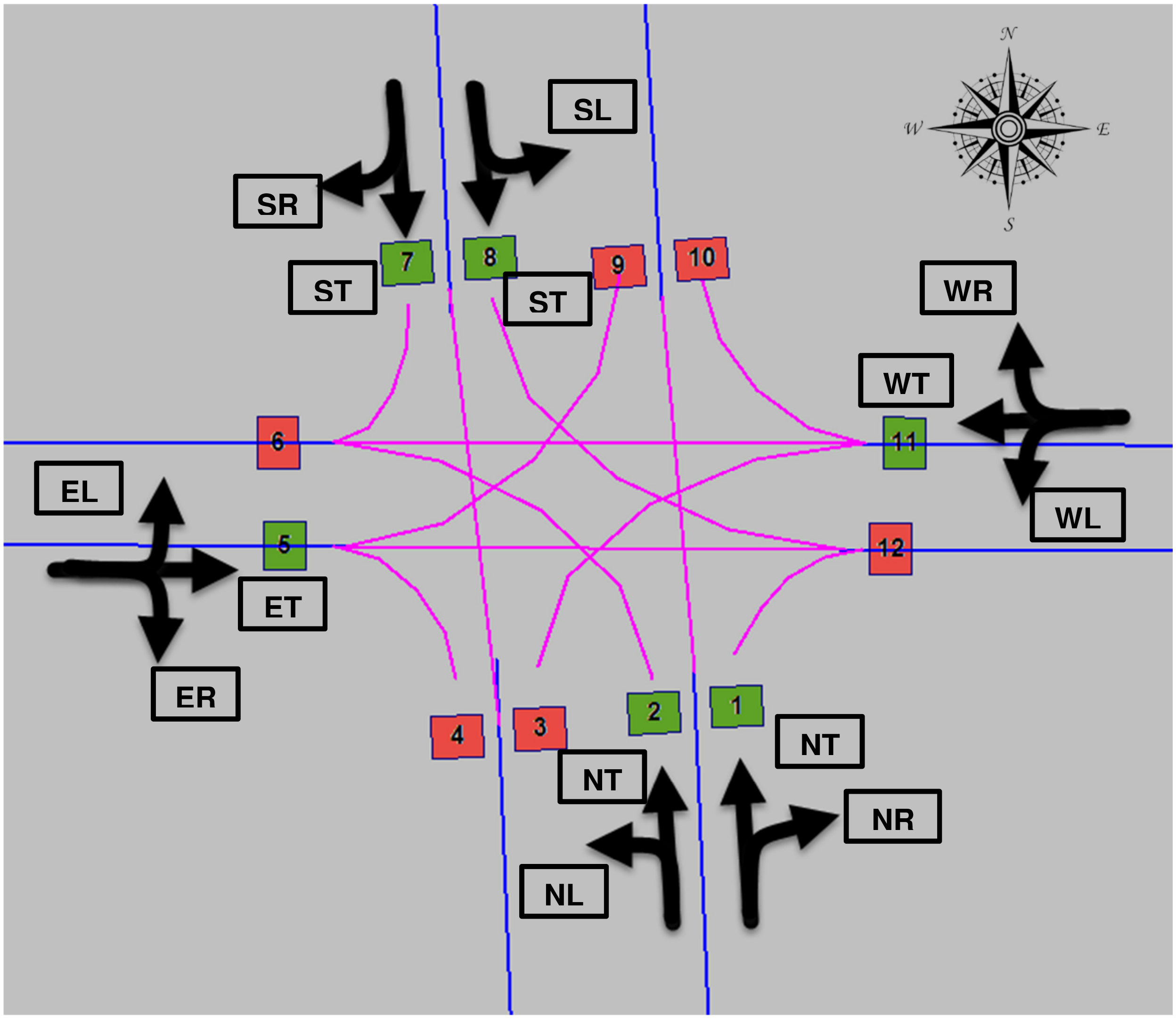

Figure 16: Intersection #2 Detector and Turning Design

6.1 Simulation Results

6.1.1 Intersection #1 – 4-Way Intersection with Designated Turn Lanes

Table 1: Intersection #1 – ATMIS Error Output Data

Warning	Error	Feed Dect.	Act. Time	Deact. Time	Feed Dect. Movement	Sink Dect. Movement	Turning Movement	Reason for Error	Car color	Additional Explanation
ERROR	Unmatched Feed Detection	2	67	96.8	2	12	ST	Accident	White	A 7 to 14 movement turning left at a red light cut off the 2 to 12 movement who had a green light.
ERROR	No Feed Detection	13	104.4	104.8	2	13	ST	Lane change	Blue	Lane change through the intersection.
ERROR	Unmatched Feed Detection	3	446	456.6	3	13	ST	Lane change	Green	Car next to it changed lanes causing a 3 to 12 movement.
ERROR	No Feed Detection	12	461.8	462.2	3	12	ST	Lane change	Blue	Lane change through the intersection.
ERROR	Unmatched Feed Detection	2	550.4	576.8	2	12	ST	Loop time exp.	Blue	1st car at red light opened the 2 loop.
ERROR	No Feed Detection	14	583.8	584.6	1	14	SR	Turning conflict	Red	The 1 to 14 movement had to wait for the 7 to 14 movement to finish.
ERROR	No Feed Detection	13	587.6	588	2	13	ST	Lane change	Light Gray	Lane change through the intersection.
ERROR	No Feed Detection	9	599	599.4	6	10	WR	Lane change	Blue	Lane change through the intersection.
ERROR	Unmatched Feed Detection	2	602.4	636.8	2	12	ST	Loop time exp.	White	1st car at red light opened the detector 2 loop.
ERROR	No Feed Detection	14	675	675.4	5	14	WT	UNKNOWN	Red	No reason – Legal Movement
WARNING	Dead Lock Break!!!!!!	9	702	702.4	6	9	NT	Turning conflict	Light Gray	The 6 to 11 movement had to wait while the 6 to 9 movement was completed. Dead Lock 5x
ERROR	Unmatched Feed Detection	2	739.6	756.8	2	12	ST	Loop time exp.	Yellow	1st car at red light opened the 2 loop.
ERROR	Unmatched Feed Detection	2	758.2	758.8	2	12	ST	Loop time exp.	Yellow	1st car at red light opened the 2 loop.
ERROR	Unmatched Feed Detection	2	788.6	816.8	2	12	ST	Loop time exp.	Red	1st car at red light opened the 2 loop.
ERROR	No Feed Detection	13	825.4	825.8	2	13	ST	Lane change	Gray	Lane change through the intersection.
WARNING	Dead Lock Break!!!!!!	12	937.8	938.6	8	12	ER	Turning conflict	Red	2 to 12 movement had green light while a 8 to 12 movement occurred on red
ERROR	No Feed Detection	12	945.8	946.2	3	12	ST	Lane change	Blue	Lane change through the intersection.
ERROR	No Feed Detection	14	960	960.4	5	14	WT	Ran red signal	White	Ran red signal.
ERROR	Unmatched Feed Detection	2	1003.6	1004	2	13	ST	Lane change	Blue	Lane change through the intersection. Car was between the 2 and 3 detectors.
ERROR	No Feed Detection	9	1072.4	1072.8	6	10	NT	Lane change	Black	Lane change through intersection.
ERROR	Unmatched Feed Detection	2	1108.4	1116.8	2	12	ST	Loop time exp.	Light Gray	1st car at red light opened the detector 2 loop.
ERROR	Unmatched Feed Detection	2	1122.2	1123.2	2	13	ST	Lane change	Red	Lane change through the intersection.
ERROR	No Feed Detection	13	1126.4	1126.8	2	13	ST	Lane change	Light Gray	Lane change through the intersection.
WARNING	Dead Lock Break!!!!!!	10	1154.2	1155	8	10	EL	Lane change	Red	Lane change through the intersection. Car right on the 9 & 10 detector. Dead Lock 233x

Table 1: Intersection #1 – ATMIS Error Output Data Continued

Warning	Error	Feed Dect.	Act. Time	Deact. Time	Feed Dect. Movement	Sink Dect. Movement	Turning Movement	Reason for Error	Car color	Additional Explanation
ERROR	No Feed Detection	10	1154.2	1155	8	10	EL	Lane change	N/A	See Dead Lock Break above.
ERROR	No Feed Detection	11	1163.2	1163.8	8	11	ET	Accident	Black/Red	A 8 to 11 movement crashed into a vehicle making a 8 to 10 movement
WARNING	Dead Lock Break!!!!!!	12	1180.6	1181	3	12	ST	Turning conflict	White	White bus caused error. Dead Lock 105x
WARNING	Dead Lock Break!!!!!!	12	1182	1182.4	3	12	ST	Turning conflict	White	Lane change through the intersection. Dead Lock 97x
WARNING	Dead Lock Break!!!!!!	12	1183.2	1183.6	3	12	ST	Turning conflict	White	White bus caused error. Dead Lock 91x
WARNING	Dead Lock Break!!!!!!	12	1186.6	1188	3	12	ST	Turning conflict	White	White bus caused error. Dead Lock 69x Bus
ERROR	Unmatched Feed Detection	2	1203.2	1237	2	12	ST	Loop time exp.	Blue	1st car at red light opened the detector 2 loop.
ERROR	Unmatched Feed Detection	2	1255.2	1255.6	2	13	ST	Lane change	Light Blue	Lane change through the intersection.
WARNING	Dead Lock Break!!!!!!	10	1300.8	1302.4	8	10	EL	Ran red signal	Gray	Completed an 8 to 10 movements at red while a 2 to 12 and a 3 to 13 movement was occurring. Bus
ERROR	Unmatched Feed Detection	2	1321.8	1356.8	2	12	ST	Loop time exp.	White	1st car at red light opened the detector 2 loop.
ERROR	No Feed Detection	13	1361.6	1362	2	13	ST	Lane change	Black	Lane change through intersection.
ERROR	No Feed Detection	9	1375	1375.4	6	9	NT	UNKNOWN	Light Gray	No Reason – Legal Movement
ERROR	Unmatched Feed Detection	2	1384	1416.8	2	12	ST	Loop time exp.	White	1st car at red light opened the detector 2 loop.
ERROR	No Feed Detection	14	1645.8	1646.4	5	14	WT	Turning conflict	Gray	The 5 to 14 movement had to wait while the 1 to 14 movement was completed.
WARNING	Dead Lock Break!!!!!!	9	1660.4	1660.8	8	9	EL	Turning conflict	Red	The 6 to 9 movement had to slow down for an 8 to 10 movement to complete. Dead Lock 22x
WARNING	Dead Lock Break!!!!!!	9	1661.6	1662	8	9	EL	Turning conflict	Red	The 6 to 9 movement had to slow down for an 8 to 10 movement to complete. Dead Lock 14x
WARNING	Dead Lock Break!!!!!!	9	1663.4	1663.8	8	9	EL	Turning conflict	Red	The 6 to 9 movement had to slow down for an 8 to 10 movement to complete. Dead Lock 6x.
ERROR	No Feed Detection	11	1689.6	1690	8	11	ET	UNKNOWN	Black	No reason – Legal Movement
ERROR	Unmatched Feed Detection	2	1705	1716.8	2	12	ST	Loop time exp.	Light Blue	1st car at red light opened the detector 2 loop.
WARNING	Dead Lock Break!!!!!!	9	1717.6	1718.4	5	9	WR	Turning conflict	Gray	6 to 9 movement had green light while a 5 to 9 movement occurred on red
ERROR	Unmatched Feed Detection	2	1718	1719.2	2	12	ST	Loop time exp.	Light Gray	1st car at red light opened the detector 2 loop.
WARNING	Dead Lock Break!!!!!!	12	1722.6	1723	2	12	ST	UNKNOWN	Blue	No reason – Legal Movement
ERROR	No Feed Detection	13	1791.2	1791.4	2	13	ST	Lane change	N/A	Lane change through the intersection.

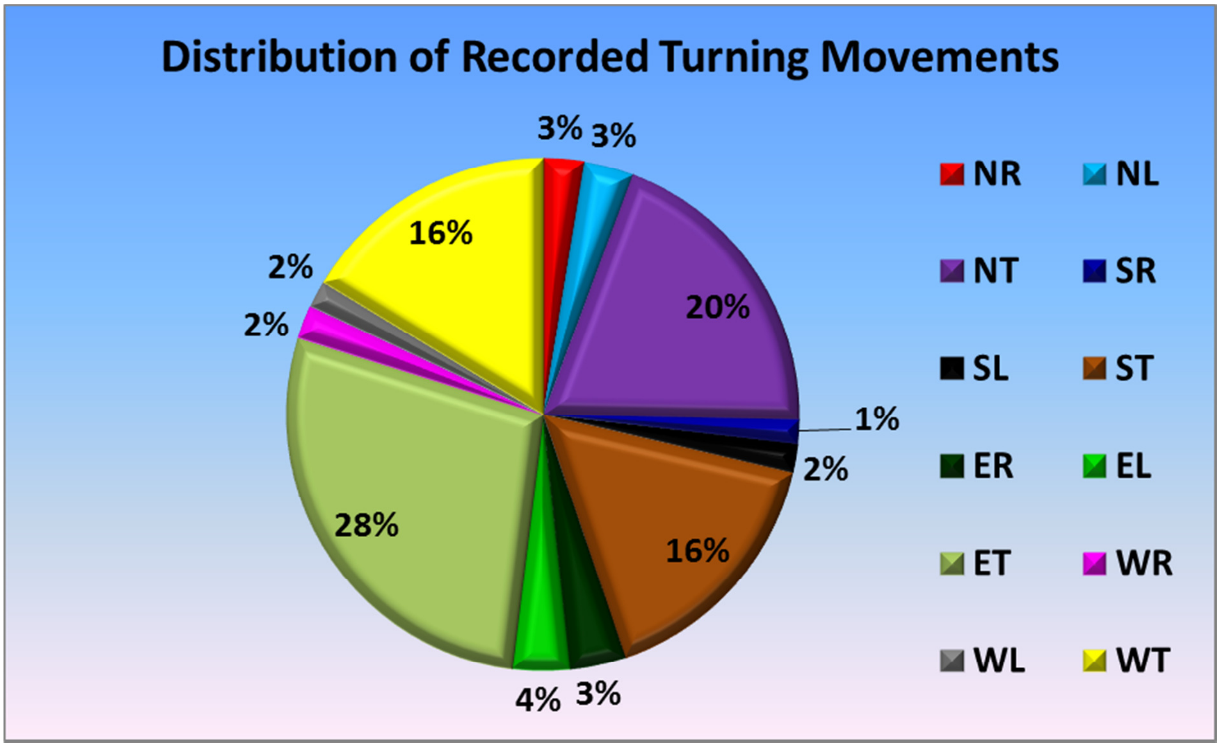

Figure 17: Intersection #1 – Distribution of Recorded Turning Movements

Table 2: Intersection #1 – Movement and Error Traffic Counts

	NR	NL	NT	SR	SL	ST	
Recorded Movements	27	33	206	16	19	170	
Errors	0	0	3	1	0	29	
Percent Correct	100.00%	100.00%	98.56%	94.12%	100.00%	85.43%	
	ER	**EL**	**ET**	**WR**	**WL**	**WT**	**Totals**
Recorded Movements	37	38	293	22	18	172	1051
Errors	1	6	2	2	0	3	47
Percent Correct	97.37%	86.36%	99.32%	91.67%	100.00%	98.29%	95.72%

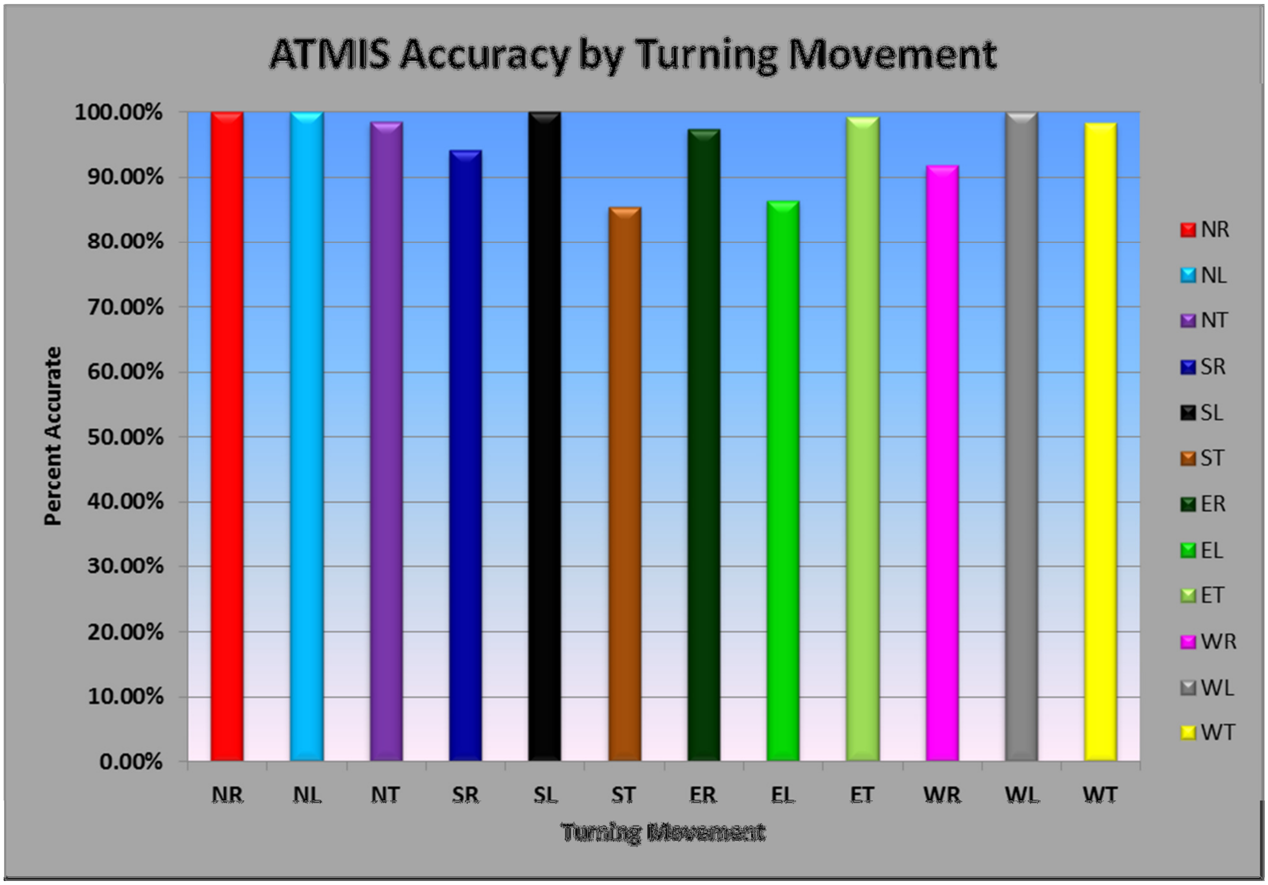

Figure 18: Intersection #1 – ATMIS Accuracy by Turning Movement

Table 3: Intersection #1 – Reason of Error Occurrences

Reason for Error	Accident	Lane Change	Loop Time Expiration	Turning Conflict	Ran Red Signal	Unknown
Amount	2	16	11	12	2	4
Percent of Total Errors	4.26%	34.04%	23.40%	25.53%	4.26%	8.51%

6.1.2 Intersection #2 – 4-Way Intersection without Turn Lanes

Table 4: Intersection #2 – ATMIS Error Output Data

Warning	Error	Feed Dect.	Act. Time	Deact. Time	Feed Dect. Movement	Sink Dect. Movement	Turning Movement	Reason for Error	Car color	Additional Explanation
ERROR	No Feed Detection	9	245.8	246.2	1	9	NT	Lane change	White	Lane change through the intersection.
WARNING	Dead Lock Break!!!!!!	12	271.4	271.8	1	12	NR	Right turn	Blue	Vehicle made a 1 to 12 right turn.
WARNING	Dead Lock Break!!!!!!	12	279.8	280.4	5	12	ET	UNKNOWN	Blue	No Reason – Legal Movement
ERROR	Unmatched Feed Detection	7	423.2	424	7	4	ST	UNKNOWN	Light Blue	No Reason – Legal Movement
WARNING	Dead Lock Break!!!!!!	6	543	543.6	7	6	SR	Right turn	Light Gray	Vehicle made a 7 to 6 right turn.
ERROR	Unmatched Feed Detection	2	677.2	677.6	2	10	NT	Lane change	Light Blue	Same vehicle as above. Lane change through the intersection.
ERROR	No Feed Detection	10	679.8	680.4	2	10	NT	Lane change	Light Blue	Lane change through the intersection. Vehicle was on top of the 2 and 3 detector.
ERROR	No Feed Detection	9	853	853.4	1	9	NT	Lane change	Red	Lane change through the intersection.
ERROR	Unmatched Feed Detection	2	881.4	906.2	2	10	NT	Lane change	Light Gray	Lane change through the intersection.
ERROR	No Feed Detection	9	905.8	906.2	1	9	NT	Lane change	White	Lane change through the intersection.
ERROR	Unmatched Feed Detection	7	965.6	966	7	6	SR	Right turn	Black	Vehicle made a 7 to 6 right turn.
ERROR	No Feed Detection	10	1036.4	1036.8	2	10	NT	Lane change	Black	Lane change through the intersection.
ERROR	Unmatched Feed Detection	7	1152.2	1152.6	7	6	SR	Right turn	Red	Vehicle made a 7 to 6 right turn.
ERROR	No Feed Detection	10	1626.2	1626.8	2	10	NT	Lane change	Light Gray	Lane change through the intersection.
ERROR	Unmatched Feed Detection	8	1738.4	1747.6	8	12	SL	Loop time exp.	Yellow	1st car at red light opened the 8 loop.
ERROR	Unmatched Feed Detection	2	1776.2	1805	2	9	NT	Loop time exp.	Blue	1st car at red light opened the 2 loop.
ERROR	No Feed Detection	12	1794.6	1795	5	12	ET	UNKNOWN	Black	No Reason – Legal Movement

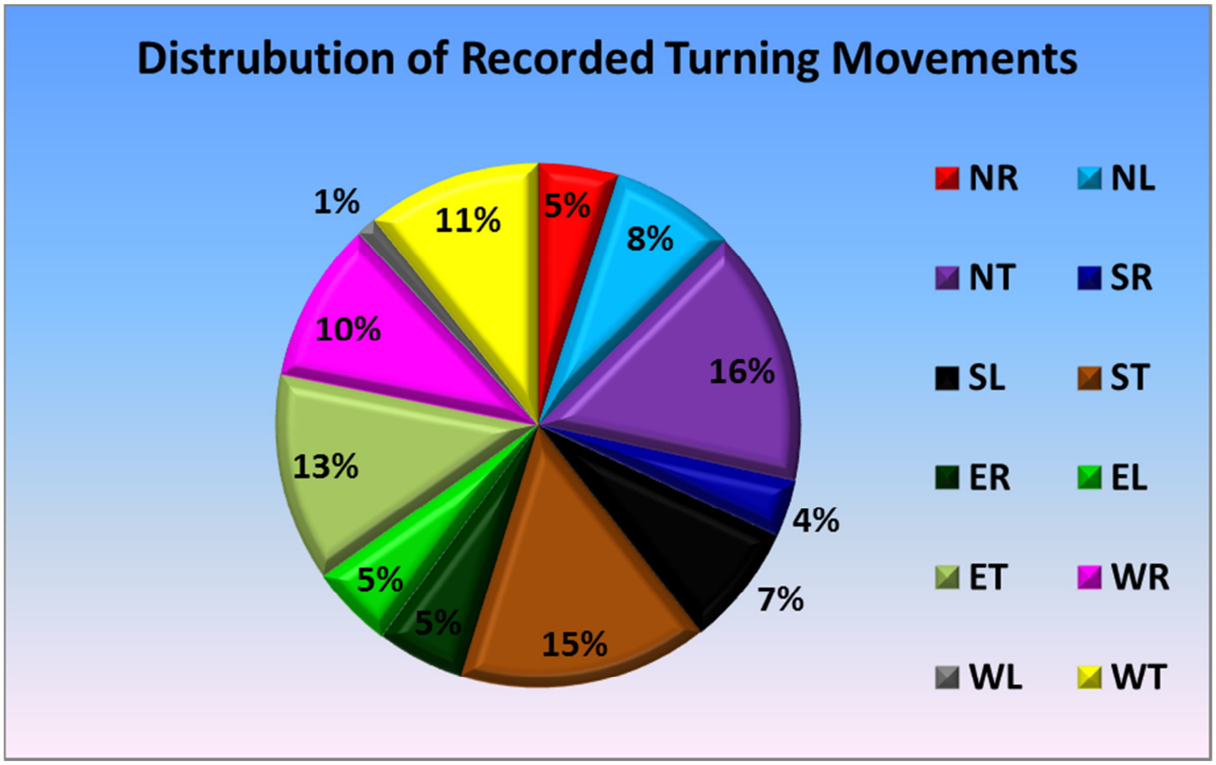

Figure 19: Intersection #2 – Distribution of Recorded Turning Movements

Table 5: Intersection #2 – Movement and Error Traffic Counts

	NR	NL	NT	SR	SL	ST	
Recorded Movements	35	54	112	25	53	109	
Errors	1	0	9	3	1	1	
Percent Correct	97.22%	100.00%	92.56%	89.29%	98.15%	99.09%	
	ER	**EL**	**ET**	**WR**	**WL**	**WT**	**Totals**
Recorded Movements	38	36	91	70	9	76	708
Errors	0	0	2	0	0	0	17
Percent Correct	100.00%	100.00%	97.85%	100.00%	100.00%	100.00%	97.66%

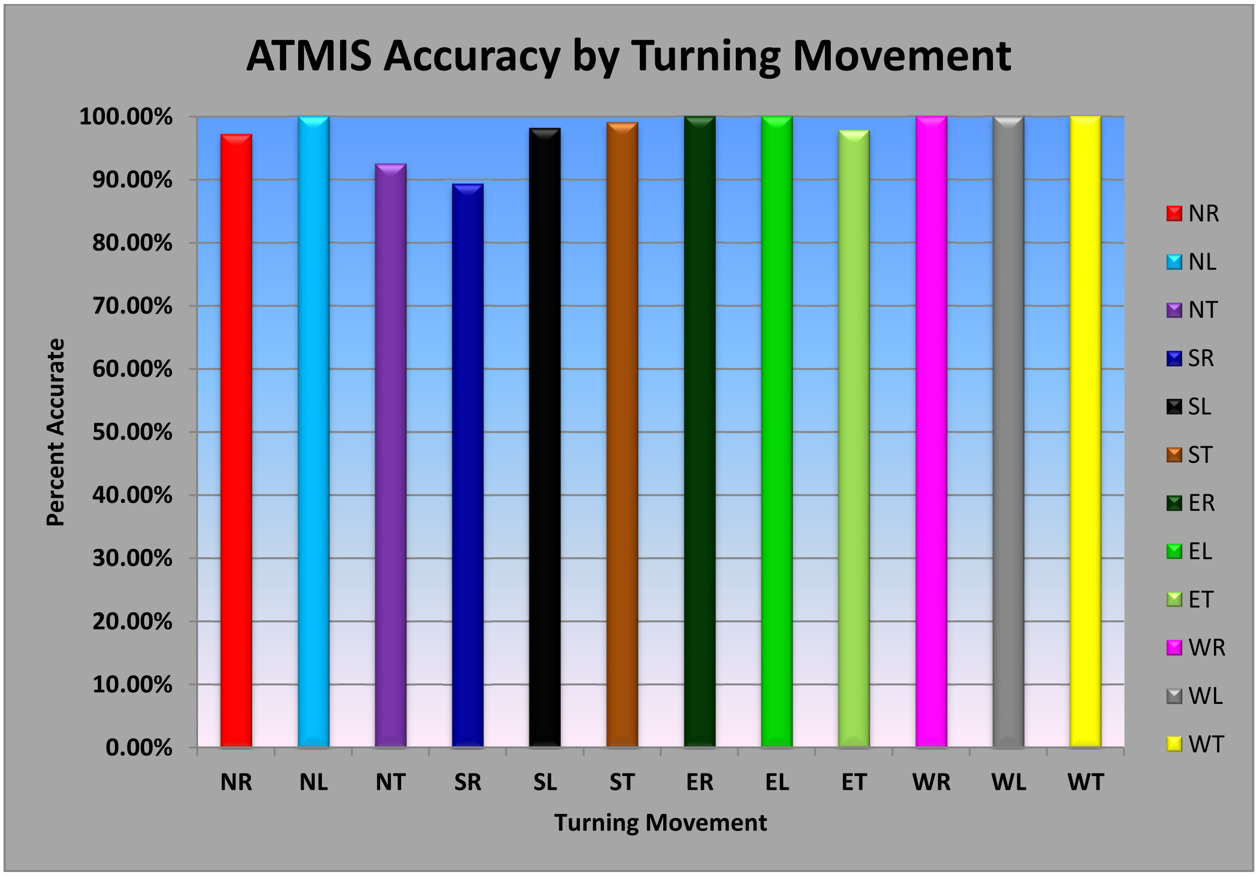

Figure 20: Intersection #2 – ATMIS Accuracy by Turning Movement

Table 6: Intersection #2 – Reason of Error Occurrences

Reason for Error	Accident	Lane Change	Loop Time Expirations	Turning Conflict	Right Turn	Unknown
Amount	0	8	2	0	4	3
Percent of Errors	0.00%	47.06%	11.76%	0.00%	23.53%	17.65%

7.0 DISCUSSION

Although the two simulations had different geometric layouts, they both produced similar errors. Categorized by the ATMIS software, there were three different errors detected: no feed detections, unmatched feed detections, and dead lock breaks. Those types of errors were then broken down into five categories. These categories described the vehicle activity that caused the ATMIS errors. The conditions that caused ATMIS errors were determined to be from accidents, lane changes, loop time expirations (time expired in order to find a turning movement match), turning conflicts, and vehicles running red lights. As seen in *Table 1 and Table 4*, the data is color coded based as shown in the Data Table Color Legend section.

No feed detections and unmatched feed detections were found to produce similar types of errors. A no feed detection was found to occur when ATMIS was unable to determine a pairing feed detector for a specific turning movement. Similar to a no feed detection error, an unmatched feed detector error also occurred when ATMIS could not identify a matching sink detector for the found feed detector of a vehicle passing through the intersection. Both of these errors were due to either vehicles changing lanes in-between feed and sink detectors, loop time expirations, running red lights, or accidents.

The third type of error, a dead lock error, was found to be very different from both the unmatched feed detections and no feed detection errors. Dead lock errors occurred when a vehicle was in the process of completing a turning movement that held up all other traffic. This situation occurred several times in both simulations due to either changing traffic signals or due to a vehicle crossing other traffic flow, regardless of its direction. From previous research done at Kent State University, there are four conditions that must have occurred in order for a dead lock error to have happened: mutual exclusion, hold and wait condition, no-preemptive condition, and a circular wait condition (Muhammad, 2015). A mutual exclusion error occurred when one or more vehicles shared the same section of street or detector at the same time. A hold and wait condition occurred when a vehicle's turning movement was interrupted by having to wait to complete a turning movement. A no-preemptive condition occurred when a turning movement was interrupted. When any of these four conditions occurred, ATMIS software could not handle the vehicle's event, which caused the algorithm to continually run through the options until time expired and no match was found.

7.1 Intersection #1 – 4-Way Intersection with Designated Turn Lanes

After the thirty minute simulation of Intersection #1, the ATMIS outputs were tabulated. A sample of the ATMIS output for the first 280 seconds in the simulation are displayed in the Appendix under Section 10.1.1 *Table A-1*. In *Table A-1*, ATMIS's output included the type of turning movement, feed detector number, time stamp when the feed detector was activated and deactivated, sink detector number, and time stamps when the feed detector was activated and deactivated.

All the turning movement errors that ATMIS recorded were also tabulated. These results are included in *Table 1*. *Table 1* includes the type of error that occurred, the feed detector number (the detector that ATMIS was able to distinguish), and a time stamp for when the detector was activated and deactivated. The feed detector movement, sink detector movement, type of turning movement, reason for error, car color, and additional explanation was added after each error event was documented. As mentioned before, the error events that are highlighted in orange in *Table 1* represent errors in which could not be identified. After watching the simulation, there was no evidence of an illegal turning movement that would cause an ATMIS error.

A graphic look at the distributions of the turning movements throughout the entire thirty minute simulation is shown in *Figure 17*. *Table 2* shows the traffic counts that ATMIS was able to record accurately and the ATMIS error output counts for each turning movement. From *Figure 17* and *Table 2*, ET was the most prevalent turning movement, comprising 28% of all traffic turning movements, a total of 293 vehicles counts. 2 errors were recorded for ET movements making ATMIS 99.32% accurate in recording ET turning movements.

The second most prevalent turning movement was found to be NT, which contained 20% of all turning movement (206 vehicle counts). 3 errors were detected for NT movements, making ATMIS 98.56% percent accurate for NT movements. ST traffic comprised of 16% of turning movements, with 170 accurately calculated vehicle counts. It was found that ST turning movements had 29 errors, resulting in ATMIS being 85.43% accurate in ST movements. WT movements only took up 16% of all turning movements, with 172 counts total counts, and only had 3, errors resulting in ATMIS being 98.29% accurate in recording WT movements.

As seen in *Table* 2, NL, NT, SL, and WL turning movements were all found to have no ATMIS errors, resulting in perfect turning movement performance. Although EL turning movements only comprised 4% of all turning movement with 38 counts, there were still 6 errors found. This resulted in 86.36% accuracy for EL turning movements. The rest of the turning movement data is shown in *Figure 17* and *Table 2.*

In all, ATMIS recorded 1051 turning movements for Intersection #1 and had a total of 47 errors, which resulted in ATMIS being 95.72% accurate. A graphic look at the accuracy of ATMIS for each different turning movement is shown in *Figure 18*.

Out of the 47 errors that were recorded for Intersection #1, 16 errors were found to be unmatched feed detection errors, 18 were no feed detections, and 13 errors were dead lock break errors. The percentage of what conditions caused the errors can be seen in *Table 3*.

7.1.1 Intersection #1 – Error Examples

Examples of errors that occurred in Intersection #1's simulation are displayed in the Appendix. The first type of error shown is the unmatched feed detection error. There are two examples of unmatched feed detection errors shown in the Appendix under Section10.1.2 in *Figures A-1* and *A-2.* Both accident errors in Intersection #1's simulation were found to be unmatched feed detection. Since the vehicles had collided with each other, ATMIS could not locate the appropriate turning movement. The second example illustrates a movement where the detector loop 2 was activated too early (while the signal light was still red) and by the time the vehicle had crossed its sink detector, the time to make an appropriate match had already expired. This is depicted in the Appendix under Section10.1.2 in *Figures A-3* and *A-4*.

The next error shown in the Appendix is the no feed detection error. In Section 10.1.3, there is an example which illustrates a vehicle changing lanes in-between the feed detector and the sink detector shown in *Figure B-1*. When this occurs, the algorithm does not recognize the combination of feed/sink detector and automatically computes an error in the output, resulting in a no feed detection error.

Lastly, one of the more common errors, the dead lock error, has an example in Section 10.1.4 in the Appendix. *Figures C-1* and *C-2* represent a vehicle traveling EB when it decides to make a left turn heading NB. As the vehicle sits in the intersection waiting for traffic heading WB to clear, the light turned red. Once traffic was clear, the vehicle then proceeded to make the turn. The problem with this situation was that the vehicle was stuck in the intersection when the light turned red and had to proceed even though it was an illegal movement. Because of this illegal movement, the vehicles traveling NB and SB had to be held up even though their light was green. This caused a deadlock at all traffic directions.

7.2 Intersection #2 – 4-Way Intersection without Turn Lanes

Similar to the simulation on Intersection #1, a 30 minute long simulation was also performed for Intersection #2. All results from the Intersection #2 simulation were organized in a Microsoft Excel sheet. A sample of the ATMIS turning movement output for the first 415 seconds are displayed in the Appendix under Section 10.2.1 in *Table B-1*. All tables and figures developed for Intersection #2 have the same setup as the figures and tables made for Intersection #1. Once again all the ATMIS turning movement errors were tabulated for Intersection #2. These results are in included in *Table 4*. Color coding of the errors follows the same method as Intersection #1, which is described in the Data Table Color Legend.

A graphical look at the distributions of the turning movements throughout the entire 30 minute simulation for Intersection #2 is shown in *Figure 19*. *Table 5* was generated to show the traffic counts that ATMIS recorded accurately and also the ATMIS error output counts for each turning movement. From *Figure 19* and *Table 5*, NT was the most dominant turning movement comprising 16% of all traffic turning movements, a total of 112 vehicles. 9 errors were found to for NT movements making, ATMIS 92.56% accurate in NT turning movements for Intersection #2.

The second most common turning movement was ST, comprising of 15% of all movements. One error was detected, which made ATMIS 99.09% percent accurate for ST movements. WR took up 10% of turning movements and did not have any errors, a perfect performance. Movements NL, ER, EL, EL, and WT also were found to have no errors.

The turning movement SR was found to have the lowest ATMIS recording accuracy rate, at 89.29% for Intersection #2. SR was determined to have 25 vehicle counts with 3 recording errors. All other turning movements for Intersection #2 had ATMIS recording accuracy rates of 90% or higher.

In all, ATMIS recorded 708 turning movements with 17 errors for Intersection Simulation #2, resulting in 97.66% accuracy. A graphic look at the accuracy of ATMIS for each different turning movement is shown in *Figure 20*.

A total of 17 errors were recorded for Intersection #2. It was found that 7 errors were considered unmatched feed detections, 7 no feed detections, and 3 errors dead lock break errors. *Table 6* displays the occurrence for each reason of error.

7.2.1 Intersection #2 – Error Examples

All error examples for Intersection #2 can be found in the Appendix under Section 10.2. For the unmatched feed detection errors, a similar error occurred in Intersection #2 as it did in Intersection #1. Seen in Section 10.2.2 in *Figures D-1* and *D*-2, a vehicle activates a feed detector when the light is red and eventually runs out of time to find an appropriate turning movement match. This type of error only occurred once for Intersection #2 compared to the 11 times in Intersection #1.

Similar to Intersection #1, Intersection #2 had vehicle changing lanes between the feed detector and sink detector. This can be seen in Section 10.2.3 in *Figures E-1* and *E*-2. This demonstrates a no feed detection error.

The next error seen in Section 10.2.4 is the dead lock error. There are two examples shown in this section. In the first example, as shown in *Figure F-1,* the vehicle heading NB makes a right turn when the light is yellow. Rather than yielding to the yellow light and stopping at the signal, the vehicle made the right turn. Because of how ATMIS is programmed, the algorithm believes a dead lock occurred, which causes the error. Although the vehicle may not have caused any traffic issues or made an illegal movement, the program still followed protocol and triggered an error.

The next dead lock error example in Section 10.2.4 in *Figure F-2,* a vehicle is heading SB and is making a right turn. This error may have caused a deadlock for two different reasons. The vehicle can be seen making the turn at an abnormal angle. The back end of the vehicle is almost hitting the curb of the roadway. With an awkward angle, the sink detector may have had trouble picking up the vehicle, or had trouble identifying the vehicle itself. Another reason a deadlock may have occurred is because the vehicle had to slow down to make a right turn. For this particular intersection, there are no designated turning lanes unlike in Intersection #1. As the vehicle traveled SB, it had to slow down to make the appropriate turn. Vehicles traveling behind the turning vehicle would have had to also slow down causing the ATMIS program to potentially trigger a deadlock.

8.0 RECOMMENDATIONS

After analyzing both intersections and the errors produced from their simulations, it is believed that several errors can be resolved. This being said, it is likely that the ATMIS software efficiency can indeed be increased. As previously discussed, many errors were due to detector issues. Issues such as detectors activated too early and vehicles changing lanes within the intersection are problems that can ultimately be fixed. Alterations to the ATMIS programming/coding could help eliminate such issues. Giving the feed detectors more turning movement options could help eliminate a lane changing error, which was found to be fairly common in both simulations. Adding another feed detector in designated left turning lanes that are programmed to be only activated when the signal is green can eliminate some of the turning conflict errors. With more options to choose from, the algorithm will be able to find a correct match for the turning movement.

Although many errors have the potential to be fixed, there are still several errors that can be attributed to human error. In both simulations, many vehicles caused errors due to illegal turning movements, such as the various dead lock break errors. As of today, the ATMIS software is only designed for a utopian environment and can only distinguish legal movements. It cannot detect illegal turning movements such as running red lights or accidents. When thinking about drivers in real time scenarios, it is easy to believe there are many illegal turning movements made throughout a day. Each of the two simulations analyzed only ran for a total duration of thirty minutes. This raised the question of how many errors would occur in a given day.

If some of the errors can be corrected and the efficiency of ATMIS can be increased, the use of this software can expand throughout the nation. Counting traffic can become much easier and companies and municipalities can have data analyzed much quicker than it is currently done today. ATMIS is a program that has much potential and by fixing several of the errors mentioned above, can help alleviate the hassle of manual traffic counting.

9.0 REFERENCES

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10.0 APPENDIX

10.1 Intersection #1 Information

10.1.1 Intersection #1 Output

Table A-1
Intersection #1 – ATMIS Turning Movement Output

Turning	Feed Det.	Act. Time	Deact. Time	Sink Det.	Act. Time	Deact. Time	Intersection (T.T)	App No	Lane No
ET	8	5	5.4	11	6.8	7.2	1.8	2	8
WT	5	8.6	9	14	10.6	10.8	1.8	4	5
WT	5	13.2	13.6	14	15	15.4	1.8	4	5
WT	5	14.2	14.6	14	16.2	16.4	1.8	4	5
ET	8	17.4	18.4	11	22	22.4	4	2	8
ER	8	19.2	19.8	12	21.2	21.8	2	2	8
WT	5	20.2	20.8	14	22.8	23	2.2	4	5
WT	5	22.8	23.2	14	24.8	25.2	2	4	5
WT	5	29	29.4	14	30.8	31.2	1.8	4	5
ET	8	31	31.2	11	32.6	33	1.8	2	8
ST	2	34.2	36.6	12	40	40.4	3.8	1	2
ET	8	35.4	61.6	11	66.8	67.2	5.6	2	8
NT	6	36.2	36.8	9	39	39.4	2.6	3	6
ST	3	36.2	36.8	13	39.4	39.8	3	1	3
WT	5	39.8	61.8	14	65.2	65.6	3.8	4	5
ST	3	41.2	41.6	13	43.2	43.4	1.8	1	3
NT	6	51.2	51.4	9	53	53.2	1.8	3	6
ST	2	52.8	53	12	54.6	55	2	1	2
NL	7	57.8	58.8	14	62.4	63	4.2	3	7
ST	3	60.6	96.8	13	100.2	100.8	4	1	3
ET	8	62.8	64	11	68	68.4	4.4	2	8
NR	6	63.2	64.4	11	64.8	65.4	1	3	6
WT	5	63.2	65.8	14	83.4	83.8	18	4	5
ET	8	65	65.6	11	71.6	72	6.4	2	8
ET	8	67	67.8	11	72.4	72.8	5	2	8
NR	6	67	97	11	103.4	104.2	7.2	3	6
WT	5	67.6	84	14	94.6	95	11	4	5
ET	8	68.8	69.4	11	73.6	74	4.6	2	8
EL	8	70.2	70.6	10	71.2	71.8	1.2	2	8
ET	8	71.6	72	11	75.2	75.6	3.6	2	8
ET	8	73.2	73.6	11	80.2	80.6	7	2	8
ET	8	75.2	76.2	11	81.6	82	5.8	2	8
ER	8	77.4	78	12	79.4	80.2	2.2	2	8
ET	8	79.2	79.8	11	84.8	85	5.2	2	8
ET	8	83	83.2	11	87.2	88.2	5	2	8
WL	5	86	87.8	13	88.8	89.6	1.8	4	5
NL	7	88.8	97.2	14	101	101.8	4.6	3	7
WL	5	89	90.8	13	91.2	92	1.2	4	5
ET	8	90.2	90.6	11	92.2	92.6	2	2	8
WT	5	92	122	14	137.6	138	16	4	5
ET	8	94.2	121.4	11	124.6	125.2	3.8	2	8
ST	2	98	99	12	100.2	100.6	1.6	1	2
NT	6	98.2	99.2	9	100.2	100.8	1.6	3	6
ST	3	98.4	99	13	101.8	102.2	3.2	1	3
ST	2	100.4	101.2	12	103.2	103.6	2.4	1	2
NT	6	100.8	101.6	9	102	102.4	0.8	3	6
NT	6	102.4	103	9	105.6	106	3	3	6
NT	6	104	104.4	9	106.6	107	2.6	3	6
NT	6	111.2	111.4	9	113.2	113.4	2	3	6
ST	2	112.4	113	12	114.6	115.4	2.4	1	2
NT	6	115.6	116	9	117.6	117.8	1.8	3	6

Table A-1 Continued

Turning	Feed Det.	Act. Time	Deact. Time	Sink Det.	Act. Time	Deact. Time	Intersection (T.T)	App No	Lane No
SR	1	117	117.8	14	120	120.8	3	1	1
ET	8	122.6	123.8	11	126.6	127.2	3.4	2	8
WT	5	124	136.2	14	139.2	139.8	3.6	4	5
ET	8	125	125.8	11	128	128.4	2.6	2	8
ET	8	126.8	127.4	11	129.6	130	2.6	2	8
ET	8	129.2	130.2	11	135	135.4	5.2	2	8
NT	6	130.8	157	9	160.6	161	4	3	6
ST	2	131.4	157	12	167.4	168	11	1	2
ER	8	131.6	132.4	12	133.4	134.2	1.8	2	8
ET	8	133.2	133.8	11	136.2	136.6	2.8	2	8
WT	5	137.6	138.4	14	142	142.4	4	4	5
WL	5	139.2	139.8	13	141.8	142.4	2.6	4	5
EL	8	139.8	155.8	10	161	162.8	7	2	8
WT	5	141.4	142	14	144.4	144.8	2.8	4	5
SL	4	142.2	169.8	11	174.2	175	5.2	1	4
WT	5	143	143.6	14	146	146.4	2.8	4	5
WT	5	144.8	145.8	14	151.2	151.6	5.8	4	5
NL	7	145.8	160	14	163.8	164.4	4.4	3	7
WT	5	146.6	147.6	14	152.4	152.8	5.2	4	5
WR	5	148.2	149	9	149.4	150	1	4	5
WL	5	149.6	150.2	13	150.8	151.4	1.2	4	5
WL	5	151.2	152	13	155	155.8	3.8	4	5
WT	5	153.4	194	14	202.4	203	9	4	5
ST	3	156.2	157.2	13	165.2	165.8	8.6	1	3
ET	8	157.4	181.6	11	185.4	186	4.4	2	8
ST	2	158.2	159.8	12	169.4	170	10.2	1	2
NT	6	158.4	159.2	9	161.8	162.2	3	3	6
NT	6	160.4	161.2	9	163.8	164.2	3	3	6
NR	6	163	164	11	166.4	167.4	3.4	3	6
NR	6	165	165.8	11	169.6	170.6	4.8	3	6
ST	3	165.8	166.4	13	168	168.6	2.2	1	3
NT	6	166.8	167.8	9	168.4	168.8	1	3	6
NT	6	168.8	169.4	9	172	172.4	3	3	6
NT	6	174.6	174.8	9	176.6	177	2.2	3	6
NR	6	181.4	217	11	226	226.8	9.8	3	6
ET	8	182.8	184	11	188.2	188.6	4.6	2	8
ST	2	183.4	217	12	221	221.4	4.4	1	2
ET	8	185.2	186	11	190.2	190.8	4.8	2	8
EL	8	187.2	188	10	187.8	188.6	0.6	2	8
ET	8	189.4	190.2	11	193.8	194.2	4	2	8
ET	8	190.8	191.4	11	198.2	198.6	7.2	2	8
EL	8	192.6	193.6	10	193.6	194.2	0.6	2	8
ER	8	194.6	195.4	12	196.6	197.6	2.2	2	8
WL	5	195.4	198.2	13	198.2	199	0.8	4	5
ET	8	196.4	197.2	11	199.4	199.8	2.6	2	8
ET	8	198.2	198.8	11	200.6	201	2.2	2	8
SL	4	200	236.8	11	241.4	242.2	5.4	1	4
WT	5	200.2	203	14	209.4	209.8	6.8	4	5
ET	8	202.2	203.4	11	206.6	207	3.6	2	8
ST	3	203.4	216.6	13	220.2	220.6	4	1	3
ER	8	204	204.6	12	204.6	205.6	1	2	8

Table A-1 Continued

Turning	Feed Det.	Act. Time	Deact. Time	Sink Det.	Act. Time	Deact. Time	Intersection (T.T)	App No	Lane No
WR	5	204	205.8	9	205.4	207.2	1.4	4	5
ET	8	205.4	205.8	11	207.8	208.2	2.4	2	8
WT	5	206.6	208.8	14	214.6	215.2	6.4	4	5
ET	8	208	208.8	11	212.6	213	4.2	2	8
ER	8	209.4	210	12	211.4	212.2	2.2	2	8
WT	5	209.4	241.8	14	245.2	245.8	4	4	5
ST	3	217.8	219	13	222.2	222.8	3.8	1	3
ST	2	218.2	219.2	12	222.2	222.6	3.4	1	2
NT	6	218.4	219.4	9	220.6	221	1.6	3	6
NT	6	220.6	221.4	9	222.2	222.8	1.4	3	6
NT	6	222.6	223.6	9	224	224.6	1	3	6
NT	6	224.6	225.2	9	227.8	228.2	3	3	6
NT	6	226.2	226.6	9	228.8	229.2	2.6	3	6
NT	6	228.4	229	9	231.4	231.8	2.8	3	6
NT	6	230.8	231.2	9	233.4	233.6	2.4	3	6
NT	6	232	232.4	9	234.4	234.6	2.2	3	6
NT	6	233.2	233.6	9	235.4	235.8	2.2	3	6
ST	2	233.6	234	12	235.6	235.8	1.8	1	2
NT	6	235.4	235.8	9	237.4	237.6	1.8	3	6
ET	8	235.4	241.6	11	244.8	245.4	3.8	2	8
ST	3	236.6	237	13	238.6	239	2	1	3
NT	6	236.8	237.2	9	238.8	239	1.8	3	6
ET	8	242.8	244	11	246.6	247	3	2	8
WT	5	243	245.2	14	254.4	254.8	9.6	4	5
ET	8	246.2	246.8	11	248.8	249.4	2.6	2	8
ET	8	248.6	249	11	250.8	251	2	2	8
NT	6	249	277.2	9	280.8	281.2	4	3	6
ET	8	251	251.2	11	252.8	253	1.8	2	8
WT	5	251	253.2	14	256.2	256.6	3.4	4	5
ST	2	251.6	276.8	12	280.6	281	4.2	1	2
WT	5	254.4	255.2	14	258	258.4	3.2	4	5
WT	5	256.4	257	14	259.4	259.8	2.8	4	5
WT	5	258.2	258.8	14	261	261.4	2.6	4	5
WT	5	259.6	260.2	14	262	262.4	2.2	4	5
ST	3	260.4	276.6	13	280.4	280.8	4.2	1	3
WT	5	261.2	261.6	14	263.6	263.8	2.2	4	5
ET	8	262.4	263.4	11	267.2	267.8	4.4	2	8
WT	5	263.2	264.8	14	268.8	269.4	4.6	4	5
EL	8	264	264.8	10	267.6	268.4	3.6	2	8
WT	5	266.2	267.4	14	270.2	270.6	3.2	4	5
WT	5	268.8	269.2	14	271.4	271.8	2.6	4	5
WT	5	270.4	270.8	14	272.8	273.2	2.4	4	5
WT	5	271.6	272.2	14	274.2	274.6	2.4	4	5
WT	5	274	302	14	323.4	324	22	4	5
NT	6	278	278.8	9	281.6	282	3.2	3	6
ST	3	278	279	13	282	282.4	3.4	1	3
ST	2	278	279	12	283.8	284.2	5.2	1	2
ER	8	279.6	280.6	12	281.8	282.4	1.8	2	8
NT	6	279.8	280.6	9	283	283.4	2.8	3	6
ST	3	280.8	281.6	13	284	284.4	2.8	1	3
ST	2	280.8	281.4	12	285.4	285.8	4.4	1	2

10.1.2 *Unmatched Feed Detection Error Examples*

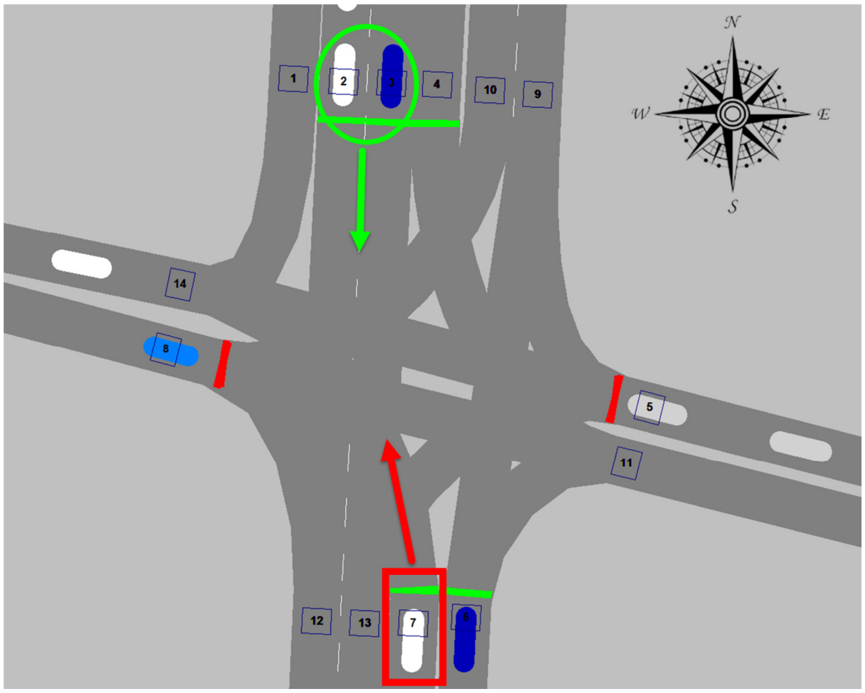

Figure A-1
Before Accident (Time Stamp: 67-96.8 sec)

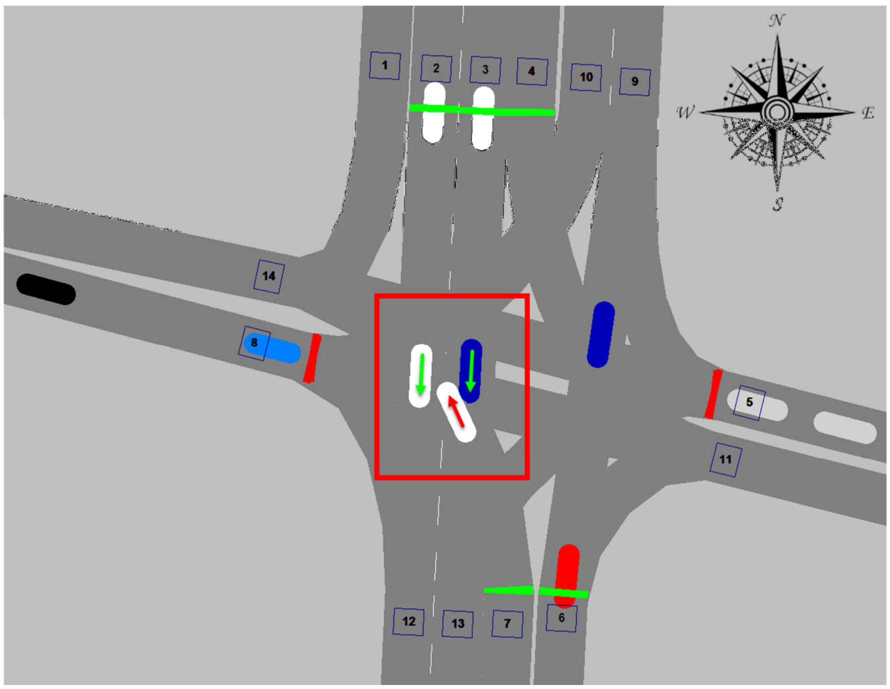

Figure A-2
During accident (Time Stamp: 67-96.8 sec)

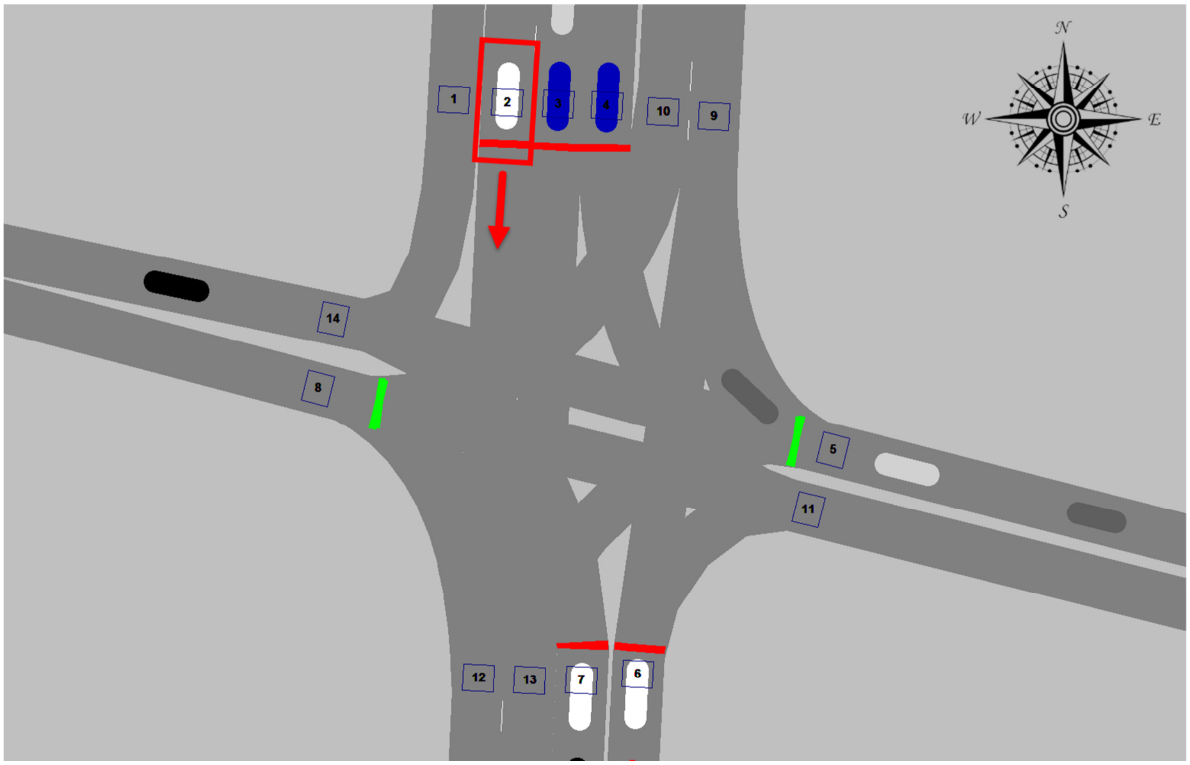

Figure A-3
Detector 2 Activated Early (Time Stamp: 602.4-636.8 sec)

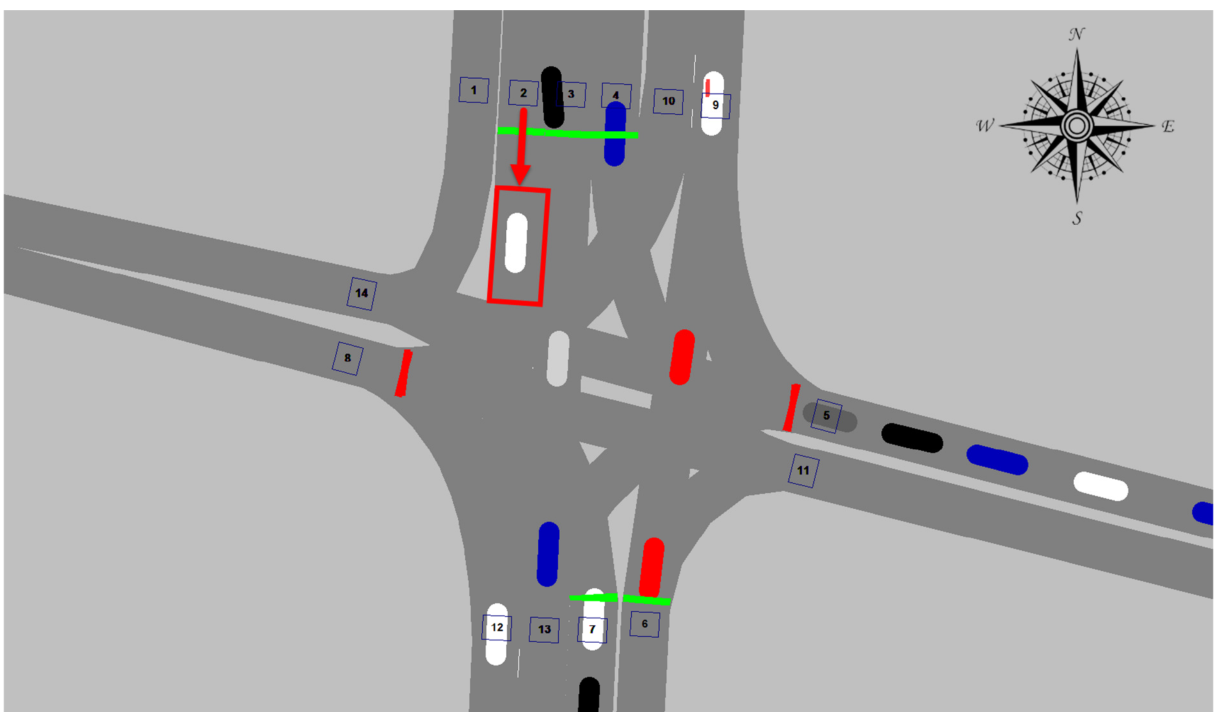

Figure A-4
Detector 2 Time Expires Before Match (Time Stamp: 602.4-636.8 sec)

10.1.3 No Feed Detection Error Examples

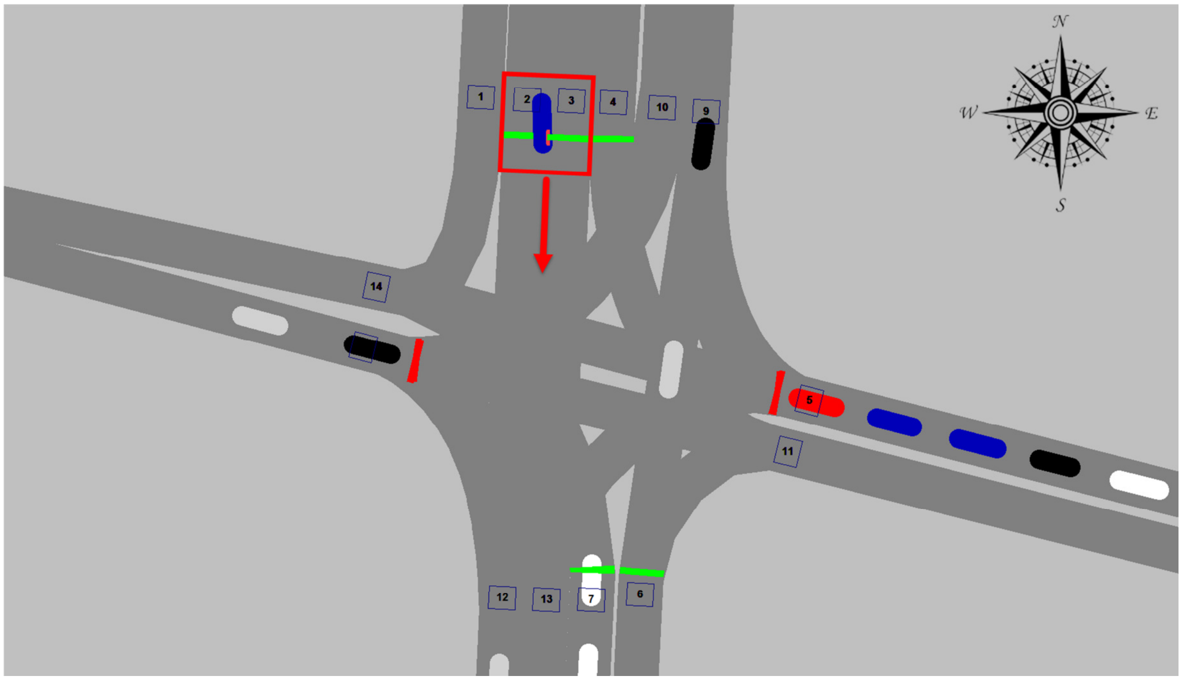

Figure B-1
Lane Change over Detector (Time Stamp: 587.6-588 sec)

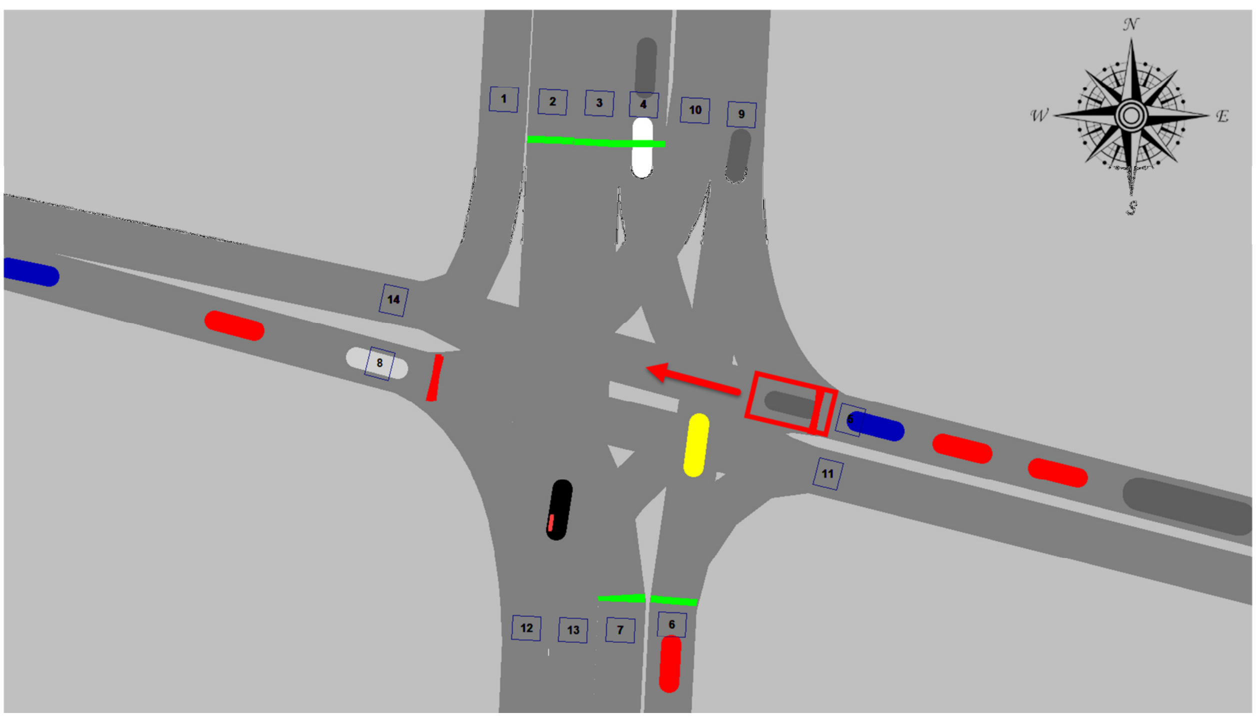

Figure B-2
Vehicle Running Red Light (Time Stamp: 587.6-588 sec)

10.1.4 Dead Lock Error Examples

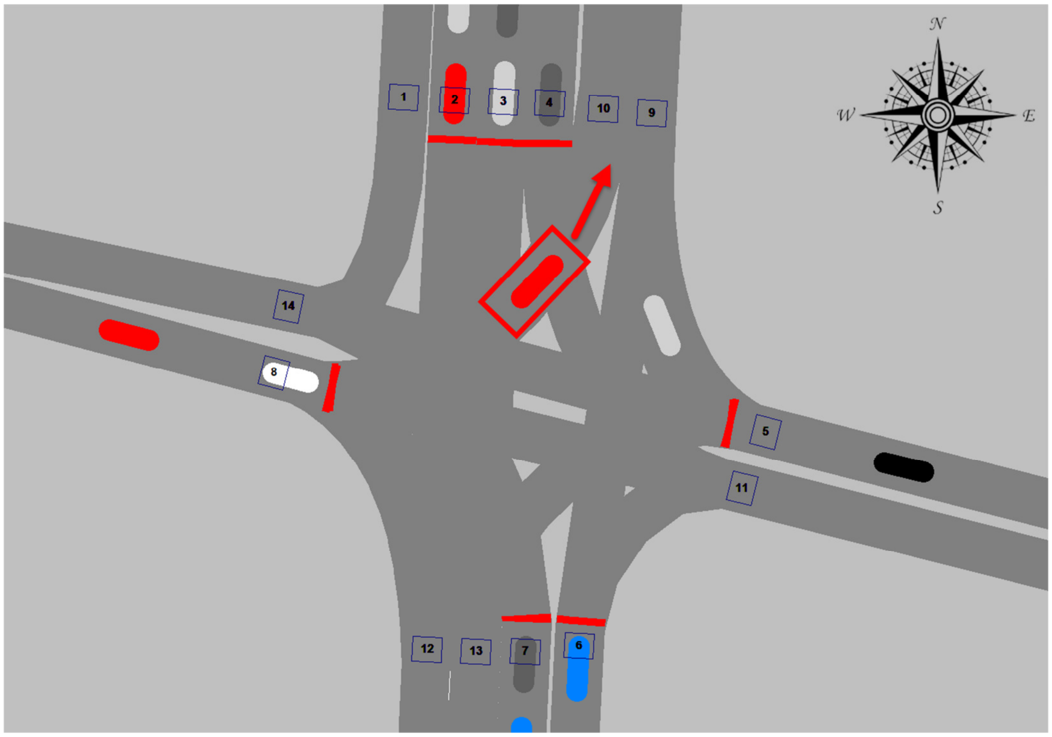

Figure C-1
Vehicle Turning on Red (Time Stamp: 702-702.4 sec)

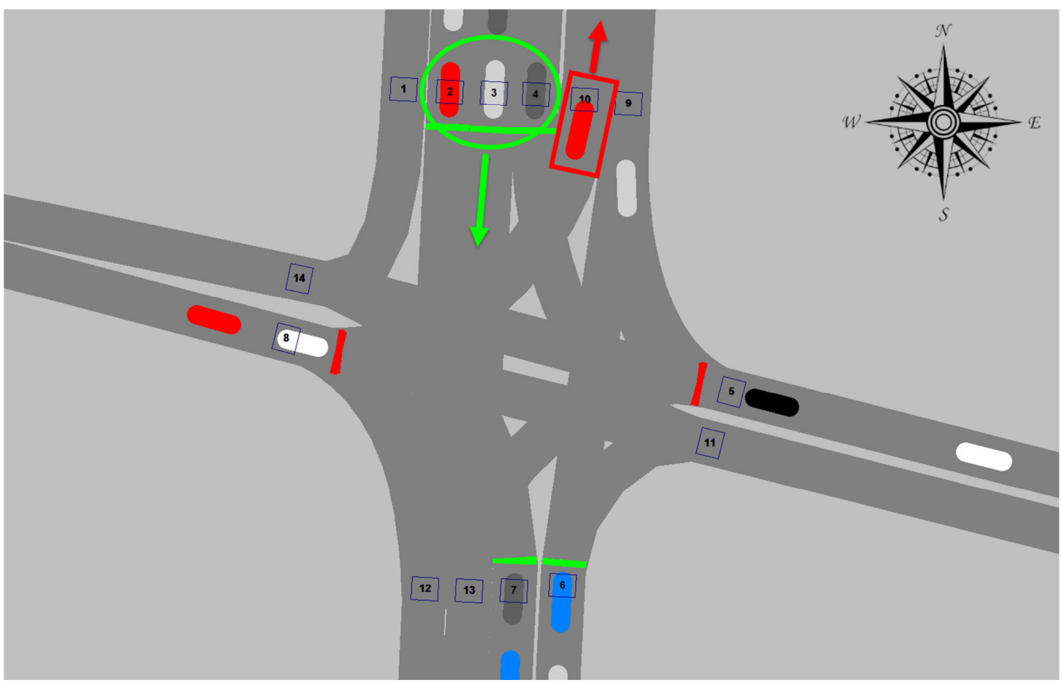

Figure C-2
Southbound Lanes Delayed (Time Stamp: 702-702.4 sec)

10.2 Intersection #2 Information

10.2.1 Intersection #2 Output

Table B-1

Intersection #2 – ATMIS Turning Movement Output

Turning	Feed Det.	Act. Time	Deact. Time	Sink Det.	Act. Time	Deact. Time	Intersection (T.T)	App No	Lane No
ER	5	14	37	4	38	38.6	1.6	2	5
WR	11	21.6	37	10	38.2	38.8	1.8	4	11
NL	2	24.2	24.6	6	25.8	26.2	1.6	3	2
ST	7	25.4	25.8	4	27	27.4	1.6	1	7
ST	8	35.2	62.2	3	64.2	64.6	2.4	1	8
WR	11	38.2	39.2	10	40	40.6	1.4	4	11
ET	5	38.4	39.4	12	41.4	41.8	2.4	2	5
NT	1	38.6	62.2	10	63.8	64.2	2	3	1
NT	2	38.6	65	9	66.8	67.4	2.4	3	2
ER	5	44.2	44.6	4	45	45.4	0.8	2	5
ET	5	46.8	47.2	12	48.4	48.8	1.6	2	5
EL	5	48.4	48.8	9	49.8	50.2	1.4	2	5
ET	5	50	50.4	12	51.8	52.2	1.8	2	5
WR	11	61.6	97.2	10	98.2	99	1.8	4	11
NT	1	63.2	64.2	10	65.4	66	1.8	3	1
NL	2	66.8	70.6	6	72.6	73.2	2.6	3	2
ST	7	67.8	68.2	4	69.2	69.6	1.4	1	7
ET	5	69.4	97	12	99.2	99.8	2.8	2	5
ST	8	74.8	75.2	3	76.2	76.6	1.4	1	8
ST	7	75.8	76.2	3	77.8	78.2	2	1	7
ST	8	76.4	76.8	4	77.2	77.6	0.8	1	8
SL	8	79.6	80	12	81.2	81.6	1.6	1	8
NL	2	81.6	82.2	6	83.4	83.8	1.6	3	2
ST	7	88.6	89	4	90.2	90.6	1.6	1	7
ET	5	98.4	99.4	12	101.6	102.2	2.8	2	5
WT	11	98.4	99.2	6	101.2	101.8	2.6	4	11
WT	11	100.4	101.2	6	103	103.4	2.2	4	11
NT	1	101.4	122.2	10	124	124.6	2.4	3	1
ST	8	103.4	122.2	3	124.2	124.8	2.6	1	8
ET	5	104.8	105.2	12	106.6	107	1.8	2	5
NT	2	106.2	125.2	9	127.2	127.6	2.4	3	2
WR	11	107	107.4	10	107.8	108.2	0.8	4	11
ET	5	107.6	108.4	12	109.4	110.2	1.8	2	5
WR	11	108.6	109	10	109.4	109.8	0.8	4	11
ET	5	109.2	109.6	12	111	111.4	1.8	2	5
WR	11	110.4	110.8	10	111.2	111.8	1	4	11
WR	11	116.4	116.8	10	117.4	117.8	1	4	11
NT	1	123.6	124.4	10	125.8	126.2	1.8	3	1
NT	1	126.4	127.4	10	129	129.6	2.2	3	1
SR	7	127.8	128.2	6	128.6	129.2	1	1	7
SL	8	128.4	132.6	12	134.8	135.4	2.8	1	8
NL	2	130.4	130.8	6	132	132.6	1.8	3	2
WT	11	138.8	157	6	159.4	160	3	4	11
ST	7	140.6	141	4	142.2	142.6	1.6	1	7
SL	8	143.6	144	12	145	145.4	1.4	1	8
ET	5	144.2	157.2	12	160	160.6	3.4	2	5
SL	8	151.4	152	12	153	153.6	1.6	1	8
NT	1	156	182	10	183.8	184.4	2.4	3	1
WR	11	158	159	10	159.8	160.4	1.4	4	11
ET	5	158.6	159.4	12	161.2	161.8	2.4	2	5
WT	11	160	160.8	6	162.6	163	2.2	4	11

Table B-1 Continued

Turning	Feed Det.	Act. Time	Deact. Time	Sink Det.	Act. Time	Deact. Time	Intersection (T.T)	App No	Lane No
WT	11	162.4	163.2	6	165	165.4	2.2	4	11
WR	11	164.2	164.8	10	165.2	165.8	1	4	11
NT	2	166.8	184.8	9	186.4	187	2.2	3	2
WR	11	169.8	170.2	10	170.6	171	0.8	4	11
SL	8	171.8	188.4	12	190.6	191.2	2.8	1	8
ET	5	178.8	217.2	12	219.4	219.8	2.6	2	5
ST	7	181.4	182	4	183.2	183.6	1.6	1	7
NT	1	183.8	184.4	10	185.6	186.2	1.8	3	1
WT	11	185.8	217	6	219.4	219.8	2.8	4	11
NL	2	186	186.8	6	188.4	188.8	2	3	2
SL	8	189.8	190.8	12	192.6	193.2	2.4	1	8
NL	2	193.4	193.8	6	195.2	195.6	1.8	3	2
ST	7	197.4	197.8	4	198.8	199	1.2	1	7
NT	1	197.6	198	10	198.8	199.2	1.2	3	1
NT	1	201.2	201.6	10	202.6	203	1.4	3	1
SL	8	203	203.6	12	205	205.4	1.8	1	8
ET	5	218.4	219.2	12	221	221.6	2.4	2	5
WT	11	218.4	219.4	6	221.8	222.4	3	4	11
ST	8	221	242.2	3	244.2	244.8	2.6	1	8
ET	5	221.4	222.6	12	226.4	227	4.4	2	5
EL	5	223.6	224.4	9	224.6	225	0.6	2	5
NT	1	224.4	242.2	10	243.8	244.4	2.2	3	1
WR	11	225.8	226.2	10	226.6	227	0.8	4	11
EL	5	225.8	227.2	9	229	229.6	2.4	2	5
NT	2	230.8	246	9	248	248.6	2.6	3	2
SR	7	239.6	242.2	6	243	243.8	1.6	1	7
NR	1	243.2	244.2	12	248.8	249.4	5.2	3	1
WT	11	243.4	277	6	281.6	282.2	5.2	4	11
ST	8	243.6	250	4	250.6	251	1	1	8
NT	1	245.6	246.2	10	247.4	248	1.8	3	1
NL	2	247.6	252	6	254	254.6	2.6	3	2
NR	1	247.8	248.4	12	252.6	253.2	4.8	3	1
ST	7	249	249.4	3	258	258.4	9	1	7
ET	5	249.6	277.4	12	279.8	280.4	3	2	5
NL	2	253	254	6	255.6	256.2	2.2	3	2
SL	8	256.6	257	12	271.4	271.8	14.8	1	8
SL	8	264	264.4	12	265.6	266.2	1.8	1	8
SL	8	266	266.4	12	267.6	268.2	1.8	1	8
NL	2	269	269.4	6	270.4	271	1.6	3	2
NT	1	270.8	271.2	10	278	278.8	7.6	3	1
ET	5	278.2	279.2	12	281	281.4	2.2	2	5
WT	11	278.4	279.4	6	286	286.4	7	4	11
NR	1	279.8	302.6	12	303.4	304.4	1.8	3	1
ER	5	280.4	281.2	4	281.8	282.4	1.2	2	5
WR	11	280.4	281	10	281.8	282.2	1.2	4	11
ER	5	282.2	282.8	4	283.2	283.8	1	2	5
WR	11	282.2	282.8	10	283.4	283.8	1	4	11
ET	5	284	284.6	12	286	286.6	2	2	5
WR	11	284	284.4	10	286.8	287.2	2.8	4	11
WR	11	285.8	286.2	10	305.8	306.2	20	4	11
EL	5	287.8	288.2	9	289.4	289.8	1.6	2	5

Table B-1 Continued

Turning	Feed Det.	Act. Time	Deact. Time	Sink Det.	Act. Time	Deact. Time	Intersection (T.T)	App No	Lane No
ST	8	289.6	302.4	4	304	304.4	2	1	8
ET	5	290.4	290.8	12	292.2	292.8	2	2	5
NT	2	291.6	305.8	9	307.8	308.4	2.6	3	2
ET	5	295.4	295.8	12	297	297.4	1.6	2	5
ST	7	298	302	3	304.6	305.2	3.2	1	7
NR	1	303.8	304.4	12	311.2	311.6	7.2	3	1
WT	11	305.8	354.4	6	367.2	367.6	13.2	4	11
ER	5	307.8	337.2	4	340	340.6	3.4	2	5
ST	7	309.4	309.8	4	310.8	311.2	1.4	1	7
NR	1	310.4	310.8	12	329.6	330.2	19.4	3	1
NL	2	310.8	312	6	313.6	314.2	2.2	3	2
NT	1	325.6	326	10	326.8	327.2	1.2	3	1
ST	8	327	328	3	356.8	357.4	29.4	1	8
NL	2	332.4	332.8	6	334	334.4	1.6	3	2
ET	5	338.4	339.2	12	339.4	340	0.8	2	5
ER	5	340.2	340.8	4	341.6	342	1.2	2	5
ST	8	340.6	362.2	4	363.8	364.4	2.2	1	8
ET	5	342.2	342.8	12	344.6	345	2.2	2	5
EL	5	345.2	345.8	9	347	347.4	1.6	2	5
ER	5	347.4	347.8	4	348.4	348.8	1	2	5
NT	2	350.2	365	9	365.8	366.2	1.2	3	2
EL	5	350.8	351.2	9	352.2	352.6	1.4	2	5
ET	5	352.4	352.8	12	354.2	354.6	1.8	2	5
WT	11	355.8	397	6	399.6	400	3	4	11
NT	1	357.4	362.2	10	363.8	364.4	2.2	3	1
ST	7	360.2	362	3	364.2	364.8	2.8	1	7
NT	1	363.6	364.4	10	368.4	368.8	4.4	3	1
NT	1	366	367	10	373	373.4	6.4	3	1
ET	5	367	397.2	12	399.4	400	2.8	2	5
ST	7	367.8	368.2	3	369.4	369.8	1.6	1	7
ST	8	368	368.4	4	369.4	369.8	1.4	1	8
ST	7	369.2	369.6	4	370.6	371	1.4	1	7
SR	7	371.2	371.6	6	372	372.4	0.8	1	7
NT	1	371.6	372.2	10	405.4	405.8	33.6	3	1
ST	7	373	373.4	4	374.4	374.8	1.4	1	7
SR	7	381	381.4	6	381.8	382.2	0.8	1	7
NL	2	383.8	384.4	6	385.6	386	1.6	3	2
ST	7	393.2	393.8	4	394.8	395.2	1.4	1	7
WT	11	398.4	399.4	6	401.8	402.4	3	4	11
EL	5	398.8	415.4	9	418	418.6	3.2	2	5
ST	8	398.8	422.2	4	425.6	426	3.8	1	8
ST	7	399.4	422	3	424	424.4	2.4	1	7
WT	11	400.6	401.4	6	403.2	403.8	2.4	4	11
WT	11	402.4	403	6	404.8	405.2	2.2	4	11
WL	11	404.2	404.8	3	412	412.4	7.6	4	11
WR	11	405.2	405.8	10	406.2	406.6	0.8	4	11
WT	11	407	407.4	6	408.8	409.2	1.8	4	11
WT	11	408.6	409	6	410.6	411	2	4	11
WT	11	410.4	410.8	6	422.8	423.6	12.8	4	11
WR	11	411.6	412	10	412.4	412.8	0.8	4	11
WR	11	413.6	414	10	414.4	414.8	0.8	4	11

10.2.2 Unmatched Feed Detection Error Examples

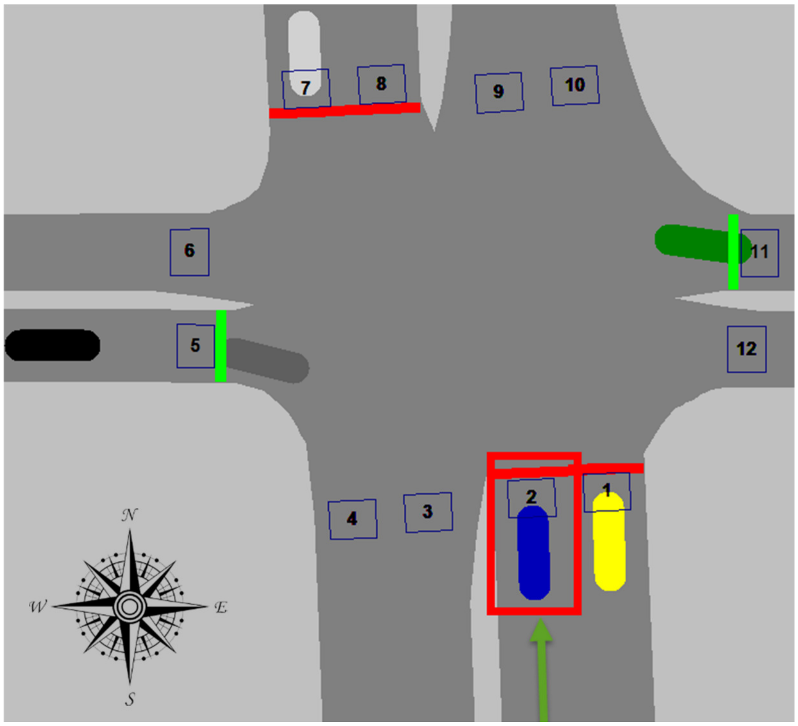

Figure D-1
Detector 2 Activated Early (Time Stamp: 1776.2-1795 sec)

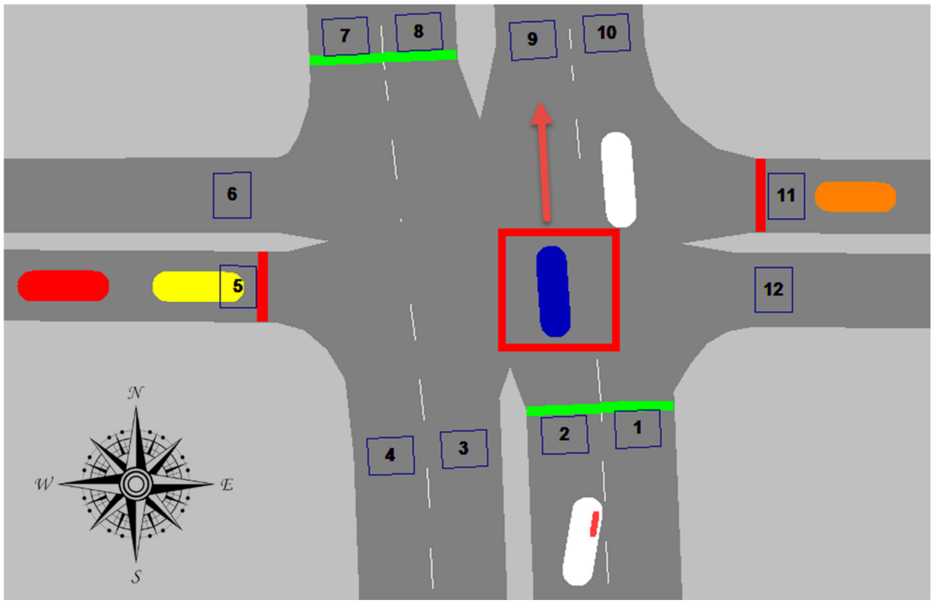

Figure D-2
Detector 2's Time Expires Before Match (Time Stamp: 1776.2-1795 sec)

10.2.3 No Feed Detection Error Examples

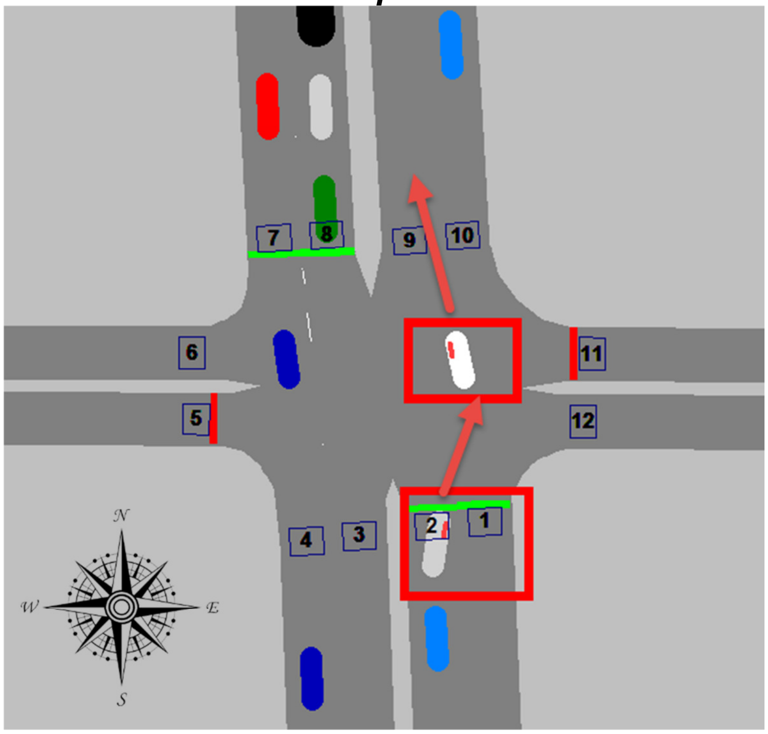

Figure E-1
Lane Change between Detector 1 (Time Stamp: 905.8-906.2 sec)

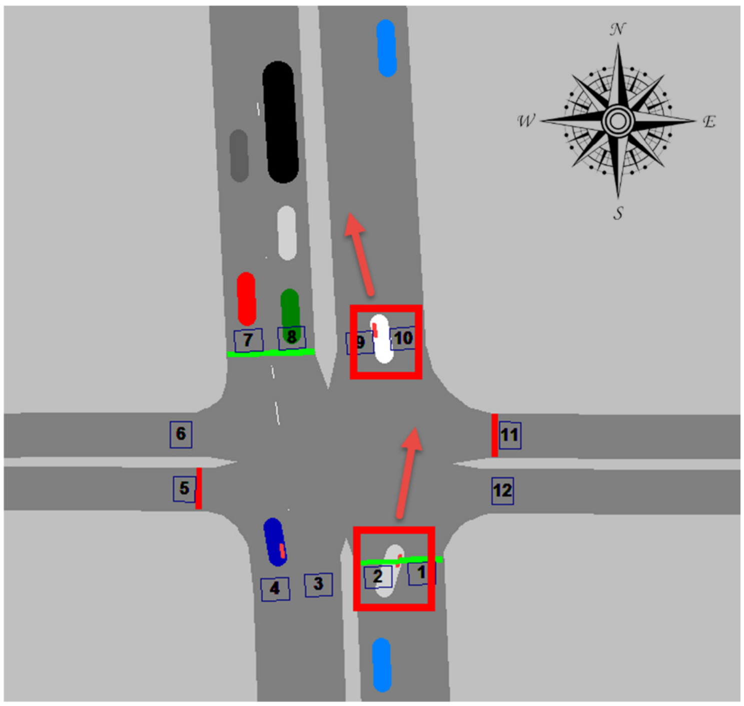

Figure E-2
Lane Change between Detectors 2 (Time Stamp: 905.8-906.2 sec)

10.2.4 Dead Lock Error Examples

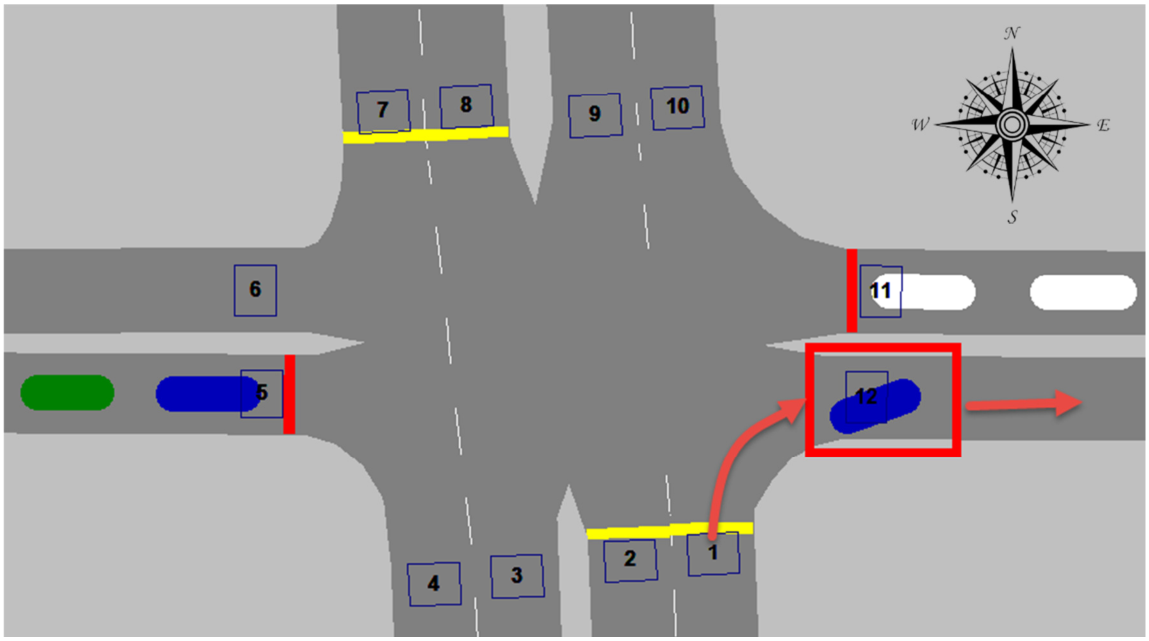

Figure F-1
Vehicle Right Turn on Yellow (Time Stamp: 271.4-271.8 sec)

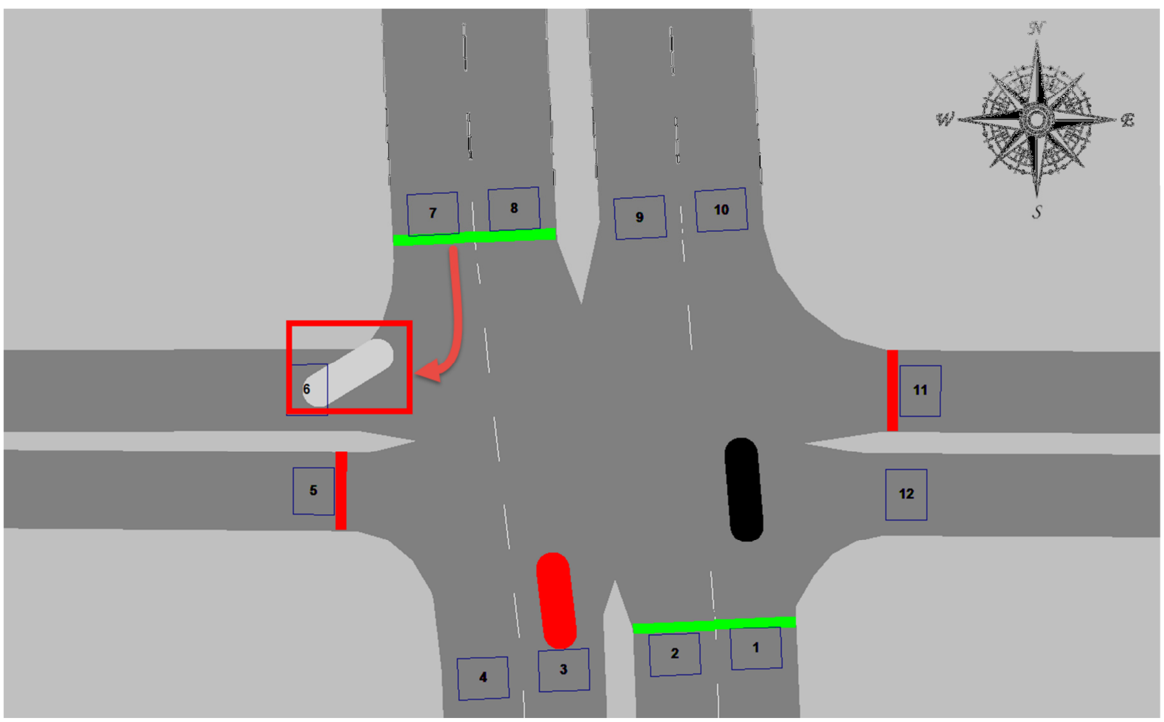

Figure F-2
Slowed Vehicle Making Right Turn (Time Stamp: 543-543.6 sec)