2011-03-16

Automated Delay Estimation at Signalized Intersections: Phase I Concept and Algorithm Development

Taylor R. Forbush
Brigham Young University - Provo

BYU ScholarsArchive Citation
Forbush, Taylor R., "Automated Delay Estimation at Signalized Intersections: Phase I Concept and Algorithm Development" (2011). *All Theses and Dissertations*. 2471.
https://scholarsarchive.byu.edu/etd/2471

Automated Delay Estimation at Signalized Intersections:

Concept and Algorithm Development

Taylor R. Forbush

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

Mitsuru Saito, Chair
Grant G. Schultz
Dennis L. Eggett

Department of Civil and Environmental

Brigham Young University

April 2011

ABSTRACT

Automated Delay Estimation at Signalized Intersections: Concept and Algorithm Development

Taylor R. Forbush
Department of Civil and Environmental Engineering, BYU
Master of Science

Currently there are several methods to measure the performance of surface streets, but their capabilities in dynamically estimating vehicle delay are limited. The objective of this research is to develop a method to automate traffic delay estimation in real-time using existing field traffic data collection technologies. This research has focused on method and algorithm development that can be applied to existing technologies. Two algorithms were developed to run automatically using Microsoft Excel and Visual Basic to calculate traffic delay from data collected from existing vehicle detection. The algorithms were developed using computer modeling software to simulate different lane configurations. The lane configurations tested were through-only lanes, through lanes with a midblock driveway, and through lanes with a turning bay. Different levels of volumes were simulated for each of the lane configurations. Results were promising for each lane configuration. The through-only configuration showed excellent results with maximum errors less than 3 seconds per vehicle for each test. The through lanes with the driveways test was evaluated using added detection at the driveway locations and no detection at the driveways. Results using the driveway sensors had 93 percent of the calculated average delays with less than 5 seconds per vehicle of error. Results without the driveway sensors had 84 percent of the calculated average delays with less than 5 seconds of error. Results for the turning bay configuration had 94 percent of the calculated turning bay results with less than 5 seconds per vehicle of error. It is recommended to conduct a hardware-in-loop analysis to make certain the algorithms developed in this study perform as expected in a dynamic operation.

Keywords: automated delay estimation, arterial delay, traffic delay

ACKNOWLEDGEMENTS

This research was made possible with funding from the Utah Department of Transportation (UDOT) and Brigham Young University (BYU).

Special thanks to Dave Kinnecom, UDOT's Traffic Management Engineer, for his ideas which led to the initial concept of this research. Special thanks are due to the Technical Advisory Committee (TAC) members, which consist of Blaine Leonard, UDOT Research and Development and the project manager of this research, Mark Taylor, UDOT Signal Systems Engineer, Glenn Blackwelder, UDOT Traffic Operations Engineer, Matt Luker, UDOT Assistant Signal Systems Engineer, John Haigwood, UDOT Freeway Operations Engineer, and David Stevens, UDOT Research and Development for their comments and suggestions through the course of the research.

Thanks are also due to Dr. Mitsuru Saito, my advisor, for his continual support, persistence, and guidance throughout this research. Thanks to Dr. Grant G. Schultz and Dr. Dennis L. Eggett for their comments and suggestions for improvement. In addition, thanks to Bradley Mecham for his outstanding programming work that made the automated portion of this research possible.

Lastly, thanks to my family and my wife, Jessica, who has always inspired me to continue learning and seek for excellence.

TABLE OF CONTENTS

LIST OF FIGURES

1 Introduction

Measuring the performance of traffic on signalized intersections has been one of the many tasks that a traffic operations center (TOC) carries out. It is difficult to measure performance of signalized intersections because of the variation in traffic volumes, vehicle speeds, queue build up, vehicle delays, and the degree of saturation. Currently there are several methods to measure the performance of signalized intersections, but their capabilities in dynamically estimating vehicle delay are limited.

Estimating traffic delay using the method found in the Highway Capacity Manual (HCM) 2000 (TRB 2000) is a time demanding process that requires field measurements of geometric, traffic, and control data. Results from the HCM method reflect only the small window of time when the data were collected and do not necessarily represent the current conditions. The HCM method requires two observers and is difficult to perform for time periods longer than 15 minutes. Researchers have worked on creating a process to automate delay and travel time data collection to obtain accurate and reliable information within minutes instead of hours or days.

With real-time traffic delay data, traffic engineers have the ability to make adjustments to traffic signal timing when delay times become unacceptable. Another advantage of real-time traffic delay data is the ability it gives traffic engineers to make travel time estimates for signalized corridors. Although several dynamic methods have been developed to estimate traffic delay in real-time, no method has produced results reliable and accurate enough to use at city-run or state-run TOCs.

Hence, there is a need for a new dynamic delay calculation method that uses current signal detection infrastructure and can be implemented easily on a signalized corridor. This study fulfills the need for developing a new delay calculation method that can be implemented on signalized corridors using existing traffic sensor technologies.

1.1 Purpose

The purpose of this research is to develop a method to automate traffic delay estimation in real-time using existing field traffic data collection technologies. The purpose is not to estimate every leg of a signalized intersection, but to estimate the delay for through vehicles. Delay and travel times for through vehicles on a major arterial could then be pieced together to estimate the travel time and delay time through an entire corridor. While most automated travel time studies in the past have focused on inventing new technologies to estimate traffic delay, this research has focused on method and algorithm development that can be applied to existing technologies.

1.2 Scope

This research completes Phase I of a three phase study. The three phases to this study are: Phase I, algorithm and method development using computer modeling; Phase II, hardware-in-loop testing of the method developed in Phase I; Phase III, field testing and calibration of the method developed in Phase II. Phase I of this study focused on the development of an algorithm to calculate traffic delay. Several approach roadway geometries were analyzed using VISSIM software in the algorithm development. The analysis in Phase I used only data collected from VISSIM.

1.3 Report Organization

This report is organized into six chapters. Chapter 1 includes the introduction, objective and scope of the study. Chapter 2 presents a literature review of the available research relating to the topic of automated delay estimation. This chapter summarizes four different research studies that have shown some success in automated delay estimation. Chapter 3 includes the study methods of the research and the roadway configuration cases that were analyzed for the study. Chapter 4 presents the concept and mechanism of the delay estimation algorithms developed in this study, explaining in depth how the algorithms that were developed in the study calculate vehicle delay. Chapter 5 discusses the results of the analysis and presents results of the delay analysis in graphs that were created from the delay estimation processes for the different lane configurations. Chapter 6 then provides the conclusions of the study and recommendations for future studies.

2 Literature Review

A literature review was conducted to identify current and forthcoming automated real-time methods of calculating vehicle delay on surface streets. This chapter presents the findings from the available research that has shown some success in determining traffic delay using real-time technologies. This chapter is divided up into sections that correspond to previous research studies to address each of the automated delay calculation methods that have been developed. The sections include the following: 1) vehicle re-identification, 2) still-image analysis, 3) maximum queue length, 4) vehicle event based method, and 5) literature review summary.

2.1 Vehicle Re-identification Method

Several technologies have been tested to determine whether or not they can provide a feasible way of determining travel-times along a roadway segment. This section identifies two studies that have used a vehicle re-identification method to determine the travel-time of a given segment of road. The first technology utilized is inductive loop detectors capable of identifying vehicles upstream and downstream. Each is time-stamped and the two are matched in order to determine the travel time of vehicles passing. The second technology is a Bluetooth technology that detects Bluetooth wireless devices in passing vehicles. Each Bluetooth device is uniquely identified at two locations on a route. Travel times are calculated by the time difference when a Bluetooth device was identified at both detection locations.

2.1.1 Vehicle Re-identification with Embedded Sensors

A study conducted by Liu et al. (2001) used loop detectors that had the added capability of producing a unique signature for each vehicle. By capturing a unique signature for each vehicle, researchers hoped that this method would allow them to re-identify vehicles downstream of where the signature was captured in order to estimate intersection delay in real-time. This study focused on using the delay data to develop a “pro-active” response to adjust traffic signals to current conditions. This method was field tested at an intersection in Irvine, California using live traffic.

The inductive loop detectors work by capturing changes to the inductance of electric current caused by the magnetic material from passing vehicles. The captured changes create a unique signature that is vehicle specific. Each vehicle will have its own unique signature that can be re-identified at different locations.

Two sets of double loops were used for each traffic lane of the study intersection. The intersection of study has three approach lanes coming from all four legs of the intersection. Approach loops in this study were set up between 325 and 375 feet from the intersection. Departure loops were also set up just downstream of the intersection. A total of 48 inductive loops were used on one signalized intersection.

The data collected from the sensors was linked into the Irvine Transportation Center where the data were stored and then processed. Because of the interruptions in flow caused by the traffic signal, there was a lower rate of identification than there was for highway situations (Liu 2001). For this signalized intersection that was tested, over 40 percent of the vehicles passing were correctly identified at both the entry nodes and the exit nodes of the system. Travel-times were calculated by subtracting the entry time from the exit time. When comparing actual travel-times to travel-times determined by the study, the travel-times in this study resulted in an average travel time that had an error of less than 15 percent from the actual travel time. Travel delays were calculated by subtracting the minimum travel time, which is calculated by dividing the distance between the inflow and outflow sensors by the speed, from the actual time. These delays are then averaged to determine the average delay through the intersection.

The study by Liu et al (2001) attempted to link the delays directly into adaptive signal controls in order to get a real time response to demand. Feedback from the delay would be given to the controller to optimize the system to reduce delay. The controller is optimized using a delay projection by considering delay from all directions. Different optimization parameters exist for actuated signals and fixed-timed signals. Algorithms for the signal optimizations were tested in Paramics, a microscopic simulation software program (Liu 2001). There was a considerable reduction in delay during times of high demand when the on-line signal optimization was used in place of a fixed control or an actuated control with all other parameters being equal. There was no difference in delay for times of low demand.

The re-identification method with loop detectors has not been tested at a network level. Additional research should be conducted in order to broaden the scope of this method to determine advantages of this method for an entire network. A drawback of this method is the large number of loop detectors required at a site. Detectors can be costly and hard to maintain. Any malfunction of the detectors would result in a failure of the system to function properly. In addition the amount of data collected by the loop detectors is large. There is a high demand on a computer system to complete the necessary computations to recognize each of the vehicles. If used on a larger network, more computing capacity would be necessary to operate the system. As a whole, this system would be very costly and would likely need regular and frequent maintenance. Due to these factors, this method is not necessarily feasible and is not to the point where it can be marketed to public operations.

2.1.2 Vehicle Re-identification Using Bluetooth Sensors

Communication technologies have allowed for another way to identify vehicles. Wireless technologies have made it possible for wireless electronic devices, like cellular phones, inside vehicles to be identified with roadside sensors. A study was conducted by Wasson et al. (2008) to estimate real-time travel time estimates using Bluetooth communications. Electronic devices with Bluetooth capabilities can be identified with a unique media access control (MAC) address. These MAC address are identified and time-stamped when they pass a sensor and can then be re-identified and time-stamped downstream. This allows for the collection of accurate travel times as vehicles traverse between the two sensors.

The travel time study for the Wasson et al. (2008) report was conducted in Indianapolis on both an arterial and an interstate. The segments tested were approximately 8.5 miles and 5.25 miles. There is an inherent spatial error of a few hundred feet with the Bluetooth devices. This error means that a vehicle could be detected upstream or downstream 100 feet from the sensor and the Bluetooth device would not be able to differentiate the two. This error is relatively small when the segment lengths between sensors are larger than 2 to 3 miles. Additional errors are added by quick stops by drivers that cause the calculated travel times to be higher than the actual travel time. Since there are only two sensors, one at the beginning and one at the end of the test segment, there was no way to tell if a vehicle stopped along the way at a store, dry cleaners, or a fast food drive-through. This error can be adjusted using a percentile method that removes unusually high travel times. A percentile method excludes travel times from vehicles that are a user defined percentage above other vehicle travel times from being weighted into an average travel time (Wasson et al. 2008).

For the field testing, a Bluetooth sensor was placed on the north side on the freeway, which collected data for both eastbound and westbound traffic. The sensor correctly identified about 1.2 percent of the daily westbound traffic, the side closest to the sensor, and about 0.7 percent of the daily eastbound traffic. These results are slightly lower than would be expected for a full deployment of the Bluetooth sensors because only one trip direction was collected for each of the MAC addresses identified. Multiple trips back and forth likely occurred for some of the MAC addresses during the tests that were only recorded once. In addition, many of the vehicles entered or exited the test section between the sensors. These vehicles also account for the small number of vehicle travel-times actually collected.

The field tests collected data during a period of sunny conditions on a Saturday and also a period of snowy conditions on a Monday workday. Comparing a plot of the two travel-times, the travel time for the snowy workday was much easier to predict. Increases in delay and travel time are easily observed on a plot of the travel time vs. time. A smaller variance was also seen in the Monday workday when compared to a sunny Saturday. Spikes in delay are seen during the peak hours of traffic as congestion increases. The daily travel time trends collected from the Bluetooth sensor follow the expected trends (i.e. larger travel times during the AM and PM peak driving times).

The spread of travel-times for traffic on the arterial street was much larger than the spread of travel-times on the Interstate. This is due to a larger variability of travel time on arterials due to signalized intersections. Since each of the vehicles does not travel in the same platoon, a higher variability of travel-times is to be expected.

The Bluetooth technology has a lot of potential applications for the future. This technology can be integrated into message boards that display travel times. Bluetooth technology would be ideal as a systems tool to determine origin-destination information system wide. This would help planners in travel demand models and route choice information. Since people generally carry their phones and wireless devices with them, this can also be used to determine changes to travel modes. In addition it can be used for pedestrian traffic in areas such as airports and malls. The technology has many potential applications to provide vital information to improve the overall system performance.

Due to the inherent spatial errors associated the Bluetooth devices, Bluetooth sensors and MAC identification is not to the point where it can be marketed to shorter arterial segments. More precision is needed on the exact location of the vehicles in order to use Bluetooth technologies on a shorter segment. Also a lack in the number of vehicles with Bluetooth-enabled devices may not make this technology practical to be a significant indicator of true travel time at the time when this literature review was conducted. Statistical testing would be needed in order to determine an appropriate sampling rate necessary to collect accurate travel-times. As the use of Bluetooth technologies becomes more popular, this may be a good method in the future to determine travel times across larger distances. In order for this method to be practical on smaller segments of arterials the spatial errors need to be reduced significantly. In addition, with this technology becoming more prevalent, there needs to be a way to calibrate the number of Bluetooth devices that are counted in a single vehicle. No information was given by Wasson et al. (2008) about calibrating for multiple Bluetooth devices in a single vehicle. Vehicles with more than one Bluetooth device can be double counted which can introduce addition errors.

Since this literature review began, additional research has been completed on Bluetooth use for travel time estimation purposes. A study by Brennan et al. (2010) identified issues with sensor placement that affects the number of the blue tooth devices detect. This study was conducted adjacent to the southbound lanes on Interstate-65 in northwest Indianapolis, Indiana. Antenna heights of 0, 2.5, 5.0, 7.5, and 10.0 feet were used on the side of the highway to determine the ideal antenna height of the Bluetooth sensor. Between 5 percent and 10 percent of the vehicle population passing the sensor had detectable Bluetooth devices. More southbound vehicles were detected than northbound vehicles. This was expected by the researchers because the southbound vehicles are closer to the sensors. The split between the percent of vehicles detected for each direction was less with 7.5- and 10-foot antenna heights than the smaller antenna heights. Brennan et al. (2010) suggest that the split bias could be mitigated by placing the Bluetooth sensor in the median of the freeway.

While lateral distances of Bluetooth devices to the antenna played a role in the successful identification of Bluetooth devices, no research has been completed on the placement of the antenna with respect to horizontal distances where Bluetooth devices can be successfully detected. Since this issue has not been researched in depth, the spatial errors associated with Bluetooth devices as mentioned in the research by Wasson et al. (2008) remains a problem with delay times at closely spaced signalized intersections.

2.2 Image Analysis Method

2.2.1 Still-Image Analysis Method

Saito et al. (2001) and Hereth et al. (2006) conducted studies using traffic cameras at signalized intersections to measure their ability to collect traffic delay data. The goal of the studies was to determine a way for traffic delay data to be collected by analyzing images taken by a traffic monitoring camera. In both studies camera image analysis software identified individual vehicles as they moved into the camera view. The software was able to track the moving vehicles by analyzing intensity values of pixels along an established line of pixels through the middle of a travel lane. Three methods were produced to analyze the video images: 1) Gap Method, 2) Gap Hybrid Method, 3) Motion Method. These methods are described in more detail in the following subsections.

2.2.1.1 Gap Method

The Gap Method analyzes traffic camera images in order to calculate the gap between subsequent vehicles (Hereth et al. 2006). Distance between subsequent vehicles is calculated by a computer software based image analyzer. When this distance is smaller than the distance specified by the operator, the vehicle is considered stopped and in the queue. The time a vehicle is stopped is added into a running total which stops at an operator specified test period. The total time is then divided by the total number of vehicles resulting in an average stopped delay.

While the theory of the gap method is relatively simple and straight forward, application is difficult in real practice. The gap method is limited by the camera angle. Cameras that are pointed upstream of the traffic cannot see the gap between subsequent vehicles because the height of the vehicle closer to the camera blocks the view of the gap. To the image processing, a whole queue appears to be a single vehicle. In order to solve this problem, the software specified a maximum vehicle length that would allow the camera to split a queue into multiple vehicles. Due to the inability of the camera to correctly measure the gap between the vehicles, it is possible that the actual number of vehicles is not the same as what the software calculates (Hereth et al. 2006). In addition, without being able to see the gap, the software may not correctly assess when a vehicle is stopped. This may incorrectly add stopped time to the total stopped time when the vehicles are still moving.

2.2.1.2 Gap-Hybrid Method

The gap-hybrid method is similar to the gap method with one notable difference. Instead of assigning a maximum vehicle length to divide up a long queue, the gap-hybrid method analyzes previous frames to estimate vehicle length before the vehicles enter the queue. The vehicle lengths are then proportioned as they enter the queue in order to better estimate the number of vehicle queued up. The software sees vehicles in the queue that are longer than normal because the gap between the vehicles is included into their lengths. Delay is then calculated in a similar manner to the Gap Method (Hereth et al. 2006).

2.2.1.3 Motion Method

The motion method analyzes the front and back of vehicles as they pass through the intersection area. Both the front and back of the vehicles are compared frame by frame to measure the distance each traversed. To obtain the speed of both the front and back of the vehicles, the distance each moved between frames is divided by the duration between consecutive frame shots. The speed of the vehicle is determined by averaging the speeds of the front and back of the vehicles. Speeds under a certain threshold, for example 5 mph, are counted as stopped. Unlike the gap and gap-hybrid methods, the motion method doesn’t look at the gap of the vehicles. The motion method, however, has similar problems to the gap methods. In each method, the camera angle makes it difficult to distinguish cars that are close together. The camera software just sees one long vehicle instead of multiple vehicles. In order to solve this problem, the software is set up to allow for a maximum vehicle length. Once a vehicle exceeds this length, the software breaks them up and counts both of them as single vehicles with the same delay time. The average delay time for all of the vehicles passing through the study approach is the sum of each vehicle delay time divided by the total number of vehicles passing (Hereth et al. 2006).

Saito et al. (2008) conducted a study to test different software technologies to automate delay estimation using the motion method of image processing. The results collected for the study were compared to the Institute of Transportation Engineers (ITE) stopped delay measurement method and the HCM 2000 (TRB 2000) control delay measurement method. Both the ITE and HCM 2000 methods had different results than the motion method. The researchers concluded that the video analysis software would produce more reliable delay estimates than the ITE or HCM 2000 delay estimation methods (Saito et al. 2008).

2.2.1.4 Performance of Compared Still-Image Methods

The still-image based methods were tested on about 5 minute of film. The analog film was digitized at 30 frames per second totaling to 9,300 still images. The film was analyzed by researchers to estimate delay manually. Delay was calculated using the ITE manual method for a 10-second, a 15-second interval. In addition, delay was calculated with a 1-second interval. The resulting delay was 12.4 seconds, 13.2 seconds, and 10.4 seconds per vehicle respectively. These results stand as a base to compare to the still-image methods. The frames were analyzed on intervals of 5, 10, 15, 20, 30, 40, and 60 frames. This equates to intervals of 1/6, 1/3, ½, 2/3, 1, 4/3, and 2 seconds respectively. The most reliable results were seen using intervals between 10 and 20 frames for the gap and gap-hybrid methods and using intervals between 10 to 40 frames for motion method. These produced an average stopped delay of 12.6, 12.9, and 11.8 seconds per vehicle for the gap, gap-hybrid, and motion methods respectively. Each of these values is very comparable to the ITE delay method values.

In order to test the validity of each image based method, another intersection was chosen to test the algorithms for each of the methods of collecting delay. The second intersection tested had a lower camera angle which had some effects on the computations. There were some problems with the motion method due to the difficulty in being able to identify the beginning and the end of a vehicle with a low camera angle. Vehicles in this method were largely over counted. Calibrations were done which improved the delay calculations slightly but the calculated delays were still considerably off from the ITE method. Camera angle had a large effect on the model accuracies. However, each still-image based method was effective and had comparable results to the ITE method of determining delay when the camera angle was high (Hereth et al. 2006). This process is not to the point where it can be marketed for public use. The process of analyzing frames has a large computing demand for a computer. Computers dedicated to processing the information would be necessary to use any of these methods. No research has been done about the amount of memory and computing speed that would be necessary to make this method practical for real-time applications. Additional research is necessary in order to make these methods feasible in real time.

2.3 Maximum Queue Length Method

Both delay and queue lengths are quantitative measures of effectiveness (MOE). Both of these values can be used to evaluate and improve the performance of a signalized intersection. Sharma et al. (2007) conducted a study using two different data collection techniques to collect vehicle delay time at signalized intersections. These data collection techniques include the input-output model and the hybrid model. The input-output model uses inputs from advance detector actuations, phase change data, and parametric data (i.e. saturation headway, storage capacity, etc.) in a collaboration to estimate the queue growth and the time in queue in order to determine an estimate of delay. The hybrid model uses inputs from advance detector actuations, stop bar detector actuations, phase change data, and parametric data (i.e. storage capacity) to estimate the queue length and delay. The hybrid model is designed to be a little more accurate due to the extra stop bar detection. It relies on the assumption that vehicles will not change lanes after crossing the advance detector and follow a first-in-first-out linear progression.

When evaluating the input-output and hybrid methods of estimating delay, the results from the input-output method were closer to the ground truth data than the hybrid method. The reason for this was due to the noise in the data that was caused by the stop bar sensor, which reduced the accuracy of the method. This study was conducted at an intersection with long left-turn and right-turn bays. This reduced the effect that the turns had on the either method for calculating delay. Where long turning bays are not available, there may be a significant reduction in the level of performance for the input-output method.

Both the input-output and hybrid methods have been successful in determining accurate delay information. The input-output method is far less expensive than the hybrid method because of the lack of a stop bar sensor. Sharma et al. (2007) stated that unless special conditions warrant the hybrid method (i.e. large spillbacks and large variability in saturation flow rate), the input-output method was the preferred alternative This technique is more cost effective and can produce results that are satisfactory in estimating delay and maximum queue length. In conditions where there are higher inflow and outflow of traffic between adjacent stop bars, the more expensive hybrid technique should be considered. The hybrid technique also produces satisfactory results (Sharma et al. 2007).

2.4 Vehicle Event Based Method

A study by Abdel-Rahim et al. (2009) produced an automated measurement of approach delay at signalized intersections. Delay estimation for all four movements at an intersection was collected using video detection. Video detection was placed at certain positions along an approach to collect data from passing vehicles. The processing of the data was automated. Average delay results collected by the automated system were compared to manual tracking of vehicles during the analysis. In addition, delay results were collected using HCM field delay estimation procedures. The results for each case were compared with each other. It was determined that the results from the automated measurement of approach delay resulted in more accurate and less biased delay estimations than the HCM delay estimations. The automated procedure also resulted in the most efficient form of delay data collection of the three tested (Abdel-Rahim et al. 2009).

2.5 Chapter Summary

The literature review focused on the available research that has shown some success in determining traffic delay using real-time technologies. Various technologies have been used by researchers in the past in hopes of finding a feasible and economical method that can be used to collect delay data. The methods include: 1) vehicle re-identification, 2) still-image analysis, 3) maximum queue length, and 4) vehicle event based method. The vehicle re-identification method uses either embedded roadway sensors or Bluetooth communication technologies to uniquely identify traveling vehicles along a given route at two locations along a route to calculate a travel time for vehicles that can be re-identified. The embedded sensors require the addition of roadway sensor infrastructure which can be costly to install and maintain. Bluetooth communication devices that are enabled that are inside of some vehicles can be uniquely identified using MAC addresses from the devices. This technology has inherent spatial errors near the data collection points that would allow a Bluetooth device to be recognized anywhere within a few hundred feet radius. When referring to travel times and delay estimation for a signalized corridor, a few hundred feet could make a big difference. As a result, this technology is better suited for longer corridor situations and not on surface streets that are closely spaced.

Still image analysis uses traffic camera image analysis to collect delay data at a signal approach. Still image analysis is very limited by camera angles and camera ability. As queues get large, the still image analysis has trouble distinguishing separate vehicles. The maximum queue length method uses stop bar detector and advance detector actuations along with phase change data and parametric data to calculate delay and maximum queue length. This method requires a lot of field calibration and vehicle storage and cannot be used at all signal locations due to its constraints. The vehicle event based method provided more reliable results than the HCM 2000 method of calculating delay. However, the vehicle based method is subject to the capabilities of the video detection it uses.

Currently, there is no dynamic delay calculation method that is ready for commercial use that can calculate delay on closely spaced arterials. There is also currently no delay calculation method ready for commercial distribution that can calculate delay using existing signal detection. Although methods have been developed to estimate a real-time traffic delay, no method has produced results reliable and accurate enough to market to city- and state-run TOCs for use on signalized arterial streets. There is a need for a new dynamic delay calculation method that uses current signal detection infrastructure and can be implemented easily on a signalized arterial street. This study fulfills the need for developing a new delay calculation method that can be implemented on signalized arterials using existing traffic sensor technologies.

3 Study Method and Cases Analyzed

Several roadway configurations were tested using VISSIM traffic simulation software. The VISSIM simulation software package has the ability to collect data similar to data collected from various types of field vehicle detection. The simulation software also has the ability to collect additional data that would not be available using field vehicle detection, but would be useful in determining actual travel time and delay information for simulated vehicles. This chapter discusses the methods of this study, the roadway configurations that were tested, and running the simulations in the VISSIM software. The sections in this chapter include the following: 1) study methods, 2) cases analyzed, 3) running simulations, and 4) chapter summary.

3.1 Study Methods

The algorithm development process was based on computer models using VISSIM traffic simulation software. Data collection points were set up in the model to collect vehicle identification (ID) number and a simulation time-stamp at each collection point in the model. Exact travel times of simulation vehicles in the models were collected by matching vehicles with their upstream and downstream sensors and subtracting the downstream time-stamp from the upstream time-stamp. The results for each computed travel time of the vehicles were averaged to determine the average travel time per vehicle. Average delay was calculated by subtracting the calculated travel time, based on the speed limit and test zone distance, from the average travel time per vehicle. The average delay per vehicle obtained in this manner represented the ground-truth delay per vehicle. The ground-truth average delay per vehicle was compared to the average delays determined by the algorithms developed in the study.

3.2 Cases Analyzed

Three approach configurations were considered in this study; 1) a single lane, 2) a double lane, and 3) a triple lane configuration. The simulation input volumes for each lane configuration included 700 vehicles per hour per lane (vphpl), 800 vphpl, and 900 vphpl. These three volume inputs were done for each lane configuration for a base total of nine simulation runs per case study. The analyzed cases include: Case 1 – Through-only vehicles; Case 2 – Mid-block driveway with driveway sensors; Case 3 – Mid-block driveway without driveway sensors; and Case 4 – Turning bay with turning bay sensors. Each simulation run was broken down into four separate 15-minute time samples. This allowed several delay tests to be done from a single simulation output. As a result, Case 1 had a total of nine simulation runs broken into four simulation samples for a total of thirty-six data samples. Case 2 tested five different driveway volumes with thirty-six data samples per driveway volume for a total of one-hundred and eighty data samples. Case 3 used the same data from Case 2 with one-hundred and eighty data samples. Lastly, Case 3 tested two different turning bay volumes with thirty-six data samples per turning bay volume for a total of seventy-two data samples. For each of the configurations, right turns were considered as through vehicles for the purposes of this study.

Simulation vehicles were set up to run with random arrival into the system. The roadway reached near saturation levels with the highest volumes tested. Traffic volumes used in each test represent extreme cases in order to test the ability of the algorithm in extreme situations. A simple pre-timed signal was used in this study. Signal times allowed for a 30 second effective green time and 30 second effective red time with a 60 second cycle length. Each case in the study is described in the subsections below.

3.2.1 Case 1 – Through-Lane-Only Vehicles

The initial trial in this study was a through-lane-only test. A through-lane-only consists of only thru lanes of traffic with no driveways or turning bays. Figure 3-1 provides an example of the approach layout used in VISSIM for the simple through-only vehicle two lane case.

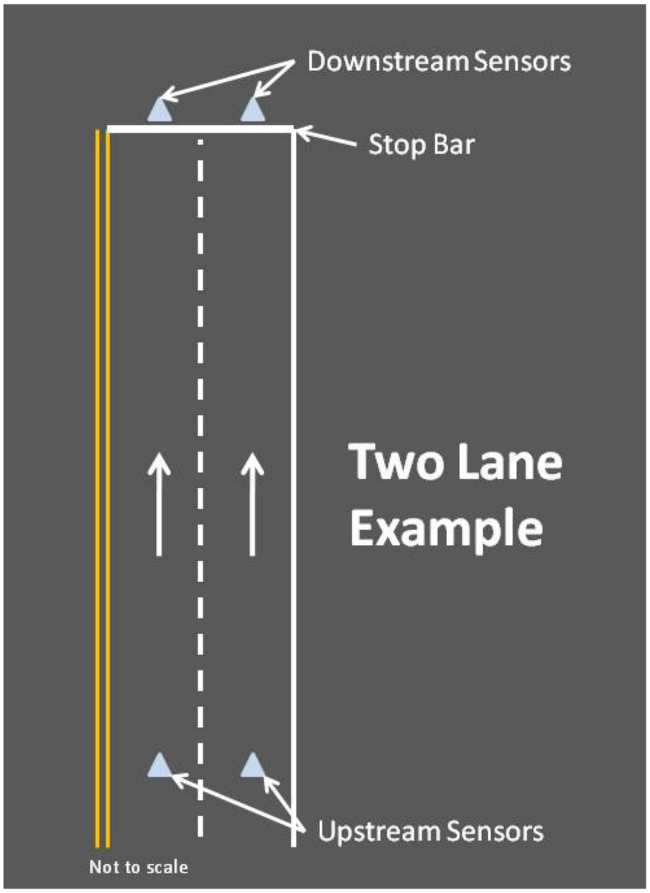


Figure 3-1: Two Lane Example of Through-only Vehicles.

The through-lane-only test was similar to train cars on a straight train track; all vehicles simply pass straight through with no turns. Vehicle sensors were located upstream of the queue and downstream of the signal stop bar. Single lane, double lane, and triple lane models were run each with three different approach volumes; 700 vphpl, 800 vphpl, and 900 vphpl.

3.2.2 Two Lane Example of Mid-block Driveway with Sensors

The next test added a midblock driveway to the simple lane test. Vehicles could freely enter from the driveway or exit onto the driveway. Extra sensors were placed at the driveway entry and exit points. Figure 3-2 provides a schematic of the two lane example of the test. In order to test the ability of the algorithm, high in and out driveway volumes were considered. Five in-and-out volume configurations were tested for each lane configuration.

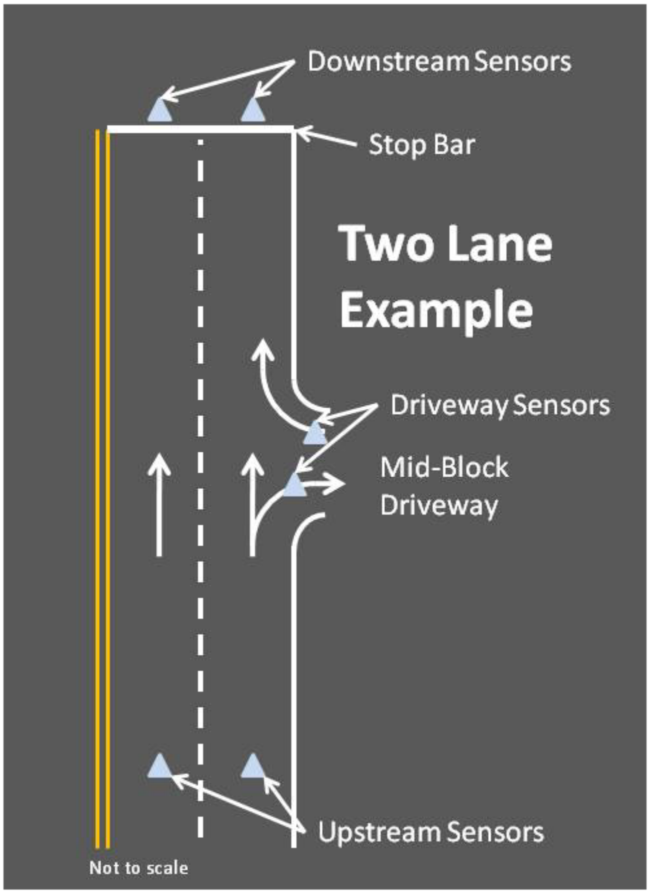


Figure 3-2: Two Lane Example of Mid-block Driveway with Driveway Sensors.

The five in and out driveway volumes tested were:

- 100 vehicles per-hour (vph) in, 0 vph out
- 100 vph in, 50 vph out
- 50 vph in, 50 vph out
- 50 vph in, 100 vph out
- 0 vph in, 100 vph out

Driveway counts were either added to or subtracted from the mainline counts at the downstream sensor depending on whether the vehicles were entering or exiting the system. For most field operations, driveway sensors are not feasible due to right of way constraints, sensor capabilities, and or outright cost of installation and maintenance.

3.2.3 Case 3 – Mid-block Driveway without Sensors

Another test was completed using the same criteria as the mid-block driveway, except without driveway sensors. The same simulation runs were used for this test as the previous test. The driveway sensor data were deleted in order to test the ability of the algorithm to obtain accurate results with differences in the in and out traffic volumes. The algorithm needed to be able to adjust for variable driveway volumes without driveway sensors since they are not typically feasible in most driveway locations.

3.2.4 Case 4 – Turning Bays with Sensors

The last test considered thru traffic with a left turning bay. The configuration used for this test was typical to most signalized intersections in Utah. This configuration was similar to the through-only case except with a left turning bay. There was a sensor at the turning bay entry and exit. Figure 3-3 provides a schematic of this test. Traffic volumes considered for the mainline through traffic were the same as the previous examples. Turning bay volumes considered for this test were large to test the performance of the algorithm. Both 200 vph and 300 vph volumes were used for the turning bay volumes. These volumes were subtracted from the mainline volumes recorded at the mainline downstream sensors.

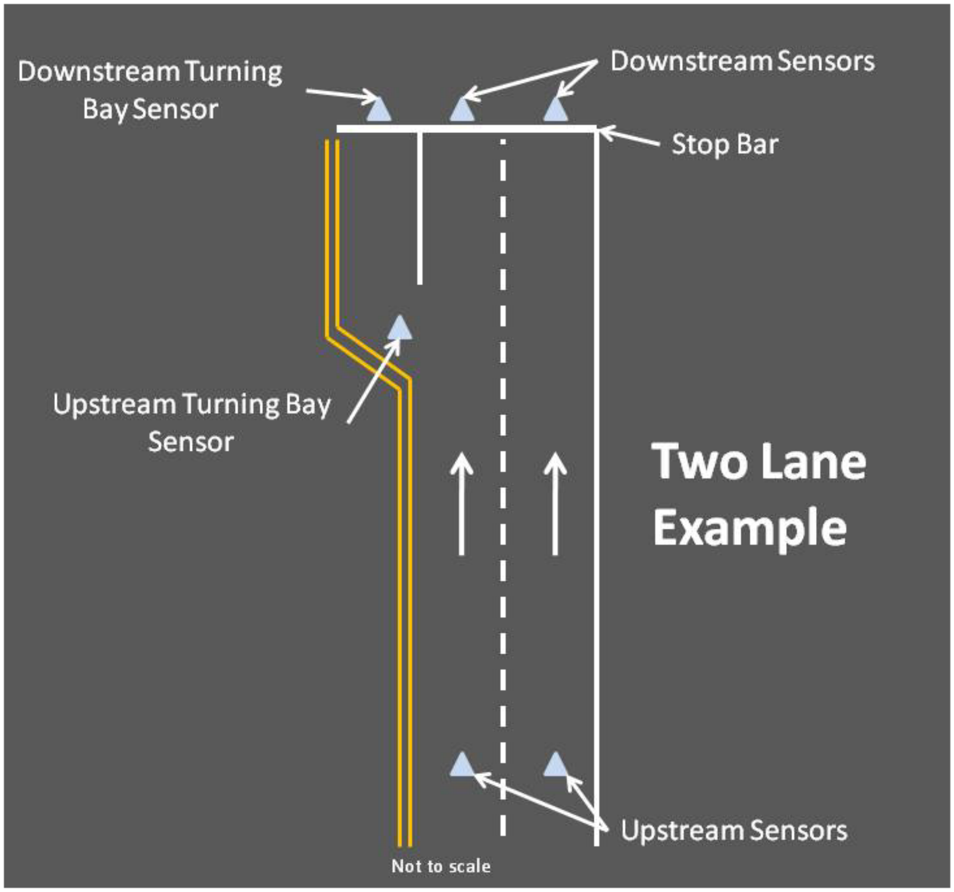


Figure 3-3: Two Lane Example of Left Turning Bay.

3.3 Running Simulations

Once each of the configuration cases were set up in the VISSIM software, the simulations were done with great consistency between different trial runs. Each simulation run collected data for 30 simulation minutes. Four 15-minute time intervals were analyzed from each of the simulation runs. Simulation seeding time was assumed to take 5 simulation minutes. No time intervals for data collection had a start time within the first 5 minutes of simulation. This 5 minute period was the system initialization time necessary for the simulation model to fill up with vehicles and operate normally. Using different 15 minute periods in a simulation models allowed for more data to be analyzed without the need to run multiple simulations of the same criteria. As previously discussed, the simulations were each equipped with a pre-timed traffic signal at the stop bar. Each analysis period began at the beginning of the red phase on the downstream traffic signal. The theory behind this is that a queue would typically be cleared by the beginning of the red phase. This reduced the residual traffic left within the test zone at the beginning of the test period. The test zone refers to the area between the upstream and downstream mainline sensors.

3.4 Chapter Summary

Chapter 3 presented the cases that were analyzed for this study and the method used for running simulations in the VISSIM software. Case 1 – Through-only vehicles was the initial setup created for the analysis with a first-in–first-out setup. All vehicles in this setup passed through the study segment without any entering or exiting vehicle midblock. Sensors for this case were set up with a sensor at the upstream end just beyond reach of typical queues and a sensor just downstream of the stop bar. Case 2 – Mid-block driveway with driveway sensors added a driveway to what was seen in Case 1. At the driveway vehicles both entered and exited, with sensors set up to collect time-stamp data of vehicles at both the entrance and exit of the driveway. Case 3 – Mid-block driveway without driveway sensors was set up similarly to Case 2 with the exception of sensors at the entrance and exit of the driveway. Case 4 – Turning bay with turning bay sensors was set up by adding a left-turn turning bay to Case 1. Case 4 includes a sensor at the entrance of the turning bay. Each of these cases was simulated in VISSIM software for 30 minutes for each trial run. Four 15-minute time intervals were analyzed from each of the simulation runs.

4 Algorithm

Two algorithms were developed in this study. The purpose of the algorithms was to estimate travel time and delay for through-only vehicles. The algorithms are referred to as Method 1 and Method 2. Both algorithms were developed to work for various roadway geometries and require generic information about the geometry to be input as variables into the algorithms (i.e. speed limit, length between sensors, number of lanes, distance to the turning bay from upstream sensors, and distance to the driveway from upstream sensors). The same algorithm was used to test Case 1 - through-only vehicles, Case 2 – Mid-block driveway with driveway sensors, Case 3 – Mid-block driveway without driveway sensors, and Case 4 – turning bay with turning bay sensors. There were, however, differences in how the algorithms run depending on the approach configuration. Approach configuration was one of the variables entered into the algorithm. The sections in this chapter include the following: 1) concept behind the algorithm development, 2) initial algorithm process, 3) preliminary vehicle data balancing, 4) removal of single time-stamp vehicle data, 5) final vehicle data balancing, 6) calculating the delay time, and 7) chapter summary.

4.1 Concept behind the Algorithm Development

The development of both of the delay calculation algorithms was based on a concept that used only time-stamp data to calculate a delay time. The concept uses travel times as a base to determine delay times. For an individual vehicle, a travel time can be determined by a time-stamp at two locations along that vehicle's route. The travel time of that vehicle was calculated by subtracting the upstream time-stamp from the downstream time-stamp. This concept could also be carried out for a group of vehicles. The sum of the upstream time-stamps could be subtracted from the sum of the downstream time-stamps for a total travel time for all of the vehicles in the group. The average travel time per vehicle was found by dividing the total travel time by the number of vehicles in the group.

The average travel time per vehicle was easily found using the matched time-stamp method for a known vehicle group where each vehicle could be uniquely identified. In reality, vehicles could not be uniquely identified using the existing vehicle detection sensor infrastructure at a typical signalized intersection. The algorithms in this study were developed based on the concept of being able to uniquely identify vehicles to estimate travel time. Each developed algorithm was designed to predict vehicle time-stamp groupings that would most closely approximate the actual average travel times of vehicles passing a travel time section.

4.2 Initial Steps of the Algorithms

In order to calculate vehicle delay, there must be the same number of vehicles entering the test zone as leaving the test zone. The algorithms, Method 1 and Method 2, were programmed to balance the data to eliminate the difference between the entering and exiting vehicles. The program set up the time-stamp data according to sensor location in descending order from beginning to last in a spreadsheet. Prior to vehicle balancing, the algorithms made slight adjustments to the approach configurations which had additional sensors (i.e. the driveway case with sensors and the turning bay case with sensors). Once the adjustments were made, the algorithms proceeded to balance the in and out volumes. First the adjustment to Case 2 and Case

3, driveway with and without driveway sensors respectively, is discussed followed by the adjustment to Case 4, turning bay with turning bay sensors.

4.2.1 Data Adjustments to the Driveway with Sensors Approach Configuration

Since the purpose of the algorithms was to calculate the delay for the through vehicles that pass through the system, the data from the driveways had to be either adjusted or removed in order to reduce the influence of the driveway on the delay results. The algorithms were programmed to account for the driveway by first eliminating all data associated with vehicles exiting the system through the driveways. Included in this were the vehicles entering into the test zone at the upstream sensor and the same vehicles exiting the test zone at the driveway. The exiting vehicle data were paired with entering upstream data and both were eliminated from the data set. Probable vehicle travel times based on the speed limit were subtracted from exiting times at the driveway. These times were then compared to entering times at the upstream sensors. The closest entering time was then paired with its respective exiting time and the data pair was removed from the total data set. Figure 4-1 provides a visual depiction of the removal of vehicle data exiting the test zone at the driveway.

Due to the difficulty in predicting travel times of vehicles entering the system from the driveway, data from vehicles entering the main system from the driveway were adjusted and added to the through only vehicle data. The assumption was that vehicles entering the driveway could be added to the main flow of traffic without adding a lot of error to the delay calculation. In order to include these vehicles in the sample, a calculated travel time from the upstream sensor to the driveway was subtracted from the driveway entering times. These new arrival times were then included in the upstream sensor time data, as if they came from the upstream sensor, to be used in the delay calculation. These data would later be sorted in ascending order of arrival time during the balancing process as discussed in Section 4.3.

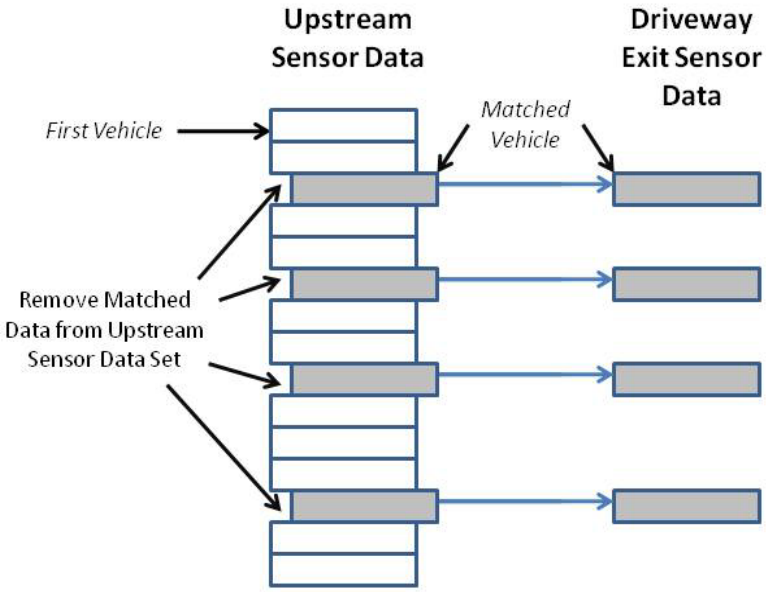


Figure 4-1: Driveway Exit Sensor Data Removal.

4.2.2 Data Adjustments to the Driveway without Sensors Approach Configuration

When driveway sensors were not used, there was no practical way to tell which vehicles entered or exited at a driveway. Because of this, removing and adjusting the data associated with the driveways is not possible without vehicle recognition. In the field application, no sensors would be placed at the entry and exit points of a driveway. However, for the purposes of this study, the same driveway data were used for both driveway configurations. For the driveway analysis without driveway sensors in this study, only the upstream entry data and downstream exit data were used. The driveway sensor data was discarded this configuration.

4.2.3 Data Removal for the Turning Bay with Sensors Approach Configuration

Data removal from the turning bay with sensor approach configuration used the same process as the data removal of the data associated with exiting vehicles through the driveway. Data from the turning bay sensor were removed by pairing turning bay data with entering upstream data. Probable vehicle travel times based on the speed limit were subtracted from exiting times at the turning bay. These times were then compared to entering times at the upstream sensors. The closest entering time was then paired with its respective exiting time from the turning bay and the data pair was removed from the total data set.

4.3 Preliminary Vehicle Data Balancing

Data balancing was implemented the same for all approach configurations. The two algorithms, Method 1 and Method 2, differentiated at this point in the process.

Method 1 balanced data by signal cycle. Data from each sensor were grouped into subsets according to the signal cycle. Each subset had to have the same number of entering vehicles as exiting vehicles. If the number of vehicles was different in either the entering sensor or the exiting sensor, vehicles were systematically removed from the higher of the two until both the entering and exiting sensors have the same number of vehicles in each signal cycle. The systematic removal process removed the extra vehicle data by removing vehicles at even intervals from the data subset. For example, if there were three extra vehicle data that needed to be removed, the data subset would be broken down into three equal sections and the median vehicle time-stamp from each of the sections would be removed from the data subset. The preliminary vehicle data balancing ensured that the number of vehicles entering the test zone equaled the number of vehicles exiting the test zone for the each signal cycle.

Method 2 balanced data using the same process as Method 1. While the process was the same, the grouping times vary. Method 2 grouped data into subsets by the total test period. For this study, a 15-minute period was used to analyze vehicle data to calculate traffic delay. The entire 15-minute period constituted a subset for each sensor. The subset with the higher vehicle count had vehicles systematically removed until the vehicle counts were the same for the entering and exiting sensors. The preliminary vehicle data balancing also ensured that the number of vehicles entering the test zone equaled the number of vehicles exiting the test zone for entire test period.

4.4 Removal of Single Time-stamp Vehicle Data

Once the entering and exiting vehicles were balanced, the groupings used to balance the data were dissolved and no longer used. The data were then organized by the sensor location. The next step in the process was the removal of single time-stamp vehicle data. Each vehicle passing completely through the test zone during the test period would have two time-stamps; one from the upstream sensor and one from the downstream sensor. Single time-stamp vehicle data referred to data from vehicles that could not have passed completely through the test zone during the test period. This included vehicles that started the test duration inside the test zone and vehicles which ended the test duration without passing the downstream sensor.

Method 1 and Method 2 both attempted to resolve the problem of extra vehicles in the test zone at the beginning of the test period and at the end of the test period. At the beginning of the test period, it was likely that there were already vehicles inside of the test zone. These vehicles would pass the downstream sensor without passing the upstream sensor during the test period. These vehicles had to be removed from the dataset to avoid very large errors. Similarly, at the end of the test period, it was likely that there were vehicles that were still inside the test zone at the termination of the test period. These vehicles passed the upstream sensor and did not pass the downstream sensor when the data collection period ends. These vehicles also had to be removed to avoid large errors. A schematic of this concept is provided in Figure 4-2. The schematic shows the vehicles which would be removed because the vehicles were inside the test zone at the beginning or the end of the test duration. These are vehicles which did not ‘pass’ through the entire test zone during the test duration or did not ‘pass’ both upstream and downstream sensors during the test duration.

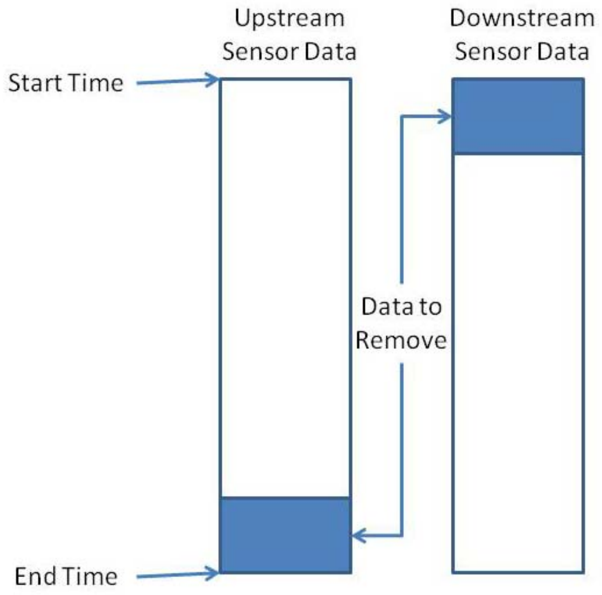


Figure 4-2: Concept of Vehicle Data Removal at the Beginning and End of Test.

4.4.1 Upstream Vehicle Removal for Method 1 and Method 2

The calculation for vehicle removal from the upstream sensor was the same for Method 1 and Method 2. Equation 4-1 provides the methodology to calculated the vehicles passing the upstream entering sensor that will be removed from the data set. All time-stamp data that meets this criterion was removed from the total data set. Entering time was the time-stamp data from the vehicles passing the upstream entering sensor. Time in queue was a variable provided by the VISSIM software that represents the duration a vehicle was waiting in a queue. In real-world applications, these data might not be as easily obtainable in the field for all vehicles in a queue, but could be estimated for a sample of vehicles at key locations using presence detection already existing at the field signals. Expected travel time was a calculated value based on the ideal travel time through the test zone without any stops. Speed limit and the length of the test area were the variables to calculate the expected travel time. The test termination time was the time at which the test period ends.

$$\begin{aligned}&(\text{Enter Time} + \text{Time in Queue} + \text{Expected Travel Time}) > \\ &\qquad (\text{Test Termination Time})\end{aligned} \tag{4-1}$$

4.4.2 Downstream Vehicle Removal for Method 1

The downstream sensor vehicle removal calculation for Method 1 was different from the calculation for Method 2. Equation 4-2 provides the Method 1 calculation for removal of the non-passing vehicles passing at the exiting sensor and not at the upstream sensor. All time-stamp data that met this criterion were removed from the total data set. Exit time was the time-stamp data from vehicles passing the exit sensor. Time in queue was determined based on how many seconds a vehicle was stopped. The estimated startup time was a user defined value that was associated with vehicle acceleration time. This value was decreased by half a second for each vehicle back in the queue and was not calculated for vehicles that are six vehicles or more in the queue. This value acted as a calibration to the time-stamp data to account for extra delay associated with vehicle acceleration time. The expected travel time was a set time that a vehicle traveling the speed limit would take to pass through the test zone. The test begin time was the time that the test period begins.

$$(\text{Exit Time} - \text{Time in Queue} - \text{Estimated Startup Time} - \text{Expected Travel Time}) < (\text{Test Begin Time}) \quad (4\text{-}2)$$

4.4.3 Downstream Vehicle Removal for Method 2

Equation 4-3 provides the Method 2 calculation for removal of vehicles passing only at the exiting sensor and not at the upstream sensor. The parameters used in Equation 4-3 were the same parameters found in Equation 4-2 with the exception of the estimated startup time, which was not included. Startup time was not included in Method 2 because Method 2 was designed to error on the side of retaining too many vehicles. Method 2 removed data based on if the predicted times are larger than the test begin time. Predicted times that are smaller are removed from the data set. Method 1 required the estimated begin time to be smaller than the actual begin time. This concept will be explained in more detail in Section 4.5 of this report. All time-stamp data that meet this criterion were removed from the total data set.

$$(\text{Exit Time} - \text{Time in Queue} - \text{Expected Travel Time}) > (\text{Test Begin Time}) \quad (4\text{-}3)$$

4.5 Final Vehicle Data Balancing

The final step in the data manipulation process was to again balance the data. The removal of single time-stamp vehicles could create another imbalance between entering and exiting vehicles, which could cause large errors in the delay calculation. Vehicle data had to again be balanced prior to calculating a delay time to reduce as much error as possible. Large errors in delay calculations would occur if there was an imbalance between the number of entering vehicles and the number of exiting vehicles.

4.5.1 Final Vehicle Data Balancing – Method 1

Method 1 balanced vehicle data using a process of six steps. By the time the final vehicle balancing began, the single time-stamp vehicles had already been removed. The final data balancing for Method 1 included the following steps demonstrated in Figure 4-3:

- Step 1: Copy the upstream, or entry, time-stamp data down in a spreadsheet data column organized from earliest time at the top of the column to the latest time at the bottom of the column.
- Step 2: Match the last time from the upstream sensor to the last vehicle passing the downstream, or exit, sensor prior to the test period termination time.
- Step 3: Copy the downstream sensor data up the column in backwards order of the data times.
- Step 4: Stop the copying when the data columns have the same number or rows in them or the downstream data column runs out of sensor data.
- Step 5: Remove any downstream data that cannot be matched by row in the columns. This will only happen when there are more downstream data than upstream data.
- Step 6: Adjust the downstream data up and remove the last vehicle out of the upstream data column until both columns have the same number of rows. This will only happen when there are more upstream data than downstream data.

After this six-step process, there should be the same number of data in the upstream sensor and the downstream sensor. The data rows across the two data columns should ideally represent vehicles passing through the test zone.

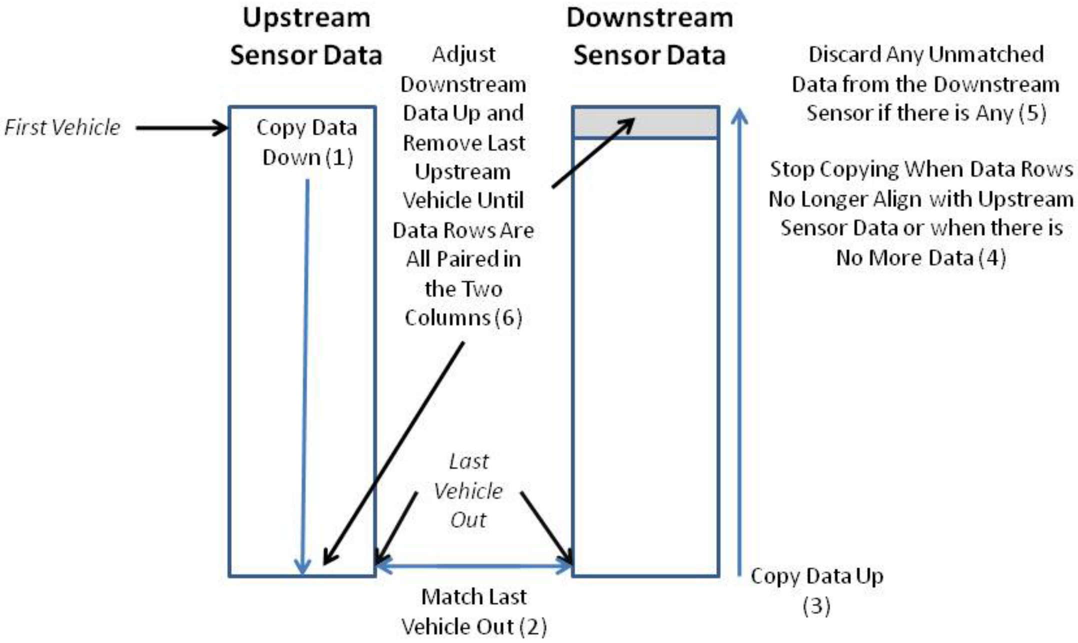


Figure 4-3: Method 1 Final Vehicle Data Balancing.

4.5.2 Final Vehicle Data Balancing – Method 2

Method 2 balances vehicle data using a process of four steps. By the time the final vehicle balancing begins, the single time-stamp vehicles have already been removed. The final data balancing for Method 2 included the following four steps demonstrated in Figure 4-4:

- Step 1: Match the first vehicle through the system. The data time with the earliest time value at the upstream sensor is copied into a new row and column. The data time with the earliest time from the downstream sensor is copied into a new column but the same row as the earliest upstream data.

- Step 2: Copy the upstream and downstream data down in their respective data column organized from earliest time at the top of the column to the latest time at the bottom of the column.
- Step 3: Copy the data down until data run out on either the upstream sensor column or the downstream sensor column. At this point, the upstream sensor data column and the downstream sensor column should have the same number of rows.
- Step 4: Remove any data that cannot be matched into rows.

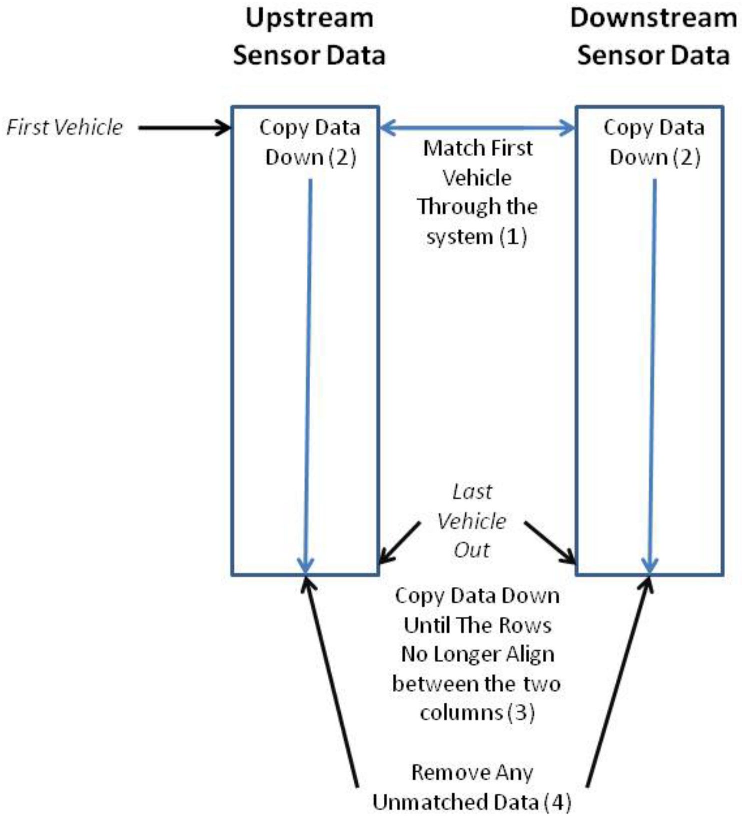


Figure 4-4: Method 2 Final Vehicle Data Balancing.

After this four-step process, there should be the same number of data in the upstream sensor and the downstream sensor. The data rows across the two data columns should ideally represent cars traveling through the test zone.

4.6 Calculating the Delay Time

The final step of the algorithm was calculating delay time. First, a summation of the vehicle entry times at the upstream sensor was calculated along with a summation of the vehicle exit times at the downstream sensor. Next, the summation of the vehicle times from the downstream sensor were subtracted from the summation of the vehicle times from the upstream sensor. This subtraction resulted in the total travel time for all vehicles passing through the test zone. The total travel time was then divided by the total number of vehicles that passed through the test zone. The quotient was an average travel time per vehicle for all the vehicles passing through the test zone. These steps are shown in Equation 4-4. Finally, the average travel time delay was calculated by subtracting the ideal travel time (the time it takes vehicles to pass through the test zone going the speed limit with no stops) from the average travel time. The result was an average delay time for all vehicles passing through the test zone. The final average delay calculation is found in Equation 4-5.

$$\text{Average Travel Time} = \frac{(\text{Exit Travel Time Sum} - \text{Entry Travel Time Sum})}{(\text{Total Number of Vehicles})} \tag{4-4}$$

$$\text{Average Delay Time} = (\text{Average Travel Time} - \text{Ideal Travel Time}) \tag{4-5}$$

This entire process was automated using Visual Basic and Excel software and took only seconds to process. Using this computer automated algorithm, travel time delay results could be calculated within seconds after data collection.

4.7 Chapter Summary

Chapter 4 presented details of the processes run by the two developed algorithms. The two algorithms were referred to as Method 1 and Method 2. Both algorithms were developed to work for various roadway geometries and required generic information about the geometry to be entered as variables into the algorithms (i.e. speed limit, length between sensors, number of lanes, distance to the turning bay from upstream sensors, and distance to the driveway from upstream sensors).

In order to calculate vehicle delay, the algorithms ran through a series of processes to remove data which could not be factored into the delay calculation. The initial process required the same number of vehicles entering the test zone as leaving the test zone. This was the same initial process for all configurations tested. As the algorithm runs, there were slightly different processes for each of the lane configurations.

For the driveway configuration, the next process in the algorithm was to account for the driveway by first eliminating all data associated with vehicles exiting the system through the driveways. Once this was complete, the algorithms manipulated the data from vehicles entering the system from the driveway and added it to the data that would later be used to calculate vehicle delay. For the driveway configuration without driveway sensors, there was no practical way to tell which vehicles entered or exited at a driveway. Because of this, the algorithm proceeded to process the data similarly to the through-only data. For the turning bay with sensor approach configuration, the algorithms used the same process used to remove data associated with exiting vehicles through the driveway.

Following the processes to account for each lane configuration, the algorithms balanced the entering and exiting vehicle data again. Once the entering and exiting vehicles were balanced, the data were then organized by the sensor location. The next step in the process was the removal of single sensor vehicle data. Single sensor vehicle data referred to data from vehicles that passed only one sensor during the test period. The calculation for single sensor vehicle removal from the upstream sensor was the same for Method 1 and Method 2. Vehicles which did not meet a certain time criteria were removed based on the unlikelihood that the vehicle would have passed more than one sensor. The equation used to determine which vehicles should be removed from the upstream sensor included enter time, time in queue, expected travel time, and test termination time. The calculation for downstream sensor vehicle removal was different for Method 1 and Method 2. Each followed a different criterion to determine which vehicle had to be removed due to the unlikelihood that the vehicle was able to pass more than one sensor. Method 1 used an equation which included variables such as exit time, estimated start up time, time in queue, test begin time, and expected travel time to determine which data should be removed from the exiting vehicle data. Method 2 used an equation with all the same variables as the Method 1 equation except for time in queue.

The next process in the data manipulation of the algorithms was a final vehicle balance. The previous processes could create another imbalance between entering and exiting vehicles which could cause large errors in the delay calculation. Method 1 balanced vehicle data using a series of six steps to create data pairs out of enter and exit times beginning with the last vehicle out. Any data that ended up without a match were removed from the total data set. After this six-step process, there was the same number of data points in the upstream sensor as the downstream sensor. Method 2 balanced vehicle data using a process of four steps. This four-step process paired enter and exit times of vehicles beginning with the first vehicle out of the test zone during the test duration. Any data that ended up without a match was also removed from the total data set. After this four-step process, there was the same number of data from the upstream sensor as from the downstream sensor.

The final process of the algorithm was calculating delay time. First, a summation of the vehicle entry times at the upstream sensor was calculated along with a summation of the vehicle exit times at the downstream sensor. Next, the summation of the vehicle times from the downstream sensor were subtracted from the summation of the vehicle times from the upstream sensor. This subtraction resulted in the total travel time for all vehicles passing through the test zone. The total travel time was then divided by the total number of vehicles that passed through the test zone. The quotient was an average travel time for all the vehicles passing through the test zone. Finally, the average travel time delay was calculated by subtracting the ideal travel time (i.e., the time it took vehicles to pass through the test zone traveling at the speed limit with no stops) from the average travel time. The result was an average delay time per vehicle for all vehicles passing through the test zone.

This entire process was automated using Visual Basic and Excel software and took only seconds to process. Using this computer automated algorithm, travel time delays could be calculated within seconds after data collection.

5 Analysis Results

This chapter presents a summary of the results of delay analyses of various configurations tested in the study. The configuration results explained in this summary include the following: Through-only lanes; through lanes with driveway and driveway sensors, through lanes with driveway and no driveway sensors, and through lanes with left turning bay and left turning bay sensors. Discussions of each configuration contain figures showing the difference between the delays calculated by the algorithm and the ground-truth delays computed by the matched vehicles. The matched vehicle delays obtained from VISSIM simulation runs were the ground truth data upon which all calculated delays were compared. A single simulation run was completed for each volume and roadway configuration combination tested. From each run, four sample times were drawn to estimate delay times. The sections in this chapter include the following: 1) through-only configuration results, 2) driveway with sensor configuration results, 3) driveway without sensors configuration results, 4) turning-bay configuration results, and 5) chapter summary.

5.1 Through-Only Configuration Results

The through-only configuration was the initial case created for this study. Delay calculation Method 1 was developed for the through-only configuration. Method 1 was later modified as configurations got more complex throughout the duration of the study. The through-only configuration is the most basic of the cases tested in the study.

Errors were calculated by taking the difference of the delays calculated for the through-only simulation samples and the ground truth data. The largest difference in delay for either the single, double, or triple lane configuration was less than 3 seconds per vehicle. Delay was calculated for 36 simulation sample times (simulation runs were done using 3 volume inputs and 3 lane inputs, for a total of 9 simulation runs with 4 samples from each run) for various volumes and numbers of lanes for the through-only configuration using Method 1. Details of the single, double, and triple through lane configuration are provided in the following subsections.

5.1.1 Single Through Lane

The results from the single lane, through-only configuration had very small errors. Twelve simulation samples were done for the single lane, through-only configuration. Of these, the largest absolute error was 2.6 seconds per vehicle calculated for one trial with a vehicle flow of 800 vph. The other eleven errors were zero. A summary of the differences in delays for the single lane, through-only simulation samples using Method 1 is shown in Figure 5-1.

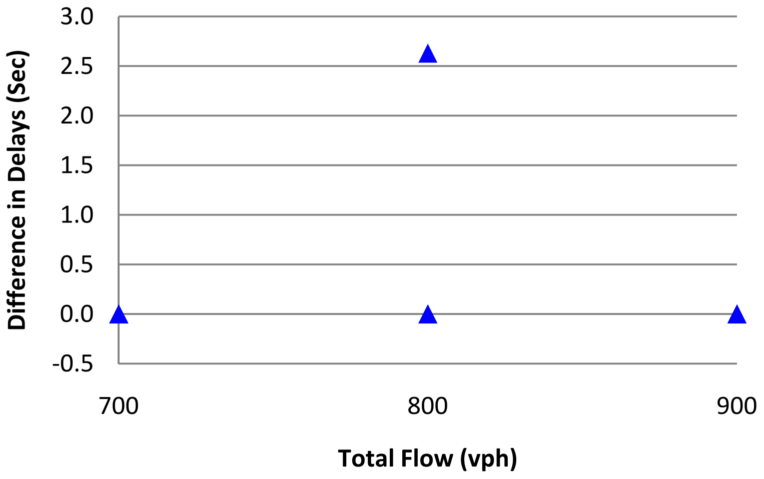


Figure 5-1: Single Lane Through Only.

5.1.2 Double Through Lane

The results from the double lane, through-only configuration showed no errors for the simulation samples tested. Twelve simulation samples were done for the double lane, through-only configuration. Of these, all of the errors were zero. A summary of the differences in delay for the double lane, through-only simulation samples using Method 1 is shown in Figure 5-2.

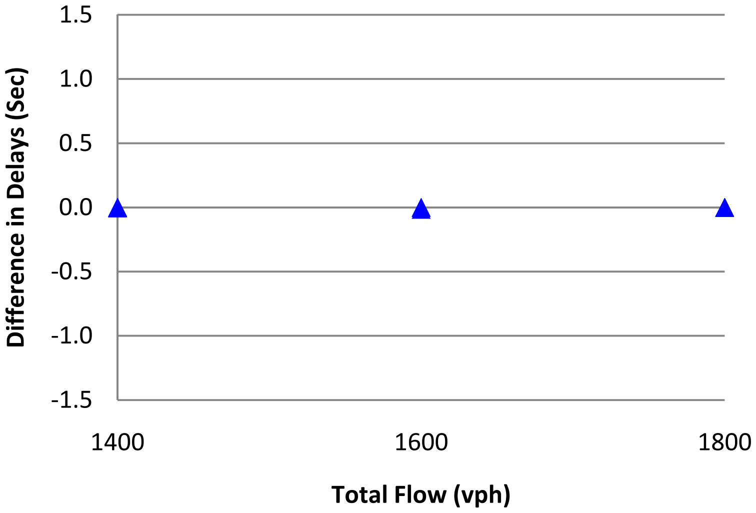


Figure 5-2: Double Lane Through Only.

5.1.3 Triple Through Lane

The results from the triple lane, through-only configuration also showed very small errors. Twelve simulation samples were done for the triple lane, through-only configuration. The largest absolute error was 1.3 seconds per vehicle. This largest error occurred for the trial with a vehicle flow of 2700 vph. All other results for the triple lane simulation samples were within 0.1 seconds of the ground truth data results. A summary of the differences in delay for the triple lane, through-only simulation samples using Method 1 is shown in Figure 5-3.

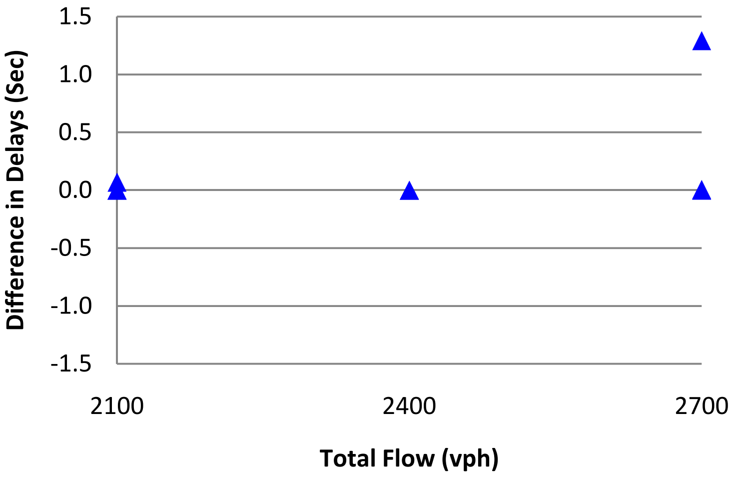


Figure 5-3: Triple Lane Through Only.

5.2 Driveway with Sensors Configuration Results

The next configuration tested was the driveway with sensors. Due to the increased complexity of having a driveway between the upstream and downstream sensors, an alternate calculation method was developed as a comparison to the initial method that was created. It was necessary to add a new method that calculates delay differently so that a comparison could be drawn to determine which method provides more accurate results. It also allowed for more options for unusual situations where one method might provide more reliable results than the other. For comparison purposes, an average of Method 1 and Method 2 was calculated to compare the average delay calculated from Method 1 and Method 2 with the average delay calculated by either Method 1 or Method 2 alone. A benchmark error of 5 seconds or less was set for this study as a goal to maintain results the fall within 5 seconds of actual delay times. Values larger than 5 seconds were flagged as values that did not meet the goal of 5 seconds or less.

The driveway test results with sensors were accurate and only had small errors. Error was kept at a minimum because of the ability of the algorithm to correctly predict which vehicle times should be removed in the data manipulation process. One hundred and eighty simulation samples (simulation runs were done using 3 volume inputs, 3 lane inputs, and 5 driveway volume combinations, for a total of 45 simulation runs with 4 samples from each run) were completed for this test. Method 1 and Method 2 were used to calculate the delay. In addition, an average value of the two methods was also calculated. There were 57 instances out of 360 (15.8 percent) delay outputs where either Method 1 or Method 2 was larger than 5 seconds. The largest of these was 12.1 seconds per vehicle off of the matched vehicle delay. There were 12 instances out of 180 (6.7 percent) where average delay of Method 1 and Method 2 was over 5 seconds per vehicle off of the matched vehicle delay. The largest error from the averages of Method 1 and Method 2 is 7.2 seconds per vehicle. The average of the two methods seemed to result in better than any single method.

A more detailed look at the driveway configuration (single, double, and triple through lanes) is provided in the subsections that follow. The driveway scenario discussed has vehicle flows of 50 vph entering the test zone from the driveway and 50 vph exiting the test zone at the driveway. Additional tables and graphs of the driveway configuration with different entering and exiting volumes are found in Appendix B.

5.2.1 Single Through Lane

The results from the single lane, driveway with driveway sensors configuration showed larger errors than the through-only configurations. Twelve simulation samples were completed for this analysis. The data from the samples were processed using Method 1 and Method 2. The driveway flows for each sample was 50 vph entering from the driveway and 50 vph exiting to the driveway. The largest absolute error was 12.1 seconds per vehicle. This error was from Method 1 with a vehicle flow of 900 vph. Errors ranged from -1.8 seconds per vehicle to 12.1 seconds per vehicle. The average of Method 1 and Method 2 produced smaller delay errors with the largest error at 6.7 seconds per vehicle. A summary of the single lane driveway with driveway sensors simulation samples is shown in Figure 5-4.

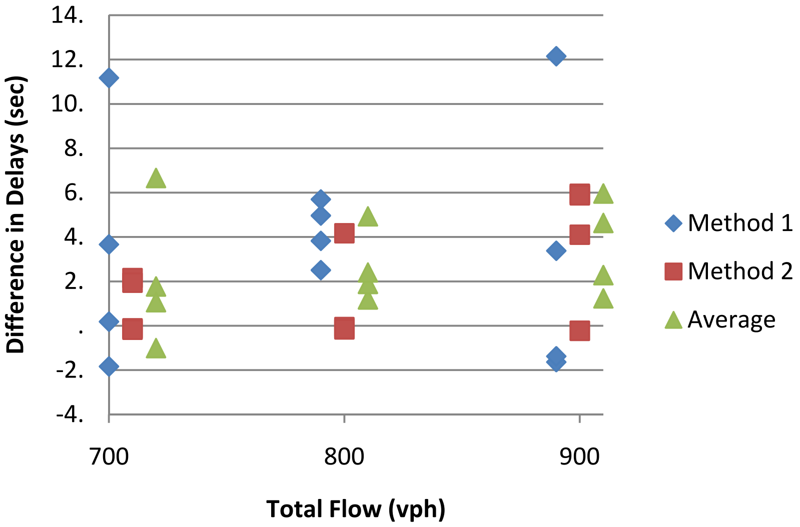


Figure 5-4: Single Lane, Driveway and Driveway Sensors (50 In/ 50 Out).

5.2.2 Double Through Lane

The results from the double lane, driveway with driveway sensors configuration again showed larger errors than the through-only configurations. Twelve simulation samples were completed for this analysis. The data from the runs were processed using Method 1 and Method 2. The driveway flows for each samples was 50 vph entering from the driveway and 50 vph exiting to the driveway. The largest absolute error was 9.1 seconds per vehicle. This error was from Method 1 with a vehicle flow of 1600 vph. Errors ranged from -2.0 seconds per vehicle to

9.1 seconds per vehicle. The average of Method 1 and Method 2 produced smaller delay errors with the largest error at 4.4 seconds per vehicle. A summary of the double lane driveway with driveway sensors simulation samples is shown in Figure 5-5.

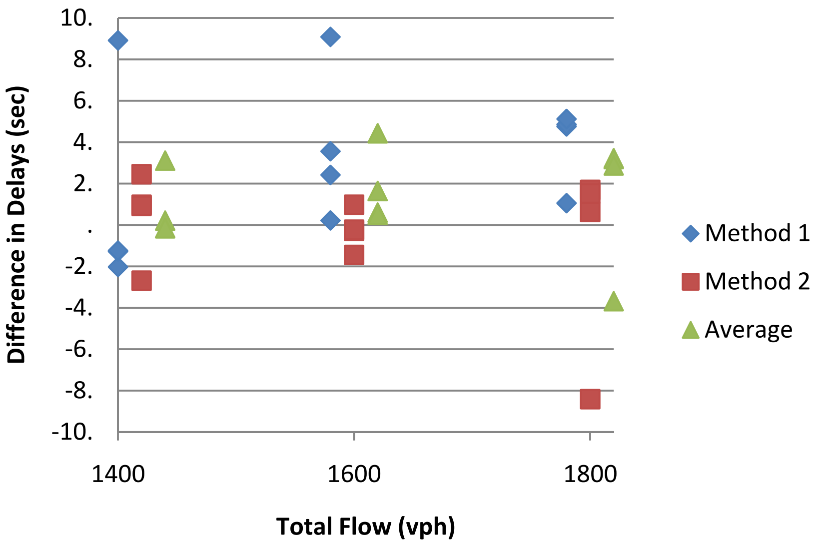


Figure 5-5: Double Lane, Driveway with Driveway Sensors (50 In, 50 Out).

5.2.3 Triple Through Lane

The results from the triple lane, driveway with driveway sensors configuration also showed larger errors than the through-only configurations. Twelve simulation samples were completed for this analysis. The data from the runs were processed using Method 1 and Method 2. The driveway flows for each sample was 50 vph entering from the driveway and 50 vph exiting to the driveway. The largest absolute error was 5.4 seconds per vehicle. This error was from Method 1 with a vehicle flow of 2400 vph. Errors ranged from -5.4 seconds per vehicle to 3.1 seconds per vehicle. The average of Method 1 and Method 2 produced smaller delay errors with the largest error at -2.9 seconds per vehicle. A summary of the triple lane driveway with driveway sensors simulation samples is shown in Figure 5-6.

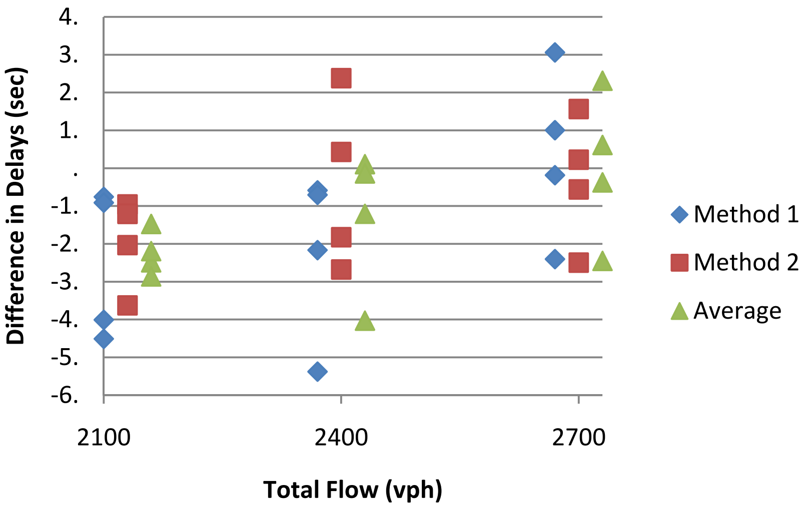


Figure 5-6: Triple Lane, Driveway with Driveway Sensors (50 In, 50 Out).

5.3 Driveway without Sensors Configuration Results

Once the driveway with sensors configuration was tested, another test was conducted to see if adequate results could be achieved on the driveway configuration while ignoring the driveway sensors. The results from this driveway test had results with slightly larger errors than the driveway test with driveway sensors. Errors were higher but most errors were still within targeted acceptable ranges (i.e. less than 5.0 seconds per vehicle of error). One hundred and eighty simulation samples (simulation runs were done using 3 volume inputs, 3 lane inputs, and 5 driveway volume combinations, for a total of 45 simulation runs with 4 samples from each run) were completed for this test. Method 1, Method 2, and the average of the two methods were used to calculate the delay. In 97 of the 360 (26.9 percent) delay outputs, either Method 1 or

Method 2 was larger than 5 seconds, ranging from 5.0 to 23.1 seconds per vehicle. In 28 of the 180 (15.6 percent) simulation samples, the average delay of Method 1 and Method 2 was over 5 seconds, ranging from 5.0 to 17.6 seconds per vehicle. There was a tendency for Method 2 to have larger errors on certain simulation samples where the driveway volumes had a large imbalance. In addition, larger errors occurred more often on the configuration with a single lane as opposed to a double lane or a triple lane configuration.

The average of Method 1 and Method 2 produced smaller error margins than either Method 1 or Method 2 alone. Most of the average values with differences higher than 5.0 seconds were between 5.0 and 6.0 seconds. Only one instance out of 180 had an average value higher than 10 seconds, with the actual value at 10.1 seconds per vehicle.

A more detailed look at the driveway configuration (single, double, and triple through lanes) is provided in the subsections that follow. The driveway scenario discussed had vehicle flows of 50 vph entering the test zone from the driveway and 50 vph exiting the test zone at the driveway. Additional tables and graphs of the driveway configuration with different entering and exiting volumes are found in Appendix C.

5.3.1 Single Through Lane

The results from the single lane, driveway without driveway sensors configuration also showed larger errors than both the through-only configurations and the driveway with sensors configuration. Twelve simulation samples were done for Method 1 and the same simulation samples were done for Method 2. The driveway flows were 50 vph entering from the driveway and 50 vph exiting to the driveway. The largest absolute error was 11.2 seconds per vehicle. This error was from Method 1 with a vehicle flow of 700 vph. Errors ranged from -6.1 seconds per vehicle to 11.2 seconds per vehicle. The average of Method 1 and Method 2 produced smaller errors with the largest error at 6.7 seconds per vehicle and others ranging between -2.0 and 6.7 seconds per vehicle. Error spreads were larger for flows of 700 vph and 900 vph and more condensed for the 800 vph flows. A summary of the single lane, driveway with driveway sensors simulation samples is shown in Figure 5-7.

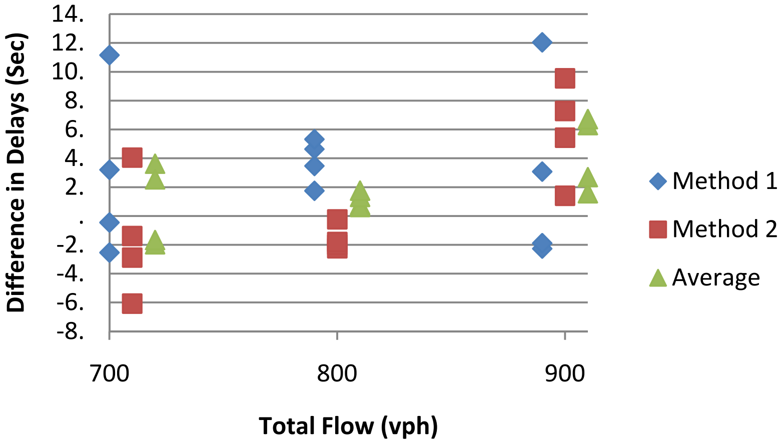


Figure 5-7: Double Driveway without Sensors (50 In, 50 Out).

5.3.2 Double Through Lane

The results from the double lane, driveway without driveway sensors configuration also showed larger errors than both the through-only configurations and the driveway with sensors configuration. Twelve simulation samples were done for Method 1 and the same simulation samples were done for Method 2. The driveway flows were 50 vph entering from the driveway and 50 vph exiting to the driveway. The largest absolute error was 10.4 seconds per vehicle. This error was from Method 2 with a vehicle flow of 1800 vph. Errors ranged from -10.4 seconds per vehicle to 9.3 seconds per vehicle. The average of Method 1 and Method 2 produced smaller errors with the largest error at 4.8 seconds per vehicle and others ranging between -4.5 and 4.8 seconds per vehicle. Error spreads were also more condensed for the 800 vph flows. A summary of the double lane, driveway with driveway sensors simulation samples is shown in Figure 5-8.

.

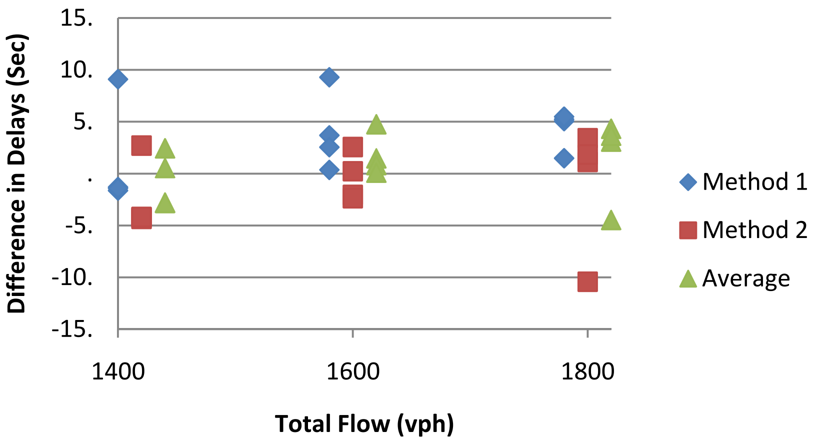


Figure 5-8: Double Driveway without Sensors (50 In, 50 Out).

5.3.3 Triple Through Lane

The results from the triple lane, driveway without driveway sensors configuration showed errors slightly smaller than the double lane driveway without sensors configuration. Twelve simulation samples were done for Method 1 and the same simulation samples were done for Method 2. The driveway flows were 50 vph entering from the driveway and 50 vph exiting to the driveway. The largest absolute error was 5.2 seconds per vehicle. This error was from Method 2 with a vehicle flow of 2400 vph. Errors ranged from -5.2 seconds per vehicle to 3.0 seconds per vehicle. The average of Method 1 and Method 2 produced slightly smaller errors with the largest error at 4.8 seconds and others ranging between -3.7 and 2.2 seconds per vehicle. Error spreads were similar for all three vehicle flows. A summary of the triple lane, driveway with driveway sensors simulation samples is shown in Figure 5-9.

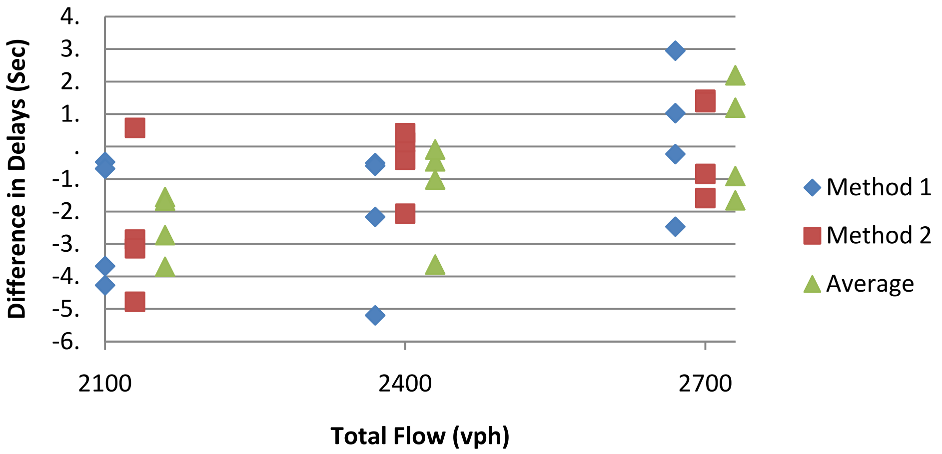


Figure 5-9: Triple Driveway without Sensors (50 In, 50 Out).

5.4 Turning-bay Configuration Results

The last configuration tested was the turning bay with sensors. The turning bay test results were accurate and only had a small number of errors. Error was kept at a minimum because of the ability of the algorithm to correctly predict which vehicle times should be removed in the data manipulation process. Seventy-two simulation samples (simulation runs were done using 3 volume inputs, 3 lane inputs, and 2 turning bay volume combinations, for a total of 18 simulation runs with 4 samples from each run) were completed for this test. Method 1, Method 2, and the average of the two methods were used to calculate the delay. The error in Method 1 or Method 2 was larger than 5.0 seconds per vehicle in only 17 of the 144 simulation samples (11.8 percent). There were 4 instances out of 72 (5.6 percent) delay outputs where the combined error in the average of Method 1 and Method 2 was over 5.0 seconds per vehicle. Most of the simulation samples with errors larger than 5.0 seconds per vehicle occurred during the single lane setup. The average of the two methods produced smaller margins or error than either Method 1 or Method 2 did alone.

A more detailed look at the driveway configuration (single, double, and triple through lanes) is provided in the subsections below. The driveway scenario discussed has vehicle flows of 200 vph exiting the test zone at the turning bay. Additional tables and graphs of the driveway configuration with different exiting volumes are found in the Appendix D.

5.4.1 Single Through Lane

The results from the single lane, turning bay with turning bay sensors configuration showed moderate errors as compared to the previously discussed configurations. A summary of the single lane, driveway with driveway sensors simulation samples is shown in Figure 5-10.

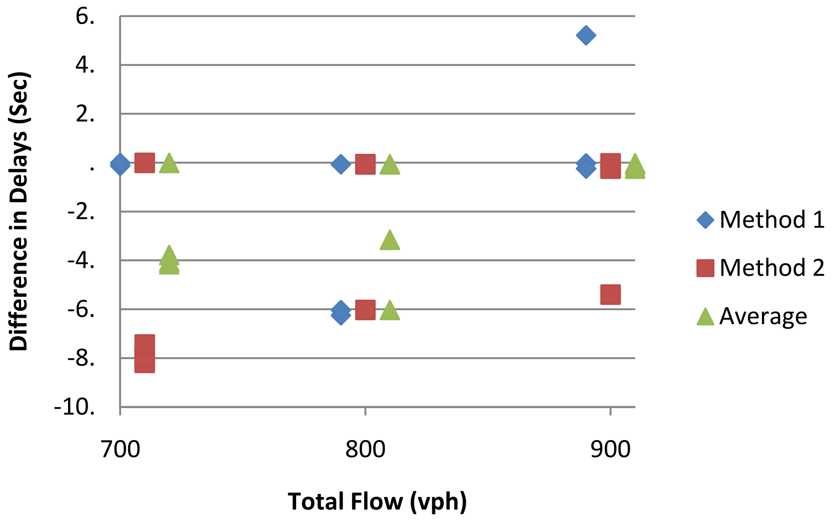


Figure 5-10: Single Lane with Turning Bay (0 In, 200 Out).

Twelve simulation samples were done for Method 1 and the same simulation samples were done for Method 2. The turning bay flows were 200 vph exiting to the turning bay. The largest absolute error was 8.2 seconds per vehicle. This error was from Method 2 with a vehicle flow of 700 vph. Errors ranged from -8.2 seconds per vehicle to 5.2 seconds per vehicle. The average of Method 1 and Method 2 produced smaller errors with the largest error at -6.0 seconds and others ranging between -6.0 and -0.1 seconds per vehicle. Error spreads were similar for all flows and tended to have errors that were negative.

5.4.2 Double Through Lane

The results from the double lane, turning bay with turning bay sensors configuration showed smaller errors than the single lane with turning bay configuration. A summary of the double lane, driveway with driveway sensors simulation samples is shown in Figure 5-11.

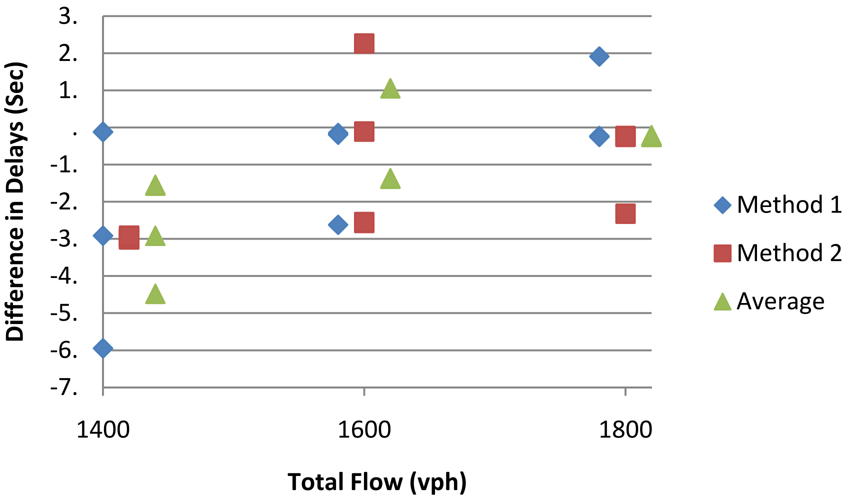


Figure 5-11: Double Lane with Turning Bay (0 In, 200 Out).

Twelve simulation samples were done for Method 1 and the same simulation samples were done for Method 2. The turning bay flows were 200 vph exiting to the turning bay. The largest absolute error was 6.0 seconds per vehicle. This error was from Method 1 with a vehicle flow of 1400 vph. Errors ranged from -6.0 seconds to 2.3 seconds per vehicle. The average of Method 1 and Method 2 produced smaller errors with the largest error at -4.5 seconds per vehicle and others ranging between -4.5 and 1.1 seconds per vehicle. Error spreads were similar for all flows and tended to have errors that were negative.

5.4.3 Triple Through Lane

The results from the triple lane, turning bay with turning bay sensors configuration showed even smaller errors than the double lane with turning bay configuration. Twelve simulation samples were done for Method 1 and the same simulation samples were done for Method 2. The turning bay flows were 200 vph exiting to the turning bay. The largest absolute error was 3 seconds. This error was from Method 2 with a vehicle flow of 2700 vph. Errors ranged from -3 seconds to 2.5 seconds per vehicle. The average of Method 1 and Method 2 produced smaller errors with the largest error at -1.9 seconds per vehicle and others ranging between -1.9 and 1.8 seconds per vehicle. Error spreads were similar for all flows and tended to have error spreads that centered on zero. A summary of the triple lane, driveway with driveway sensors simulation samples is shown in Figure 5-12.

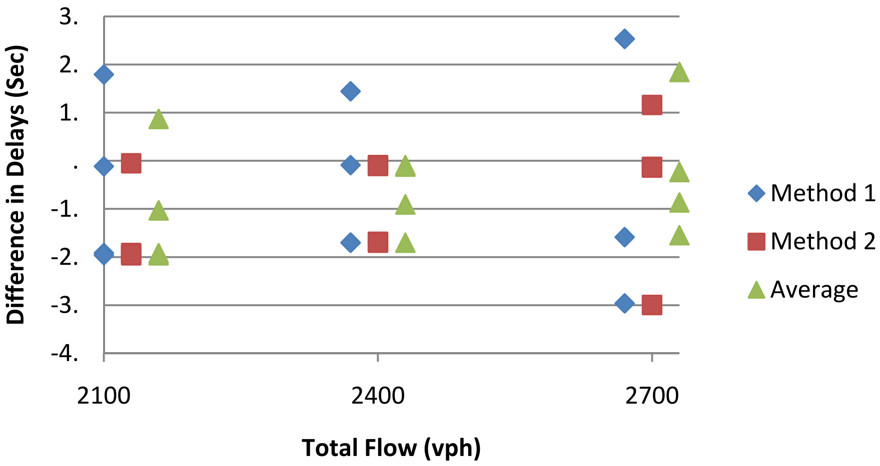


Figure 5-12: Triple Lane with Turning Bay (0 In, 200 Out).

5.5 Chapter Summary

Results from this study were promising, based on the accuracy level produced by the algorithm. The algorithm produced delay estimation within the 5 seconds of error tolerances set for this particular study. Delay values that are within 5 seconds of the actual errors could be used to determine a Level of Service or to obtain reliable travel time estimates.

Results for the through only type of facility offered the greatest level of accuracy, as expected. Delay values obtained from the through-only configuration were all within 3 seconds per vehicle of the actual delay time. The maximum level of error occurred when the algorithm was off by a single vehicle. During most of the tests, the algorithm correctly matched the correct enter and exit time of vehicles passing through the test zone.

Results for the roadway configuration with a driveway with sensors also showed accurate results. There were more outliers in this data and few errors of 0 seconds, but overall the algorithms provided reliable results that could be used for a Level of Service determination or a signal timing evaluation. Maximum errors occurred when the algorithm shifted either the entering or exiting vehicles by a few vehicles when balancing the entering and exiting vehicle data. In the configuration with the driveway sensors, 93 percent of the results had average delays with errors smaller or equal to 5 seconds per vehicle.

Results for the roadway configuration with a driveway with no sensors also showed accurate results. Maximum errors in this configuration also occurred when the algorithm shifted either the entering or exiting vehicles by a few vehicles when balancing the entering and exiting vehicle data. Errors were also expected because the algorithm has to estimate the vehicles that were entering and exiting at the driveway locations without having information on when vehicles actually exited or entered. In the configuration without the driveway sensors, 84 percent of the results had averages with errors smaller or equal to 5 seconds per vehicle. The algorithm in either driveway configuration provided reliable results that could be used for a Level of Service determination or signal operations evaluation.

Lastly, the results for the roadway configuration of a turning bay with turning bay sensors produced accurate results that were within a tolerable error range. These were similar to the driveway with sensors case where an accurate estimation of the vehicles which used the turning bay could be made. Ninety-four percent of the turning bay results had averages with errors smaller or equal to 5 seconds per vehicle. There were again a few outliers in the data but overall the algorithm provided reliable results that could be used for a Level of Service or signal timing evaluations or travel time estimation.

6 Conclusions and Recommendations

As volumes increase on signalized arterials in Utah, roadway expansion in many areas will not be feasible. Traffic signal optimization will continually play a role in increasing the capacity of already busy arterials. The need to improve the operation of traffic signals will not go away in the foreseeable future. Currently there is a need for a new dynamic delay calculation method that uses current signal detection infrastructure and can be implemented easily on a signalized arterial. At this time, it is not feasible to install new detection or infrastructure for the sole purpose of calculating delay. This study fulfills the need for developing a new delay calculation method that can be implemented on signalized arterials using existing traffic sensor technologies. As technologies progress and new detection is added, the algorithm developed in this study can be incorporated into the new technologies and improved to result in even more accurate delay estimates. Real-time traffic delay data gives traffic engineers and operators the ability to make adjustments to traffic signal timing when delay becomes unacceptable. Although several dynamic methods have been developed to estimate traffic delay in real-time, no method has produced results reliable and accurate enough for use on signalized arterials. Methods that have been tested include vehicle identification using embedded vehicle detection and Bluetooth technologies, camera image analysis, and maximum queue length analysis using vehicle detection. While each of these studies brought new advances and promise to be able to calculate vehicle delay on signalized arterials, none have achieved a level of accuracy that can be used in commercial applications.

This study has resulted in the development of a new algorithm for calculating delay based on time-stamped data from any type of vehicle detection. Using this algorithm, delay calculation can be automated and can return delay data quickly. The algorithm developed in this study can be applied to existing infrastructure at signalized intersections. However, there is still a need for some additional vehicle detection just downstream of an intersection but upstream of the delay test zone.

This study was the first phase in a multi-phase study to develop an automated process to collect delay data. Subsequent phases will focus on hardware in-loop simulation and field testing and implementation. Results from this study indicated that the algorithm produced an accuracy level that could be used in practical application. The algorithm provided results with acceptable tolerances that could be used to determine a Level of Service or to obtain travel time estimates. This chapter discusses the conclusions and the recommendations for future uses of this study.

6.1 Conclusions

This research has contributed to the development of a generic algorithm that can automate the collection of delay data at signalized intersections. The algorithm uses time-stamp data that can be collected from any type of detection to calculate delay. This study has calculated travel time and delay to an accuracy level at which the delay calculations could be used in most practical applications.

Results for the through-only type of facility offer the greatest level of accuracy, as expected. Delay values obtained from the through only configuration were all within 3.0 seconds per vehicle of the actual delay time.

Results for the roadway configuration with a driveway with no sensors also showed results that could be used in practical uses of delay estimation. In the configuration with the driveway sensors, 86 percent of the results had averages with errors smaller or equal to 5.0 seconds per vehicle. In the configuration without the driveway sensors, 84 percent of the results had averages with errors smaller or equal to 5.0 seconds per vehicle. The algorithm in either driveway configuration produced reliable results that could be used for a Level of Service determination or evaluation of through delay at a signalized intersection.

Lastly, the results for the roadway configuration of a turning bay with turning bay sensors provided accurate results. Ninety-four percent of the turning bay results had average delays with errors smaller or equal to 5.0 second per vehicles. There were again a few outliers in the data but overall the algorithm provided reliable results that could be used for a Level of Service or signal timing evaluations or travel time estimation.

6.2 Recommendations and Future Research

These results mark an end of the development phase of this multi-phase study. The results of Phase I show that by using the average of Model 1 and Model 2, traffic delay can be accurately estimated. It is recommended that Phase II begin and these algorithms be tested using a hardware-in-loop simulation. This will determine whether developed algorithm functions properly in a dynamic computation environment.

Phase II should be completed so that the algorithms can be integrated into a signal system in the future. For the algorithm to work, the signal controller needs to be able to relay detection information to a central system that would allow the data to be stored. Currently there is no setup for this to occur. Phase II will develop a way for real-time sensor data to be stored centrally.

Upon completion of Phase II, the algorithms developed in this study will be able to be implemented at signalized intersections. Upon implementation, the algorithms will give engineers the ability to quickly generate delay and travel-time information. This information will enable them to take action to reduce the overall delay for drivers.

REFERENCES

Abdel-Rahim, A., and M. Dixon. (2009). Automated Measurement of Approach Delay at Signalized Intersections: Vehicle Event-Based Method. Transportation Research Board (TRB), National Research Council. *Compendium of Papers DVD of the TRB 88th Annual Meetings.* TRB, National Research Council, Washington D.C..

Brennan, T. M., J. M. Ernst, C. M. Day, D. M. Bullock, J. V. Krogmeier, M. Martchouk. (2010). Influence of Vertical Sensor Placement on Data Collection Efficiency from Bluetooth MAC Address Collection Devices. *J. Transportation Engineering*, Vol. 136, No. 12, pp. 1104-1109.

Hereth, W. R., A. Zundel, and M. Saito. (2006). Automated Estimation of Average Stopped Delay at Signalized Intersections using Digitized Still-Image Analysis of Actual Traffic Flow. *Journal of Computing in Civil Engineering*, Vol. 20, No.2, pp. 132-140.

Institute of Transportation Engineers (ITE). (1994). *Manual of Transportation Engineering Studies*. Prentice Hall, Englewood Cliffs, N.J..

Liu, H. X., J. S. Oh, S. Oh, L. Chu, and W. Recker. (2001). On-Line Traffic Signal Control Scheme with Real-Time Delay Estimation Technology. *UCB-ITS-PWP-2001-16, California Partners for Advanced Transit and Highways*, University of California, Irvine.

Saito, M., A. K. Zundel, C. N. Taylor, J. Boyd, and M. Mendoza. (2008). Development of Automated Stopped Delay Estimation Software using Video Image Processing Technology. *Report for Trafficon*, USA. Final Report.

Saito, M., J. Walker, and A. Zundel. (2001). Use of Image Analysis to Estimate Average Stopped Delays Per Vehicle at Signalized Intersections. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1776. Transportation Research Board, National Research Council, Washington, D.C., pp. 106-113.

Sharma, A., D. M. Bullock, and J. A. Bonneson. (2007). Input-Output and Hybrid Techniques for Real-Time Prediction of Delay and Maximum Queue Length at Signalized Intersections. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2035. Transporation Research Board, National Research Council, Washington D.C., pp. 69-80.

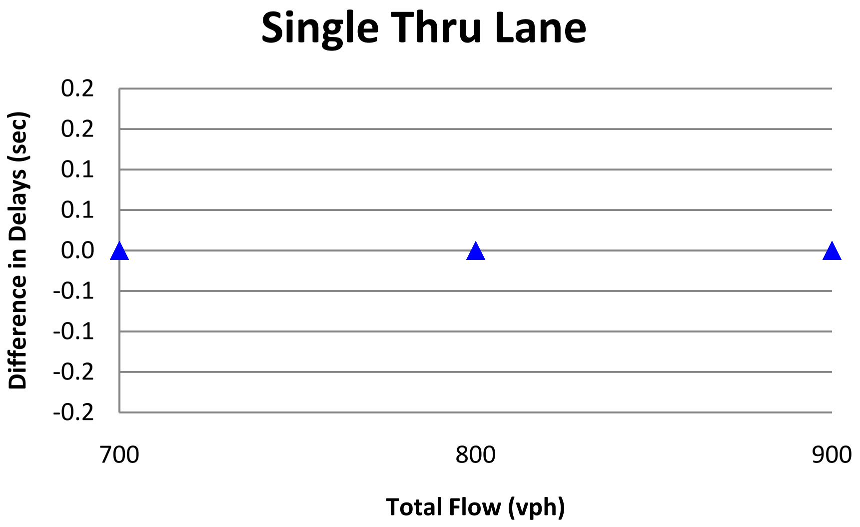
Transportation Research Board. (TRB). (2000). *Highway Capacity Manual*. Transportation Research Board, National Research Council, Washington, DC.

Wasson, J. S., Sturdevant, J. R., and Bullock, D. M. (2008). “Real-time travel time estimates using media access control address matching.” *ITE J.*, **78**(6), 20–23.

APPENDIX A: Charts and Graphs

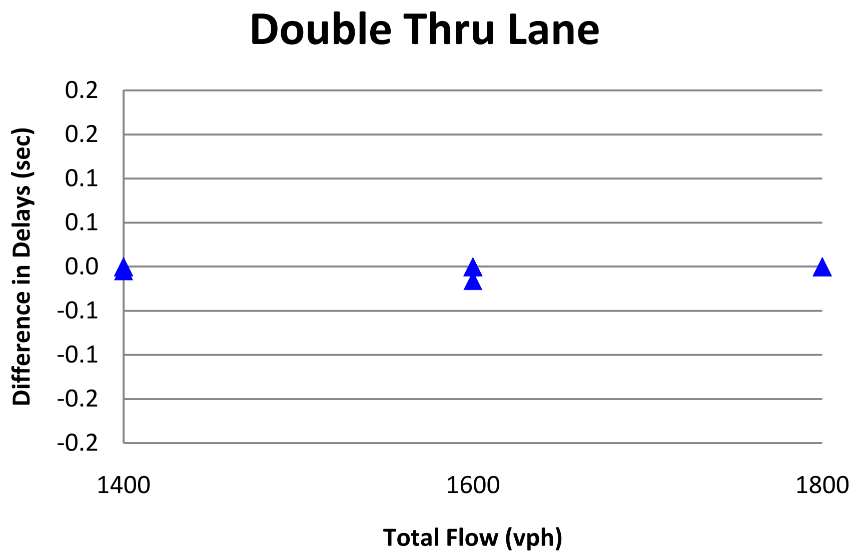
A.1 Single Through Lane

	Total Flow (vph)	Simulation Time Period (sec)	Matched Travel Time Delay (Sec/Veh)	Estimated Travel Time Delay (Sec/Veh)	Difference in Delays (Sec/Veh)	Difference in Delays %
Single Lane	700 vph	330-1230 sec	12.9	12.9	0.0	0%
		390-1290 sec	13.1	13.1	0.0	0%
		510-1410 sec	13.4	13.4	0.0	0%
		570-1470 sec	13.9	13.9	0.0	0%
	800 vph	330-1230 sec	13.5	13.5	0.0	0%
		390-1290 sec	13.9	13.9	0.0	0%
		510-1410 sec	15.1	12.4	2.6	17%
		570-1470 sec	15.2	15.2	0.0	0%
	900 vph	330-1230 sec	17.6	17.6	0.0	0%
		390-1290 sec	18.5	18.5	0.0	0%
		510-1410 sec	20.9	20.9	0.0	0%
		570-1470 sec	21.5	21.5	0.0	0%



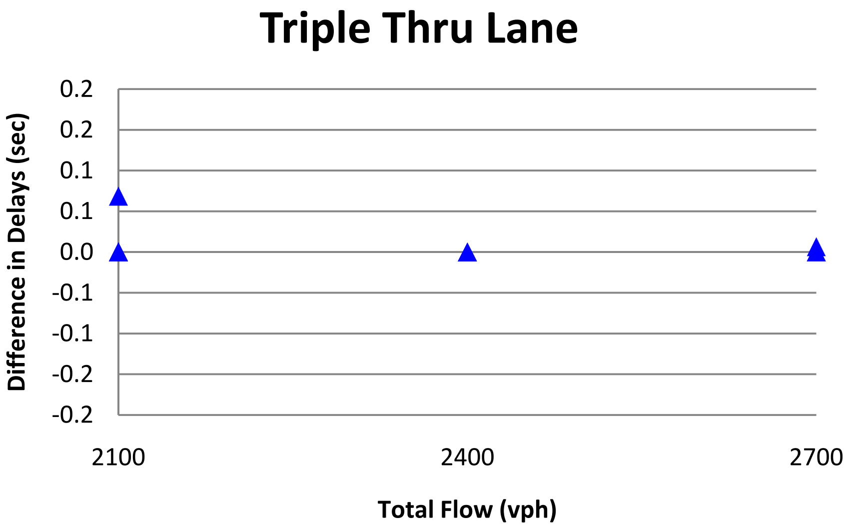
A.2 Double Through Lane

	Total Flow	Simulation Time Period	Matched Travel Time Delay (Sec/Veh)	Estimated Travel Time Delay (Sec/Veh)	Difference in Delays (Sec/Veh)	Difference in Delays %
Double Lane	1400 vph	330-1230 sec	13.1	13.1	0.0	0%
		390-1290 sec	13.2	13.2	0.0	0%
		510-1410 sec	13.2	13.2	0.0	0%
		570-1470 sec	13.1	13.1	0.0	0%
	1600 vph	330-1230 sec	13.1	13.1	0.0	0%
		390-1290 sec	14.1	14.1	0.0	0%
		510-1410 sec	14.9	14.9	0.0	0%
		570-1470 sec	15.2	15.2	0.0	0%
	1800 vph	330-1230 sec	18.5	18.5	0.0	0%
		390-1290 sec	18.7	18.7	0.0	0%
		510-1410 sec	19.0	19.0	0.0	0%
		570-1470 sec	19.0	19.0	0.0	0%



A.3 Triple Through Lanes

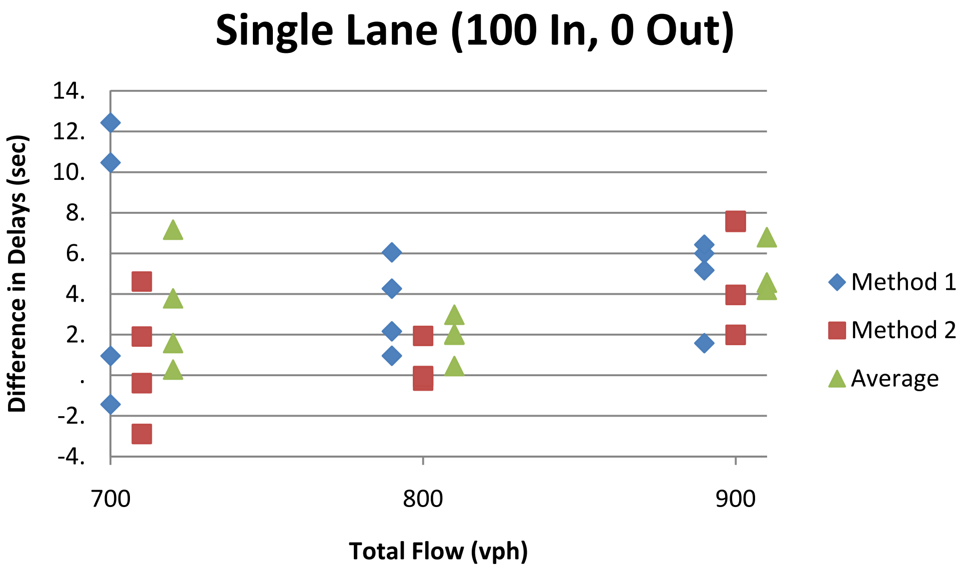
	Lane Flow	Simulation Time Period	Matched Travel Time Delay (Sec/Veh)	Estimated Travel Time Delay (Sec/Veh)	Difference in Delays (Sec/Veh)	Difference in Delays %
Triple Lane	2100 vph	330-1230 sec	12.8	12.8	0.0	0%
		390-1290 sec	12.5	12.5	0.0	0%
		510-1410 sec	12.3	12.2	0.1	1%
		570-1470 sec	12.5	12.5	0.0	0%
	2400 vph	330-1230 sec	14.0	14.0	0.0	0%
		390-1290 sec	14.1	14.1	0.0	0%
		510-1410 sec	14.0	14.0	0.0	0%
		570-1470 sec	14.1	14.1	0.0	0%
	2700 vph	330-1230 sec	16.3	15.1	1.3	8%
		390-1290 sec	16.4	16.4	0.0	0%
		510-1410 sec	15.9	15.9	0.0	0%
		570-1470 sec	16.0	16.0	0.0	0%



APPENDIX B: Charts and Graphs

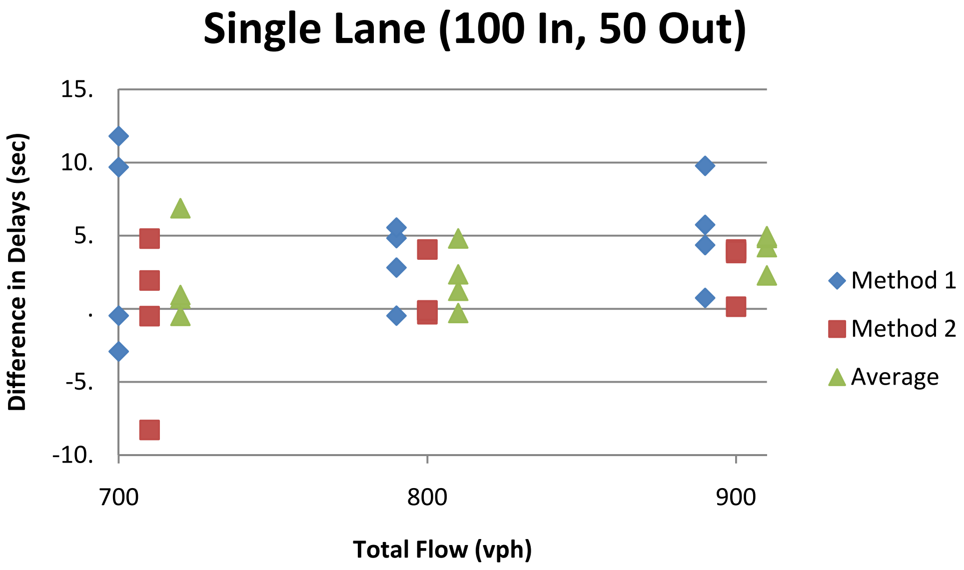
B.1 Single Lane Driveway with Sensors (100 In, 0 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Single Lane (100 In, 0 Out)	700	330-1230	14.6	4.2	10.5	71.5%	17.5	-2.9	-19.7%	3.8	25.9%
		390-1290	15.2	14.2	1.	6.3%	15.6	-.4	-2.6%	.3	1.9%
		510-1410	16.3	3.8	12.4	76.4%	14.4	1.9	11.7%	7.2	44.1%
		570-1470	17.1	18.5	-1.4	-8.4%	12.5	4.6	27.0%	1.6	9.3%
	800	330-1230	16.8	12.6	4.3	25.4%	17.1	-.3	-1.6%	2.	11.9%
		390-1290	18.1	17.1	1.	5.3%	18.1	.	-0.2%	.5	2.5%
		510-1410	18.5	12.4	6.	32.7%	18.6	-.1	-0.4%	3.	16.1%
		570-1470	18.7	16.5	2.2	11.6%	16.8	1.9	10.4%	2.	11.0%
	900	330-1230	22.2	17.1	5.2	23.2%	18.3	4.	17.8%	4.6	20.5%
		390-1290	23.	21.4	1.6	6.9%	15.4	7.6	32.8%	4.6	19.8%
		510-1410	24.7	18.8	6.	24.2%	17.1	7.6	30.7%	6.8	27.5%
		570-1470	25.1	18.7	6.4	25.6%	23.2	2.	7.9%	4.2	16.7%



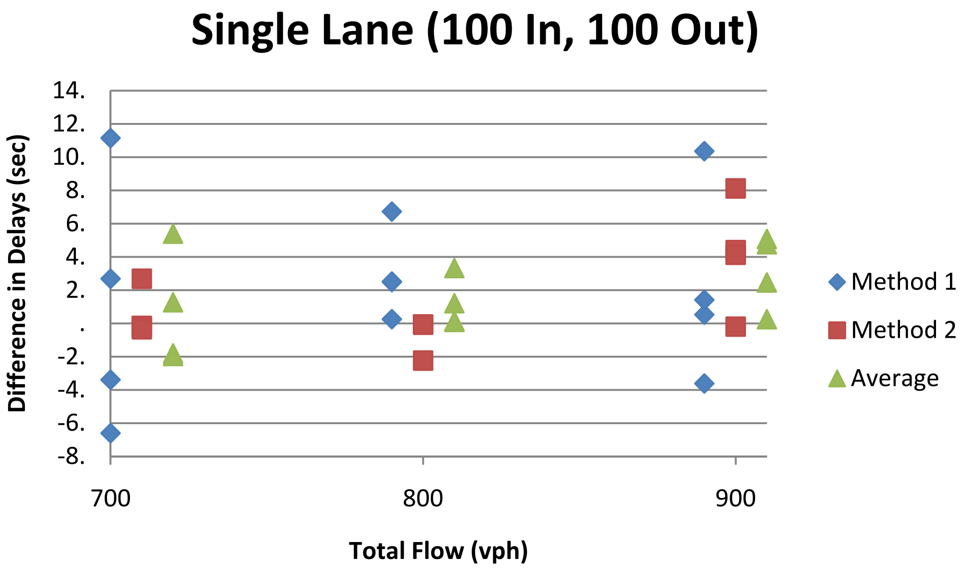
B.2 Single Lane Driveway with Sensors (100 In, 50 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Single Lane (100 In, 50Out)	700	330-1230	14.3	4.6	9.7	67.8%	22.6	-8.3	-58.0%	.7	4.9%
		390-1290	14.9	15.3	-.5	-3.1%	15.4	-.5	-3.4%	-.5	-3.2%
		510-1410	16.	4.2	11.8	73.8%	14.1	1.9	12.1%	6.9	42.9%
		570-1470	16.9	19.8	-2.9	-17.3%	12.1	4.8	28.5%	.9	5.6%
	800	330-1230	15.3	12.4	2.8	18.5%	15.6	-.4	-2.4%	1.2	8.0%
		390-1290	16.6	17.1	-.5	-2.8%	16.7	-.1	-0.7%	-.3	-1.7%
		510-1410	17.2	12.3	4.8	28.2%	17.3	-.1	-0.7%	2.4	13.7%
		570-1470	17.7	12.2	5.6	31.4%	13.7	4.1	22.9%	4.8	27.1%
	900	330-1230	22.1	17.7	4.4	19.8%	18.	4.1	18.4%	4.2	19.1%
		390-1290	22.7	21.9	.7	3.3%	18.9	3.8	16.8%	2.3	10.1%
		510-1410	24.5	18.7	5.7	23.5%	20.5	3.9	16.1%	4.8	19.8%
		570-1470	25.	15.2	9.8	39.2%	24.8	.1	0.6%	5.	19.9%



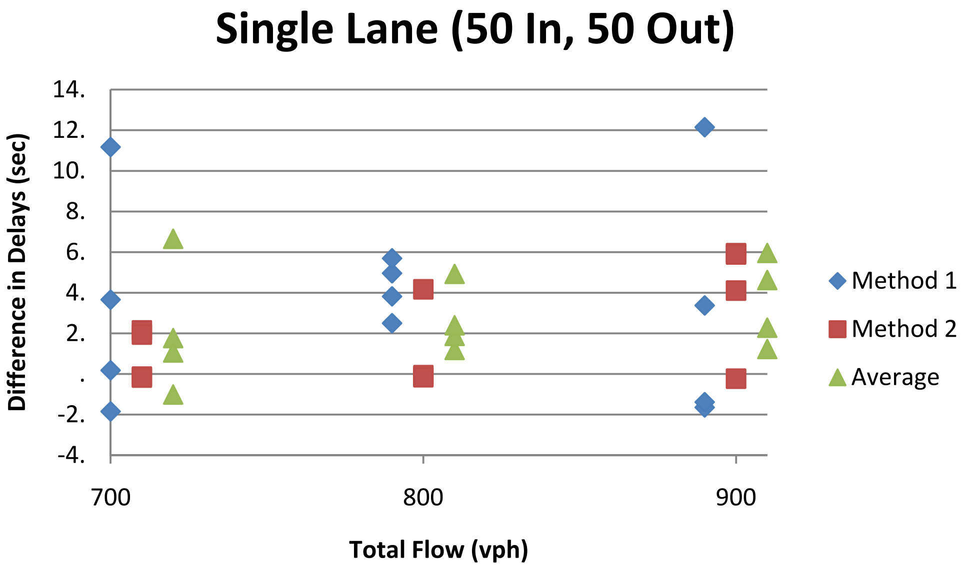
B.3 Single Lane Driveway with Sensors (100 In, 100 Out)

	Total Flow (vph)	Simulation Time Period (Sec)	Matched Travel Time Delay (Sec / Veh)	Method 1 Estimated Delay (Sec / Veh)	Method 1 Difference in Delays (Sec / Veh)	Method 1 Difference in Delays %	Method 2 Estimated Delay (Sec / Veh)	Method 2 Difference in Delays (Sec / Veh)	Method 2 Difference in Delays %	Average Difference in Delays (Sec / Veh)	Average Difference in Delays %
Single Lane (100 In, 100 Out)	700	330-1230	13.	10.3	2.7	20.7%	13.1	-.1	-1.1%	1.3	9.8%
		390-1290	13.6	16.9	-3.4	-25.0%	13.8	-.2	-1.5%	-1.8	-13.3%
		510-1410	14.2	3.1	11.2	78.4%	14.6	-.4	-2.5%	5.4	38.0%
		570-1470	15.1	21.7	-6.6	-43.9%	12.4	2.7	17.9%	-2.	-13.0%
	800	330-1230	13.9	13.7	.3	1.8%	14.	-.1	-0.5%	.1	0.7%
		390-1290	15.1	8.3	6.7	44.7%	15.1	-.1	-0.5%	3.3	22.1%
		510-1410	15.7	13.2	2.5	15.9%	15.8	-.1	-0.4%	1.2	7.7%
		570-1470	15.8	13.3	2.5	15.9%	18.1	-2.2	-14.2%	.1	0.9%
	900	330-1230	18.6	18.1	.5	2.8%	14.2	4.4	23.7%	2.5	13.3%
		390-1290	19.2	22.8	-3.6	-18.8%	15.1	4.1	21.5%	.3	1.3%
		510-1410	20.4	19.	1.4	6.9%	12.3	8.1	39.7%	4.8	23.3%
		570-1470	20.6	10.3	10.4	50.2%	20.8	-.2	-0.9%	5.1	24.7%



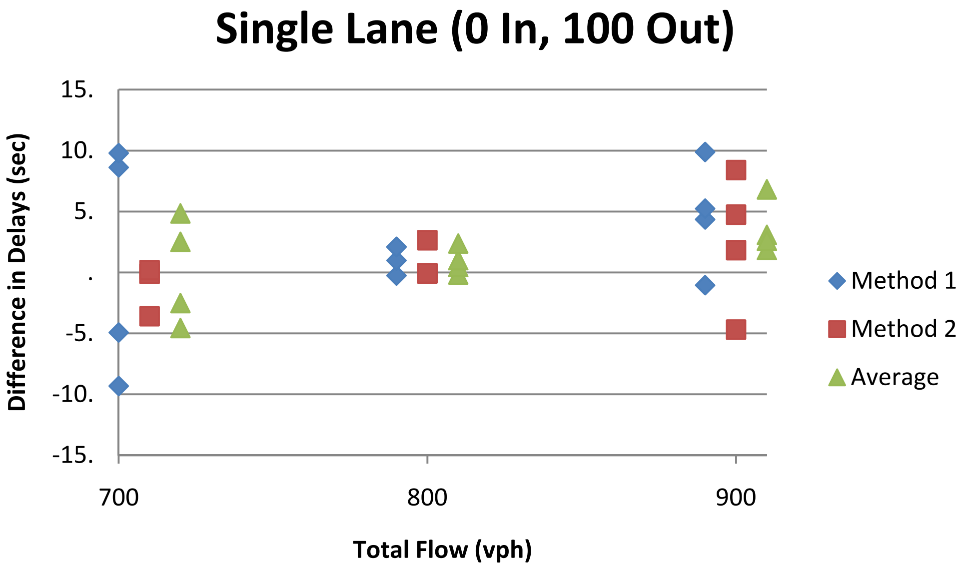
B.4 Single Lane Driveway with Sensors (50 In, 50 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Single Lane (50 In, 50 Out)	700	330-1230	13.4	9.7	3.7	27.3%	13.5	-.1	-0.9%	1.8	13.2%
		390-1290	13.9	15.8	-1.8	-13.2%	14.1	-.2	-1.3%	-1.	-7.3%
		510-1410	14.9	3.7	11.2	75.1%	12.7	2.1	14.4%	6.7	44.8%
		570-1470	15.4	15.2	.2	1.2%	13.5	1.9	12.6%	1.1	6.9%
	800	330-1230	15.1	12.6	2.5	16.6%	15.2	-.1	-0.9%	1.2	7.8%
		390-1290	16.6	12.7	3.8	23.1%	16.6	-.1	-0.4%	1.9	11.4%
		510-1410	17.3	12.3	5.	28.7%	17.4	-.2	-1.0%	2.4	13.9%
		570-1470	17.8	12.1	5.7	32.0%	13.6	4.2	23.4%	4.9	27.7%
	900	330-1230	21.	22.6	-1.6	-7.8%	16.9	4.1	19.6%	1.2	5.9%
		390-1290	21.6	23.	-1.4	-6.4%	15.7	5.9	27.5%	2.3	10.6%
		510-1410	23.	19.7	3.4	14.7%	17.2	5.9	25.5%	4.6	20.1%
		570-1470	23.4	11.3	12.1	51.9%	23.6	-.2	-1.0%	6.	25.4%



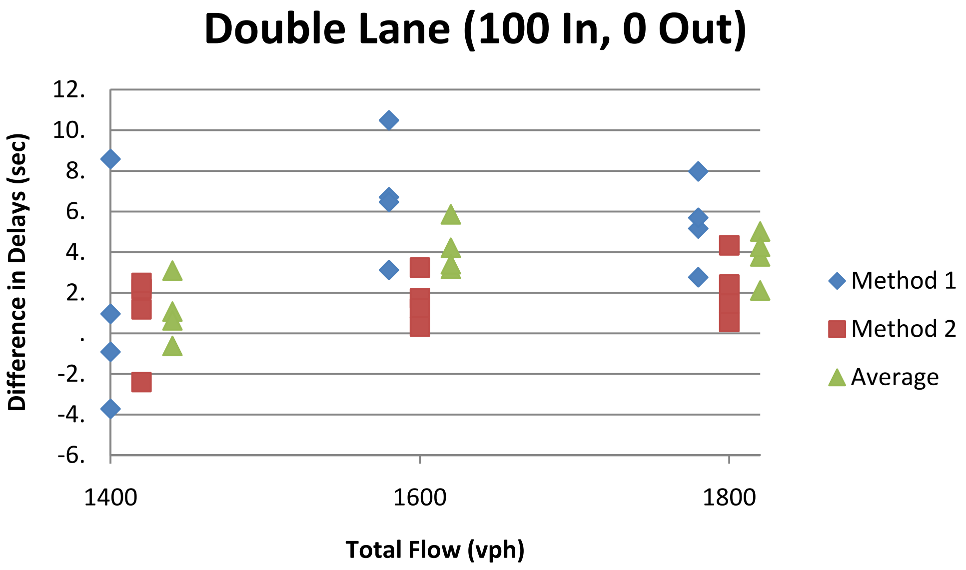
B.5 Single Lane Driveway with Sensors (0 In, 100 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Single Lane (0 In, 100 Out)	700	330-1230	12.6	4.	8.6	68.3%	16.2	-3.6	-28.5%	2.5	19.9%
		390-1290	13.1	18.	-4.9	-37.6%	13.2	-.1	-0.8%	-2.5	-19.2%
		510-1410	12.8	3.	9.8	76.5%	12.9	-.1	-0.8%	4.8	37.8%
		570-1470	13.5	22.8	-9.3	-69.1%	13.3	.2	1.4%	-4.6	-33.8%
	800	330-1230	13.5	13.8	-.3	-1.9%	13.6	-.1	-0.6%	-.2	-1.3%
		390-1290	14.7	13.7	1.	6.7%	14.8	-.1	-0.5%	.5	3.1%
		510-1410	15.4	13.3	2.1	13.5%	15.4	-.1	-0.4%	1.	6.6%
		570-1470	15.4	13.3	2.1	13.6%	12.8	2.6	17.1%	2.4	15.4%
	900	330-1230	17.3	18.3	-1.	-6.1%	12.6	4.7	27.4%	1.8	10.7%
		390-1290	18.1	13.8	4.3	24.0%	16.3	1.8	10.1%	3.1	17.0%
		510-1410	19.4	14.2	5.2	27.0%	11.	8.4	43.3%	6.8	35.1%
		570-1470	19.6	9.7	9.9	50.5%	24.3	-4.7	-23.9%	2.6	13.3%



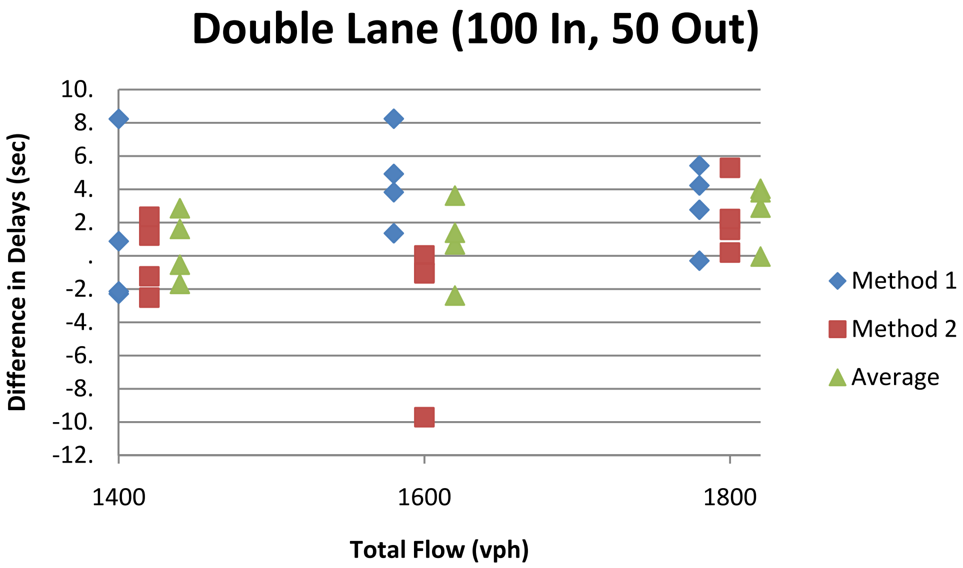
B.6 Double Lane Driveway with Sensors (100 In, 0 Out)

				Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Matched Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Double Lane (100 In, 0 Out)	1400	330-1230	13.8	12.8	1.	7.0%	12.6	1.2	8.6%	1.1	7.8%
		390-1290	13.8	5.2	8.6	62.2%	16.2	-2.4	-17.4%	3.1	22.4%
		510-1410	14.	14.9	-.9	-6.5%	11.8	2.2	15.7%	.6	4.6%
		570-1470	14.	17.7	-3.7	-26.6%	11.5	2.5	17.8%	-.6	-4.4%
	1600	330-1230	15.9	12.8	3.1	19.6%	12.6	3.2	20.4%	3.2	20.0%
		390-1290	17.2	10.5	6.7	39.0%	15.4	1.7	10.1%	4.2	24.6%
		510-1410	19.1	8.6	10.5	55.0%	17.8	1.2	6.4%	5.9	30.7%
		570-1470	19.4	12.9	6.5	33.4%	19.	.3	1.7%	3.4	17.6%
	1800	330-1230	21.5	16.3	5.2	24.0%	19.1	2.4	11.2%	3.8	17.6%
		390-1290	22.2	16.5	5.7	25.6%	17.9	4.3	19.5%	5.	22.6%
		510-1410	23.1	15.1	8.	34.5%	22.5	.6	2.4%	4.3	18.5%
		570-1470	23.3	20.5	2.8	11.9%	21.8	1.5	6.3%	2.1	9.1%



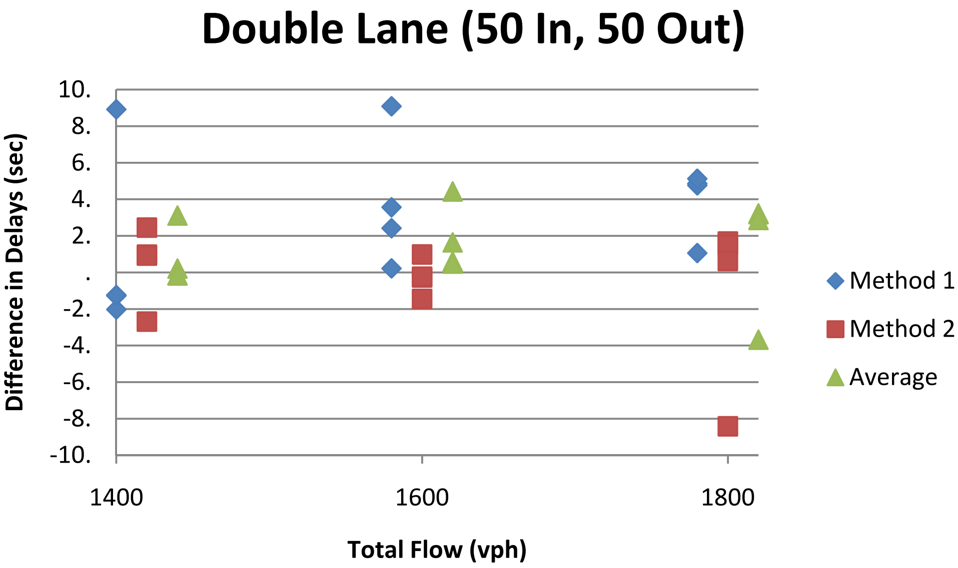
B.7 Double Lane Driveway with Sensors (100 In, 50 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Double Lane (100 In, 50 Out)	1400	330-1230	13.4	15.7	-2.3	-17.0%	12.2	1.2	9.0%	-.5	-4.0%
		390-1290	13.5	5.2	8.2	61.2%	16.	-2.5	-18.7%	2.9	21.3%
		510-1410	13.6	12.7	.9	6.4%	11.2	2.4	17.3%	1.6	11.9%
		570-1470	13.4	15.5	-2.1	-16.0%	14.6	-1.2	-9.2%	-1.7	-12.6%
	1600	330-1230	14.8	13.5	1.4	9.2%	14.8	.	0.1%	.7	4.6%
		390-1290	16.2	11.3	4.9	30.5%	25.9	-9.7	-60.0%	-2.4	-14.8%
		510-1410	17.3	9.1	8.2	47.6%	18.3	-1.	-5.8%	3.6	20.9%
		570-1470	17.5	13.6	3.8	21.9%	18.5	-1.1	-6.0%	1.4	7.9%
	1800	330-1230	18.5	14.3	4.2	22.9%	16.9	1.6	8.4%	2.9	15.7%
		390-1290	19.	16.3	2.8	14.6%	13.7	5.3	27.8%	4.	21.2%
		510-1410	19.8	14.3	5.4	27.4%	17.6	2.2	11.2%	3.8	19.3%
		570-1470	20.	20.3	-.3	-1.5%	19.8	.2	1.0%	.	-0.2%



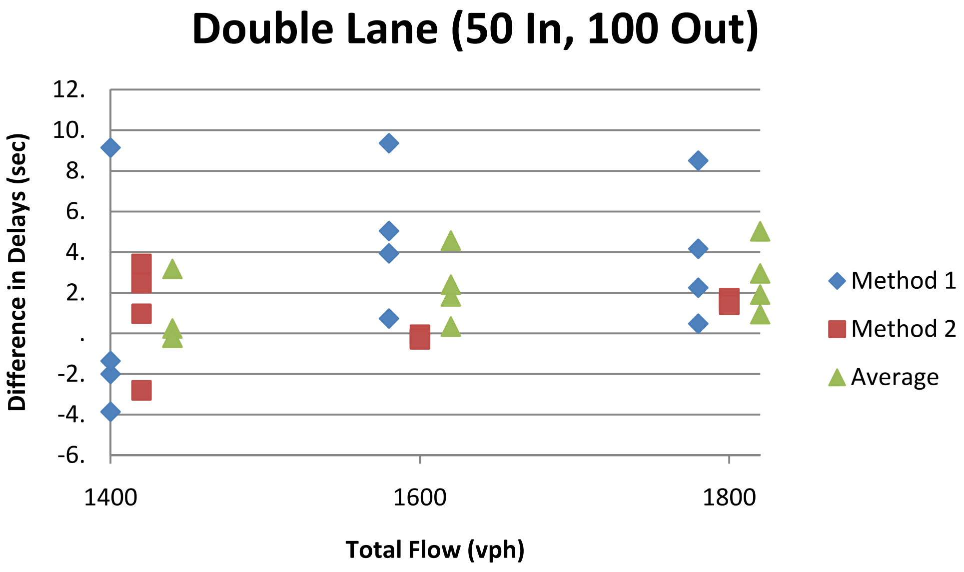
B.8 Double Lane Driveway with Sensors (50 In, 50 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Double Lane (50 In, 50 Out)	1400	330-1230	13.6	15.6	-2.	-14.9%	11.1	2.5	18.0%	.2	1.6%
		390-1290	13.6	4.7	8.9	65.5%	16.3	-2.7	-19.8%	3.1	22.9%
		510-1410	13.7	15.	-1.3	-9.3%	12.7	1.	7.2%	-.1	-1.1%
		570-1470	13.7	15.	-1.2	-9.0%	12.8	.9	6.7%	-.2	-1.2%
	1600	330-1230	13.7	13.4	.2	1.6%	12.7	1.	7.2%	.6	4.4%
		390-1290	14.9	11.4	3.6	23.9%	15.2	-.3	-1.9%	1.6	11.0%
		510-1410	16.	6.9	9.1	56.8%	16.2	-.2	-1.4%	4.4	27.7%
		570-1470	16.3	13.9	2.4	14.9%	17.7	-1.4	-8.9%	.5	3.0%
	1800	330-1230	19.1	14.3	4.8	24.9%	17.4	1.7	8.9%	3.2	16.9%
		390-1290	19.4	14.5	4.9	25.1%	17.8	1.5	7.8%	3.2	16.5%
		510-1410	19.6	14.5	5.1	26.1%	19.	.6	3.2%	2.9	14.6%
		570-1470	19.9	18.8	1.1	5.3%	28.3	-8.4	-42.3%	-3.7	-18.5%



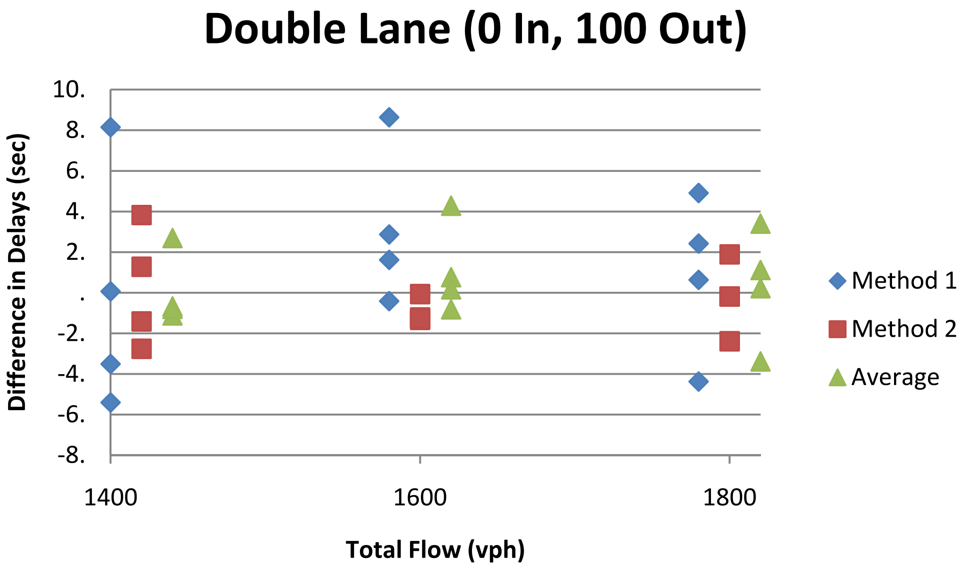
B.9 Double Lane Driveway with Sensors (50 In, 100 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Double Lane (50 In, 100 Out)	1400	330-1230	13.3	15.3	-2.	-15.0%	10.9	2.5	18.6%	.2	1.8%
		390-1290	13.4	4.3	9.1	68.2%	16.2	-2.8	-20.9%	3.2	23.7%
		510-1410	13.6	14.9	-1.4	-10.0%	12.6	1.	7.1%	-.2	-1.4%
		570-1470	13.7	17.5	-3.9	-28.2%	10.3	3.4	25.0%	-.2	-1.6%
	1600	330-1230	13.8	13.1	.7	5.3%	13.9	-.1	-0.5%	.3	2.4%
		390-1290	15.	11.1	3.9	26.2%	15.3	-.3	-2.0%	1.8	12.1%
		510-1410	15.9	6.5	9.4	58.9%	16.1	-.2	-1.5%	4.6	28.7%
		570-1470	16.1	11.1	5.	31.3%	16.4	-.3	-1.6%	2.4	14.9%
	1800	330-1230	18.	13.8	4.2	23.2%	16.2	1.7	9.7%	3.	16.4%
		390-1290	18.2	16.	2.2	12.3%	16.7	1.6	8.6%	1.9	10.5%
		510-1410	18.6	10.1	8.5	45.7%	17.1	1.5	8.3%	5.	27.0%
		570-1470	18.9	18.4	.5	2.5%	17.5	1.4	7.4%	.9	5.0%



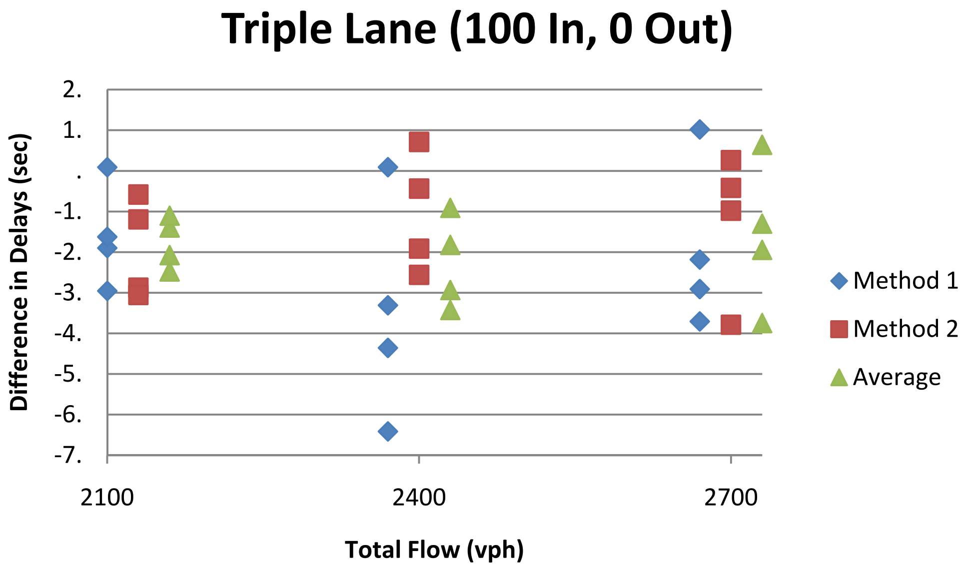
B.10 Double Lane Driveway with Sensors (0 In, 100 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Double Lane (0 In, 100 Out)	1400	330-1230	12.9	16.4	-3.5	-27.2%	11.6	1.3	9.9%	-1.1	-8.7%
		390-1290	12.9	4.7	8.1	63.3%	15.6	-2.8	-21.4%	2.7	20.9%
		510-1410	13.	12.9	.1	0.5%	14.4	-1.4	-10.9%	-.7	-5.2%
		570-1470	13.	18.4	-5.4	-41.5%	9.2	3.8	29.4%	-.8	-6.1%
	1600	330-1230	12.9	13.3	-.4	-3.2%	14.1	-1.2	-9.5%	-.8	-6.3%
		390-1290	14.1	11.3	2.9	20.3%	15.5	-1.3	-9.5%	.8	5.4%
		510-1410	14.9	6.2	8.6	58.1%	14.9	-.1	-0.4%	4.3	28.8%
		570-1470	15.1	13.5	1.6	10.7%	16.3	-1.3	-8.5%	.2	1.1%
	1800	330-1230	17.6	12.7	4.9	27.9%	15.7	1.9	10.7%	3.4	19.3%
		390-1290	17.8	17.2	.6	3.6%	18.	-.2	-1.1%	.2	1.3%
		510-1410	17.6	15.2	2.4	13.7%	17.8	-.2	-1.0%	1.1	6.3%
		570-1470	17.3	21.7	-4.4	-25.3%	19.7	-2.4	-13.8%	-3.4	-19.5%



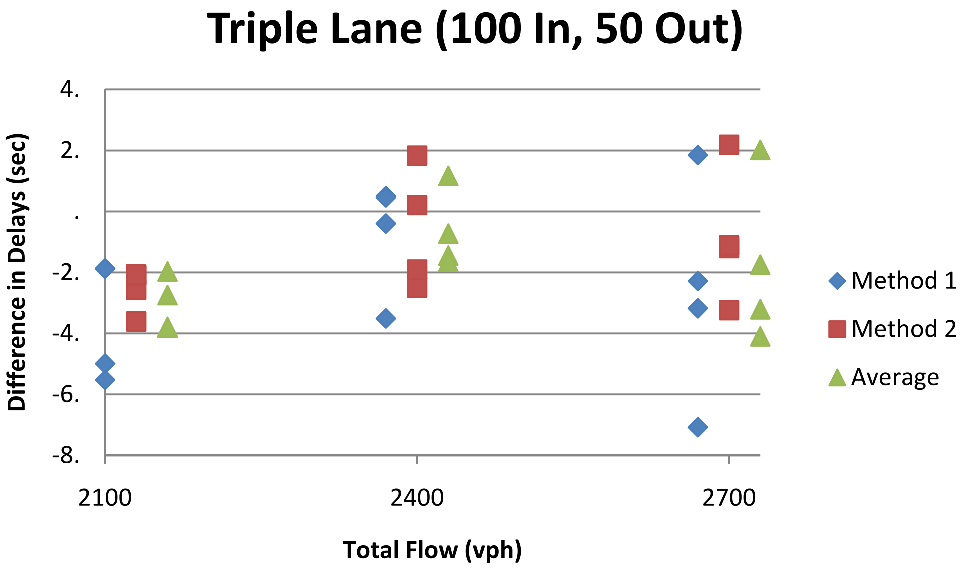
B.11 Triple Lane Driveway with Sensors (100 In, 0 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Triple Lane (100 In, 0 Out)	2100	330-1230	13.1	16.1	-3.	-22.5%	14.3	-1.2	-9.1%	-2.1	-15.8%
		390-1290	12.9	12.8	.1	0.7%	15.7	-2.9	-22.3%	-1.4	-10.8%
		510-1410	12.7	14.6	-1.9	-14.9%	15.8	-3.1	-24.0%	-2.5	-19.4%
		570-1470	12.9	14.6	-1.6	-12.6%	13.5	-.6	-4.5%	-1.1	-8.5%
	2400	330-1230	15.2	15.1	.1	0.6%	17.1	-1.9	-12.6%	-.9	-6.0%
		390-1290	15.2	19.6	-4.4	-28.6%	14.5	.7	4.7%	-1.8	-12.0%
		510-1410	14.8	21.2	-6.4	-43.4%	15.2	-.4	-2.9%	-3.4	-23.2%
		570-1470	14.7	18.	-3.3	-22.5%	17.3	-2.6	-17.4%	-2.9	-19.9%
	2700	330-1230	17.6	16.6	1.	5.8%	17.3	.3	1.5%	.6	3.7%
		390-1290	17.7	20.6	-2.9	-16.4%	18.7	-1.	-5.5%	-1.9	-11.0%
		510-1410	17.3	19.5	-2.2	-12.6%	17.8	-.4	-2.4%	-1.3	-7.5%
		570-1470	17.3	21.	-3.7	-21.4%	21.1	-3.8	-21.8%	-3.7	-21.6%



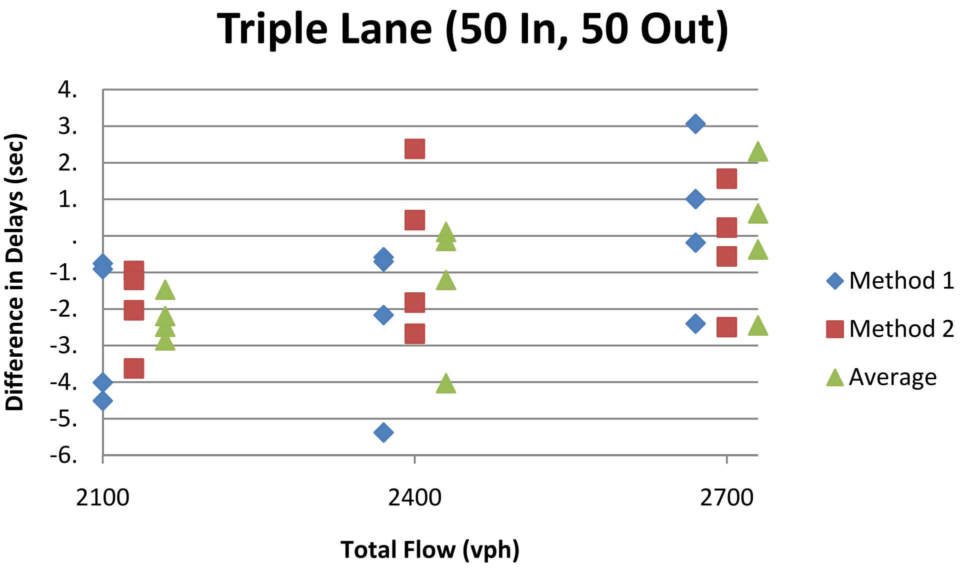
B.12 Triple Lane Driveway with Sensors (100 In, 50 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Triple Lane (100 In, 50 Out)	2100	330-1230	13.3	18.3	-5.	-37.6%	15.8	-2.6	-19.4%	-3.8	-28.5%
		390-1290	13.	14.9	-1.9	-14.4%	16.6	-3.6	-27.8%	-2.7	-21.1%
		510-1410	12.8	18.3	-5.5	-43.3%	14.9	-2.1	-16.4%	-3.8	-29.9%
		570-1470	13.	14.9	-1.9	-14.5%	15.	-2.1	-15.9%	-2.	-15.2%
	2400	330-1230	14.9	15.3	-.4	-2.7%	17.4	-2.5	-16.7%	-1.4	-9.7%
		390-1290	14.9	18.4	-3.5	-23.6%	14.7	.2	1.4%	-1.7	-11.1%
		510-1410	14.5	14.	.5	3.5%	12.7	1.8	12.6%	1.2	8.0%
		570-1470	14.4	14.	.5	3.2%	16.3	-1.9	-13.2%	-.7	-5.0%
	2700	330-1230	17.3	15.5	1.8	10.7%	15.1	2.2	12.6%	2.	11.6%
		390-1290	17.3	19.5	-2.3	-13.2%	18.5	-1.2	-6.9%	-1.7	-10.1%
		510-1410	16.6	23.7	-7.1	-42.5%	17.8	-1.1	-6.7%	-4.1	-24.6%
		570-1470	16.7	19.8	-3.2	-19.1%	19.9	-3.2	-19.4%	-3.2	-19.2%



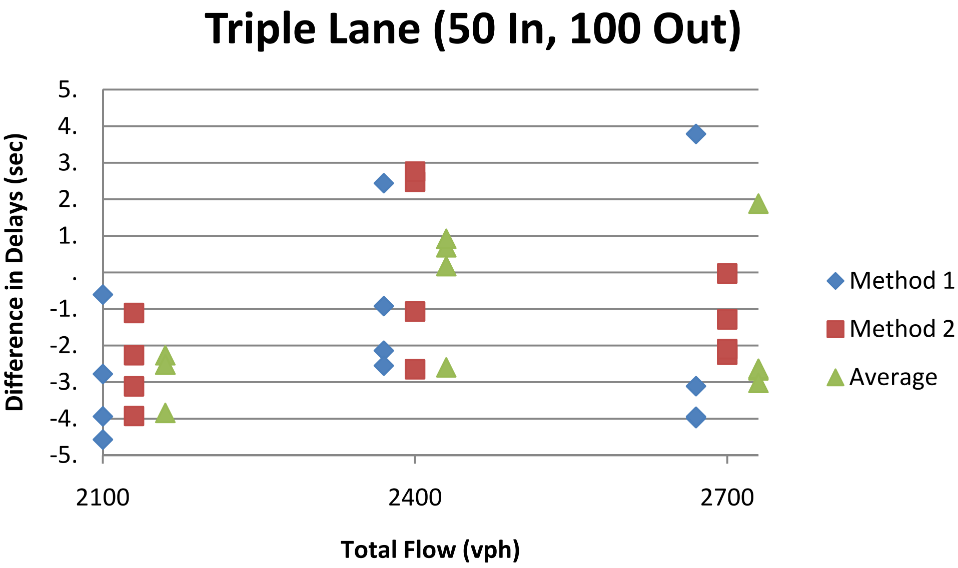
B.13 Triple Lane Driveway with Sensors (50 In, 50 Out)

	Total Flow (vph)	Simulation Time Period (Sec)	Matched Travel Time Delay (Sec / Veh)	Method 1 Estimated Delay (Sec / Veh)	Method 1 Difference in Delays (Sec / Veh)	Method 1 Difference in Delays %	Method 2 Estimated Delay (Sec / Veh)	Method 2 Difference in Delays (Sec / Veh)	Method 2 Difference in Delays %	Average Difference in Delays (Sec / Veh)	Average Difference in Delays %
Triple Lane (50 In, 50 Out)	2100	330-1230	12.7	16.8	-4.	-31.5%	13.7	-1.	-7.5%	-2.5	-19.5%
		390-1290	12.5	13.3	-.8	-6.1%	16.1	-3.6	-29.0%	-2.2	-17.5%
		510-1410	12.4	16.9	-4.5	-36.5%	13.6	-1.2	-9.8%	-2.9	-23.1%
		570-1470	12.6	13.5	-.9	-7.2%	14.6	-2.	-16.1%	-1.5	-11.7%
	2400	330-1230	14.5	15.1	-.6	-4.0%	16.4	-1.8	-12.6%	-1.2	-8.3%
		390-1290	14.6	16.8	-2.2	-14.8%	12.2	2.4	16.3%	.1	0.7%
		510-1410	14.6	15.3	-.7	-4.8%	14.1	.4	3.0%	-.1	-0.9%
		570-1470	14.5	19.9	-5.4	-37.0%	17.2	-2.7	-18.4%	-4.	-27.7%
	2700	330-1230	16.7	13.6	3.1	18.4%	15.1	1.6	9.4%	2.3	13.9%
		390-1290	16.7	19.1	-2.4	-14.4%	19.2	-2.5	-15.0%	-2.4	-14.7%
		510-1410	16.4	15.4	1.	6.1%	16.2	.2	1.4%	.6	3.8%
		570-1470	16.6	16.8	-.2	-1.1%	17.2	-.6	-3.4%	-.4	-2.2%



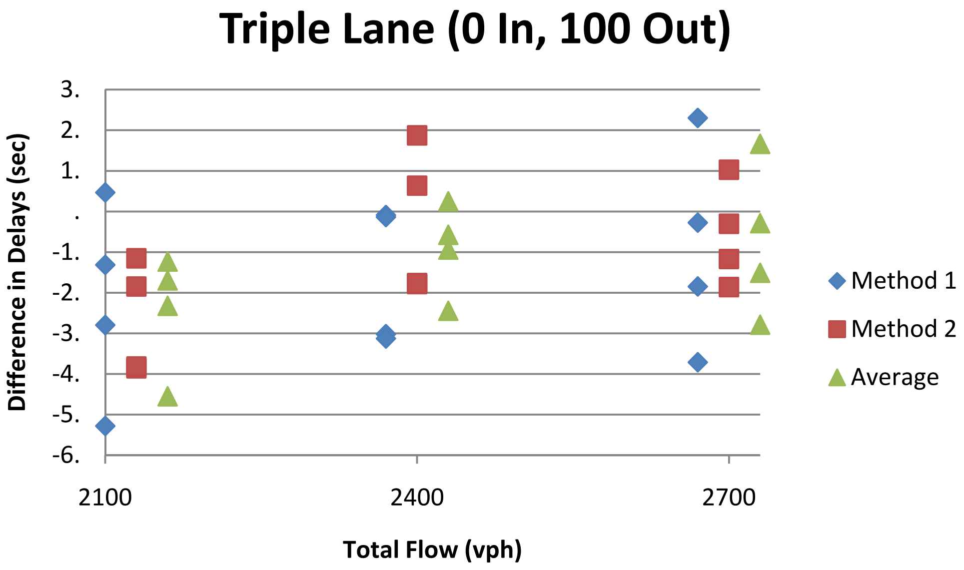
B.14 Triple Lane Driveway with Sensors (50 In, 100 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Triple Lane (50 In, 100 Out)	2100	330-1230	13.	16.9	-3.9	-30.4%	14.1	-1.1	-8.6%	-2.5	-19.5%
		390-1290	12.7	13.3	-.6	-4.8%	16.6	-3.9	-30.9%	-2.3	-17.8%
		510-1410	12.5	17.1	-4.6	-36.5%	15.6	-3.1	-24.9%	-3.8	-30.7%
		570-1470	12.7	15.5	-2.8	-21.9%	14.9	-2.3	-17.8%	-2.5	-19.9%
	2400	330-1230	14.4	11.9	2.4	17.0%	15.4	-1.1	-7.5%	.7	4.8%
		390-1290	14.5	16.6	-2.1	-14.8%	12.	2.5	17.1%	.2	1.2%
		510-1410	14.4	15.3	-.9	-6.4%	11.6	2.8	19.2%	.9	6.4%
		570-1470	14.4	16.9	-2.6	-17.8%	17.	-2.6	-18.4%	-2.6	-18.1%
	2700	330-1230	18.2	14.5	3.8	20.8%	18.3	.	-0.2%	1.9	10.3%
		390-1290	18.2	21.3	-3.1	-17.1%	20.5	-2.3	-12.4%	-2.7	-14.7%
		510-1410	17.6	21.6	-4.	-22.6%	18.9	-1.3	-7.3%	-2.6	-14.9%
		570-1470	17.9	21.8	-3.9	-22.1%	20.	-2.1	-11.7%	-3.	-16.9%



B.15 Triple Lane Driveway with Sensors (0 In, 100 Out)

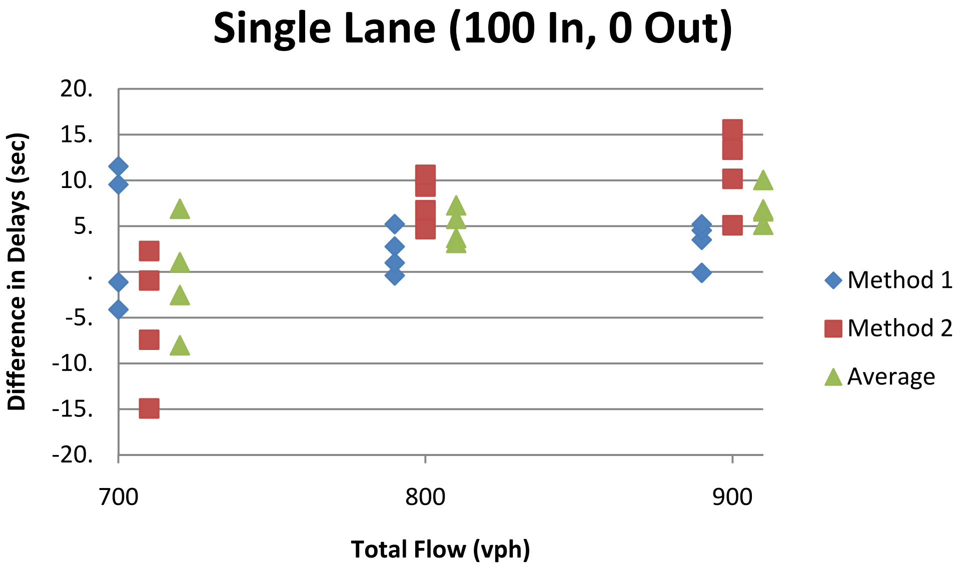
			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Triple Lane (0 In, 100 Out)	2100	330-1230	12.6	15.4	-2.8	-22.1%	14.5	-1.8	-14.6%	-2.3	-18.4%
		390-1290	12.3	11.9	.5	3.8%	16.2	-3.9	-31.3%	-1.7	-13.8%
		510-1410	12.2	17.5	-5.3	-43.3%	16.	-3.8	-31.3%	-4.5	-37.3%
		570-1470	12.4	13.7	-1.3	-10.6%	13.5	-1.2	-9.3%	-1.2	-10.0%
	2400	330-1230	14.2	14.2	-.1	-0.6%	15.9	-1.8	-12.6%	-.9	-6.6%
		390-1290	14.2	17.3	-3.	-21.2%	12.4	1.9	13.2%	-.6	-4.0%
		510-1410	14.	14.1	-.1	-1.0%	13.4	.6	4.5%	.2	1.8%
		570-1470	14.	17.2	-3.1	-22.3%	15.8	-1.8	-12.5%	-2.4	-17.4%
	2700	330-1230	16.2	13.9	2.3	14.2%	15.1	1.	6.4%	1.7	10.3%
		390-1290	15.9	19.6	-3.7	-23.3%	17.8	-1.9	-11.7%	-2.8	-17.5%
		510-1410	15.2	15.5	-.3	-1.8%	15.5	-.3	-2.0%	-.3	-1.9%
		570-1470	15.3	17.1	-1.8	-12.1%	16.5	-1.2	-7.6%	-1.5	-9.9%



APPENDIX C: Charts and Graphs

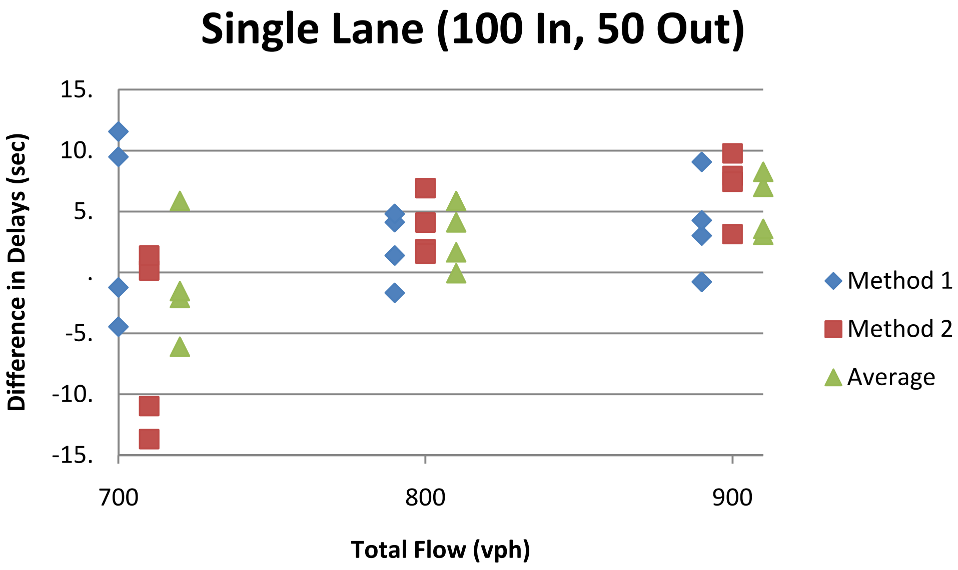
C.1 Single Lane Driveway without Sensors (100 In, 0 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Single Lane (100 In, 0 Out)	700	330-1230	14.6	5.1	9.5	65.2%	22.1	-7.4	-50.7%	1.1	7.3%
		390-1290	15.2	16.3	-1.1	-7.4%	30.1	-14.9	-98.2%	-8.	-52.8%
		510-1410	16.3	4.7	11.5	70.8%	14.	2.3	14.0%	6.9	42.4%
		570-1470	17.1	21.2	-4.1	-24.1%	18.	-.9	-5.6%	-2.5	-14.8%
	800	330-1230	16.8	14.1	2.8	16.5%	12.1	4.7	27.8%	3.7	22.1%
		390-1290	18.1	18.5	-.4	-2.1%	11.3	6.8	37.3%	3.2	17.6%
		510-1410	18.5	13.3	5.2	28.2%	9.2	9.3	50.5%	7.3	39.3%
		570-1470	18.7	17.7	1.	5.3%	8.1	10.6	56.7%	5.8	31.0%
	900	330-1230	22.2	18.7	3.5	15.8%	12.1	10.2	45.7%	6.8	30.7%
		390-1290	23.	23.1	-.1	-0.4%	9.6	13.4	58.1%	6.6	28.8%
		510-1410	24.7	20.2	4.5	18.3%	9.2	15.6	62.9%	10.1	40.6%
		570-1470	25.1	20.	5.2	20.7%	20.1	5.1	20.3%	5.1	20.5%



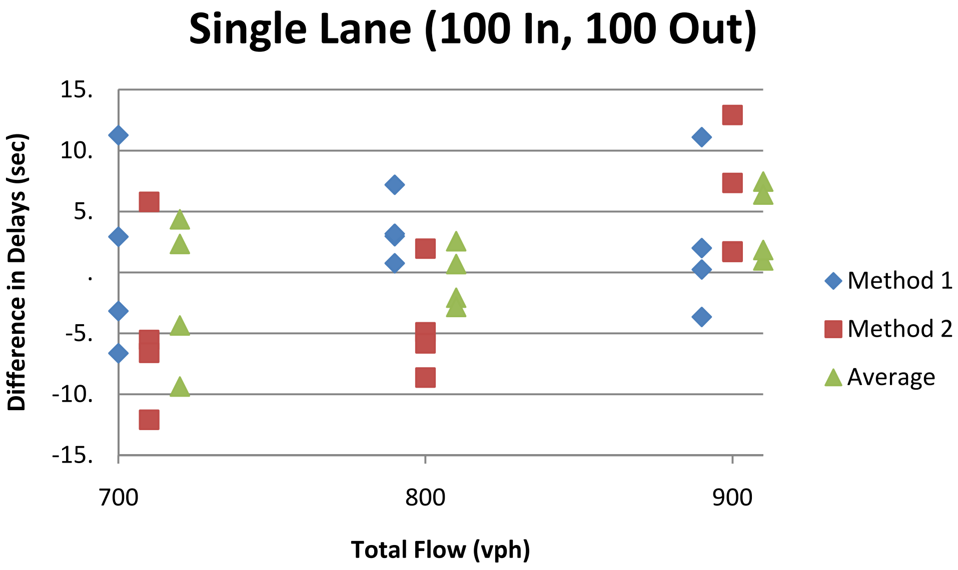
C.2 Single Lane Driveway without Sensors (100 In, 50 Out)

	Total Flow (vph)	Simulation Time Period (Sec)	Matched Travel Time Delay (Sec / Veh)	Method 1 Estimated Delay (Sec / Veh)	Method 1 Difference in Delays (Sec / Veh)	Method 1 Difference in Delays %	Method 2 Estimated Delay (Sec / Veh)	Method 2 Difference in Delays (Sec / Veh)	Method 2 Difference in Delays %	Average Difference in Delays (Sec / Veh)	Average Difference in Delays %
Single Lane (100 In, 50 Out)	700	330-1230	14.3	4.8	9.5	66.4%	28.	-13.7	-95.7%	-2.1	-14.7%
		390-1290	14.9	16.1	-1.2	-8.3%	25.8	-11.	-73.7%	-6.1	-41.0%
		510-1410	16.	4.4	11.6	72.3%	15.8	.2	1.0%	5.9	36.6%
		570-1470	16.9	21.3	-4.5	-26.5%	15.5	1.4	8.2%	-1.5	-9.1%
	800	330-1230	15.3	13.9	1.4	9.1%	13.4	1.9	12.5%	1.6	10.8%
		390-1290	16.6	18.3	-1.7	-10.1%	15.1	1.5	9.3%	-.1	-0.4%
		510-1410	17.2	13.1	4.1	24.0%	13.1	4.1	23.9%	4.1	23.9%
		570-1470	17.7	12.9	4.8	27.1%	10.8	6.9	39.0%	5.9	33.1%
	900	330-1230	22.1	19.1	3.	13.7%	18.9	3.1	14.3%	3.1	14.0%
		390-1290	22.7	23.5	-.8	-3.4%	14.8	7.9	34.9%	3.6	15.7%
		510-1410	24.5	20.2	4.3	17.5%	14.7	9.8	39.9%	7.	28.7%
		570-1470	25.	15.9	9.1	36.3%	17.5	7.4	29.8%	8.3	33.1%



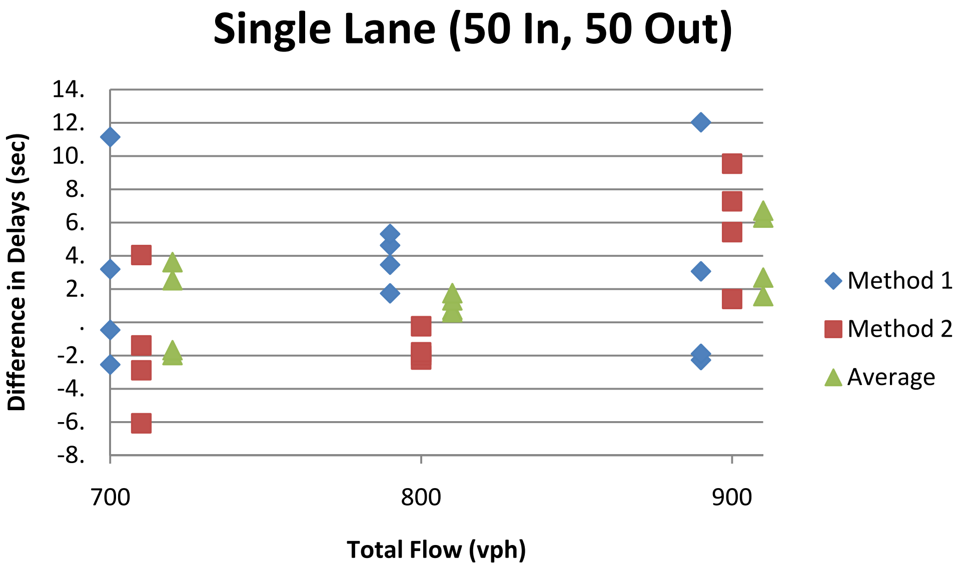
C.3 Single Lane Driveway without Sensors (100 In, 100 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Single Lane (100 In, 100 Out)	700	330-1230	13.	10.1	2.9	22.5%	7.2	5.8	44.5%	4.4	33.5%
		390-1290	13.6	16.7	-3.2	-23.4%	19.1	-5.5	-40.9%	-4.4	-32.1%
		510-1410	14.2	3.	11.3	79.2%	20.8	-6.6	-46.3%	2.3	16.4%
		570-1470	15.1	21.7	-6.6	-44.1%	27.1	-12.1	-80.3%	-9.4	-62.2%
	800	330-1230	13.9	13.2	.8	5.4%	18.8	-4.9	-35.2%	-2.1	-14.9%
		390-1290	15.1	7.9	7.2	47.8%	20.9	-5.8	-38.6%	.7	4.6%
		510-1410	15.7	12.7	3.	18.9%	24.3	-8.6	-54.9%	-2.8	-18.0%
		570-1470	15.8	12.6	3.2	20.1%	13.9	2.	12.4%	2.6	16.2%
	900	330-1230	18.6	18.4	.2	1.3%	16.9	1.7	9.3%	1.	5.3%
		390-1290	19.2	22.9	-3.7	-19.0%	11.9	7.3	38.2%	1.8	9.6%
		510-1410	20.4	18.4	2.	9.8%	7.5	12.9	63.2%	7.5	36.5%
		570-1470	20.6	9.5	11.1	53.8%	18.9	1.7	8.1%	6.4	31.0%



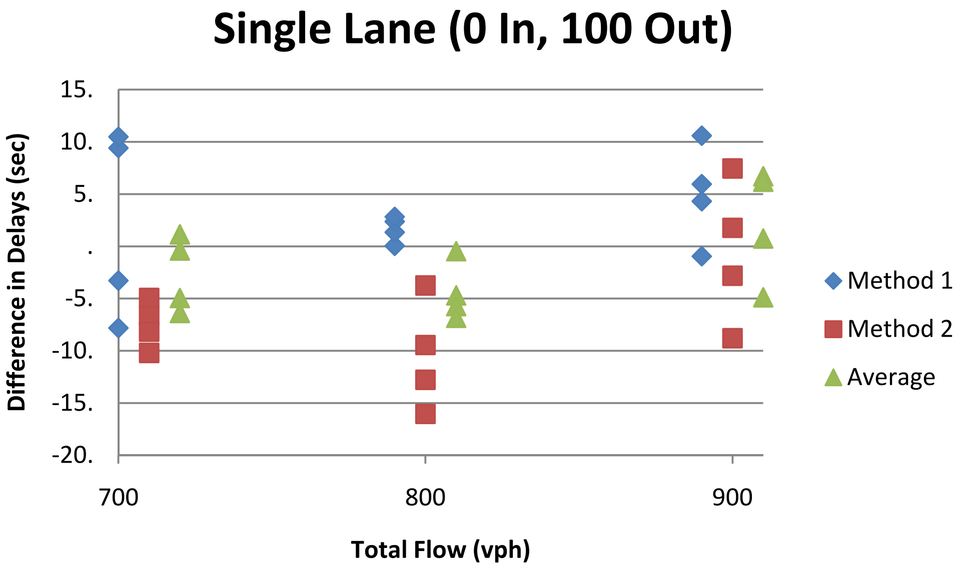
C.4 Single Lane Driveway without Sensors (50 In, 50 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Single Lane (50 In, 50 Out)	700	330-1230	13.4	10.2	3.2	23.9%	9.4	4.	30.2%	3.6	27.0%
		390-1290	13.9	16.5	-2.5	-18.3%	15.3	-1.4	-10.0%	-2.	-14.1%
		510-1410	14.9	3.7	11.2	75.0%	21.	-6.1	-40.9%	2.5	17.1%
		570-1470	15.4	15.9	-.5	-3.0%	18.3	-2.9	-18.7%	-1.7	-10.9%
	800	330-1230	15.1	13.4	1.7	11.6%	15.3	-.2	-1.6%	.8	5.0%
		390-1290	16.6	13.1	3.5	20.9%	18.8	-2.2	-13.5%	.6	3.7%
		510-1410	17.3	12.6	4.6	26.8%	19.3	-2.	-11.5%	1.3	7.7%
		570-1470	17.8	12.5	5.3	29.8%	19.6	-1.8	-10.1%	1.8	9.9%
	900	330-1230	21.	23.2	-2.3	-10.8%	15.5	5.4	25.9%	1.6	7.5%
		390-1290	21.6	23.5	-1.9	-8.8%	14.3	7.3	33.7%	2.7	12.5%
		510-1410	23.	20.	3.1	13.3%	13.5	9.5	41.4%	6.3	27.4%
		570-1470	23.4	11.4	12.	51.4%	22.	1.4	6.0%	6.7	28.7%



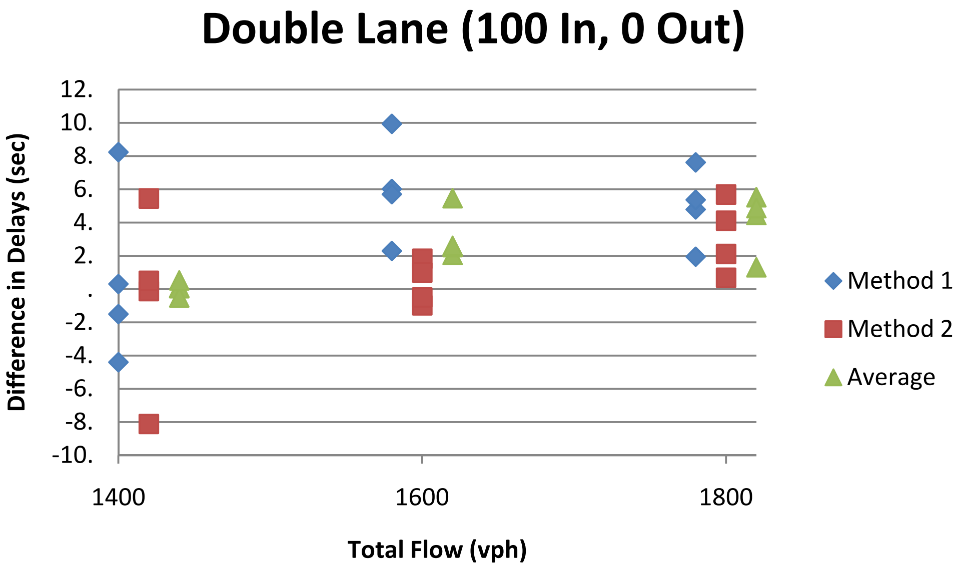
C.5 Single Lane Driveway without Sensors (0 In, 100 Out)

	Total Flow (vph)	Simulation Time Period (Sec)	Matched Travel Time Delay (Sec / Veh)	Method 1			Method 2			Average	
				Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Single Lane (0 In, 100 Out)	700	330-1230	12.6	3.2	9.4	74.6%	22.8	-10.2	-80.9%	-.4	-3.2%
		390-1290	13.1	16.4	-3.3	-25.0%	19.7	-6.6	-50.4%	-4.9	-37.7%
		510-1410	12.8	2.3	10.5	81.9%	21.	-8.2	-63.9%	1.2	9.0%
		570-1470	13.5	21.3	-7.8	-57.9%	18.4	-4.9	-36.5%	-6.4	-47.2%
	800	330-1230	13.5	13.5	.	0.4%	23.	-9.4	-69.9%	-4.7	-34.8%
		390-1290	14.7	13.3	1.3	9.1%	27.5	-12.8	-87.0%	-5.7	-38.9%
		510-1410	15.4	13.	2.4	15.4%	31.4	-16.	-104.4%	-6.8	-44.5%
		570-1470	15.4	12.6	2.8	18.3%	19.2	-3.8	-24.3%	-.5	-3.0%
	900	330-1230	17.3	18.3	-1.	-5.5%	26.1	-8.8	-50.9%	-4.9	-28.2%
		390-1290	18.1	13.8	4.3	23.8%	20.9	-2.8	-15.6%	.7	4.1%
		510-1410	19.4	13.5	5.9	30.6%	12.	7.5	38.4%	6.7	34.5%
		570-1470	19.6	9.	10.6	54.1%	17.8	1.8	9.0%	6.2	31.5%



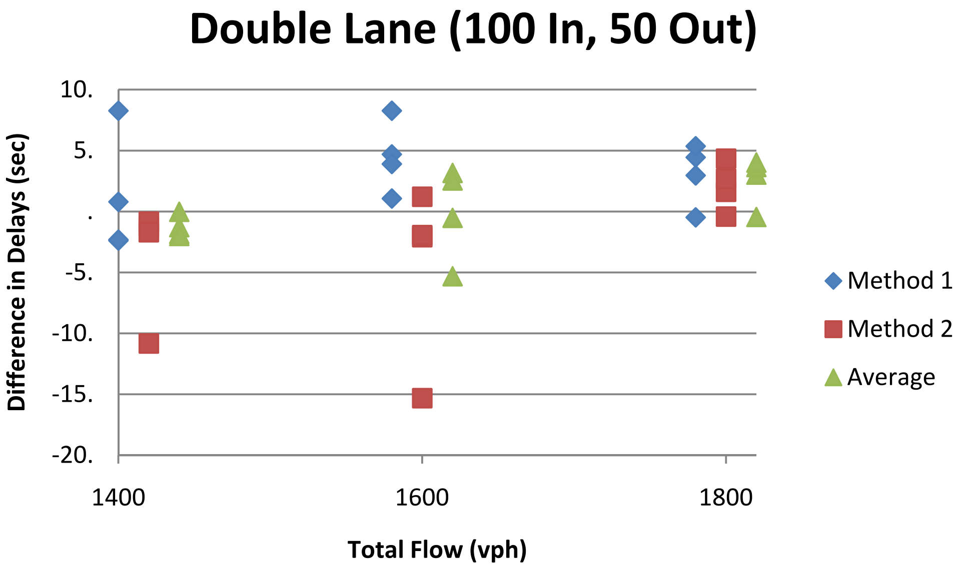
C.6 Double Lane Driveway without Sensors (100 In, 0 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Double Lane (100 In, 0 Out)	1400	330-1230	13.8	13.5	.3	2.2%	13.9	-.1	-0.9%	.1	0.7%
		390-1290	13.8	5.6	8.2	59.6%	21.9	-8.1	-58.8%	.1	0.4%
		510-1410	14.	15.5	-1.5	-10.8%	13.5	.5	3.6%	-.5	-3.6%
		570-1470	14.	18.4	-4.4	-31.5%	8.5	5.4	39.0%	.5	3.7%
	1600	330-1230	15.9	13.6	2.3	14.4%	14.1	1.8	11.5%	2.1	12.9%
		390-1290	17.2	11.1	6.	35.1%	18.1	-1.	-5.7%	2.5	14.7%
		510-1410	19.1	9.1	9.9	52.1%	18.1	1.	5.2%	5.5	28.7%
		570-1470	19.4	13.7	5.7	29.5%	19.9	-.5	-2.6%	2.6	13.4%
	1800	330-1230	21.5	16.7	4.8	22.3%	17.4	4.1	19.1%	4.5	20.7%
		390-1290	22.2	16.8	5.4	24.2%	16.5	5.7	25.6%	5.5	24.9%
		510-1410	23.1	15.5	7.6	33.0%	21.	2.1	9.1%	4.9	21.1%
		570-1470	23.3	21.3	1.9	8.3%	22.6	.7	2.9%	1.3	5.6%



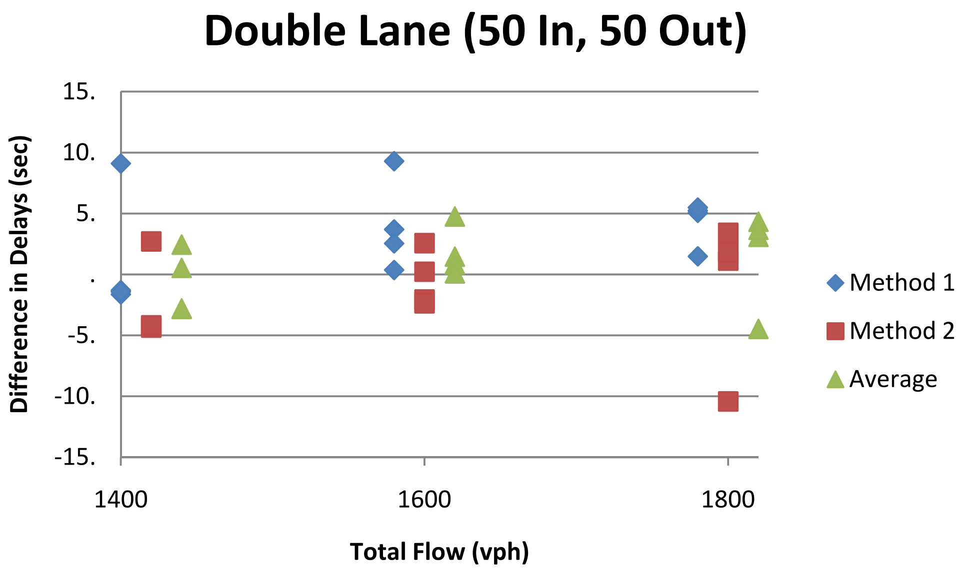
C.7 Double Lane Driveway without Sensors (100 In, 50 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Double Lane (100 In, 50 Out)	1400	330-1230	13.4	15.8	-2.4	-17.8%	14.7	-1.3	-9.4%	-1.8	-13.6%
		390-1290	13.5	5.2	8.3	61.3%	24.3	-10.8	-80.5%	-1.3	-9.6%
		510-1410	13.6	12.8	.8	5.8%	14.4	-.8	-6.1%	.	-0.2%
		570-1470	13.4	15.7	-2.3	-17.3%	15.1	-1.7	-12.8%	-2.	-15.1%
	1600	330-1230	14.8	13.8	1.1	7.1%	16.9	-2.1	-14.2%	-.5	-3.5%
		390-1290	16.2	11.5	4.7	29.0%	31.5	-15.3	-94.7%	-5.3	-32.9%
		510-1410	17.3	9.1	8.3	47.7%	19.3	-1.9	-11.2%	3.2	18.3%
		570-1470	17.5	13.6	3.9	22.3%	16.3	1.2	6.9%	2.5	14.6%
	1800	330-1230	18.5	14.1	4.4	24.0%	16.9	1.6	8.7%	3.	16.3%
		390-1290	19.	16.1	3.	15.5%	14.7	4.3	22.8%	3.6	19.2%
		510-1410	19.8	14.4	5.4	27.1%	17.1	2.7	13.6%	4.	20.3%
		570-1470	20.	20.5	-.5	-2.4%	20.4	-.4	-2.1%	-.5	-2.3%



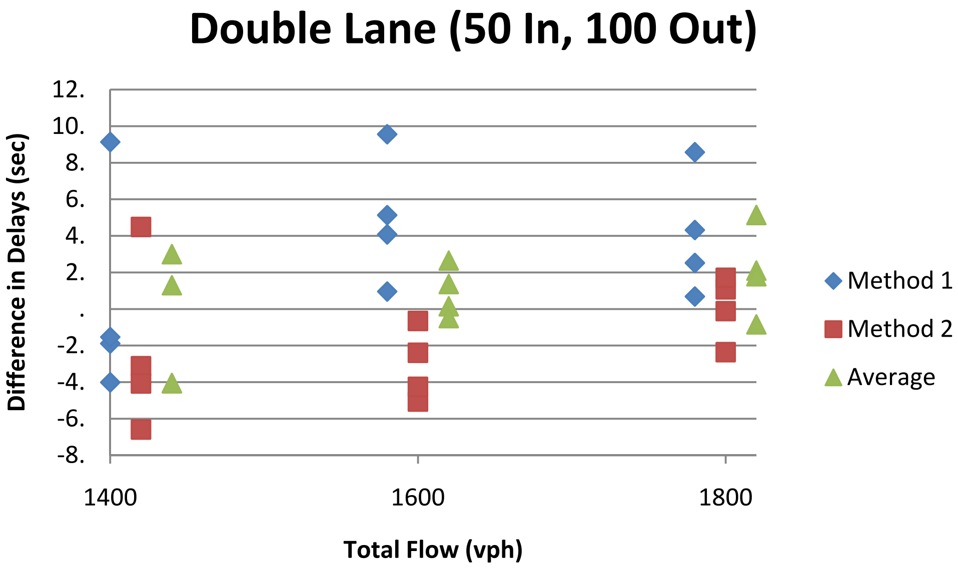
C.8 Double Lane Driveway without Sensors (50 In, 50 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Double Lane (50 In, 50 Out)	1400	330-1230	13.6	15.2	-1.6	-12.0%	10.9	2.7	19.9%	.5	3.9%
		390-1290	13.6	4.5	9.1	66.8%	17.8	-4.2	-30.9%	2.4	18.0%
		510-1410	13.7	15.	-1.3	-9.5%	18.	-4.4	-31.9%	-2.8	-20.7%
		570-1470	13.7	15.1	-1.4	-10.3%	17.9	-4.2	-30.4%	-2.8	-20.3%
	1600	330-1230	13.7	13.3	.4	2.7%	11.1	2.6	18.8%	1.5	10.7%
		390-1290	14.9	11.2	3.7	24.7%	17.	-2.	-13.7%	.8	5.5%
		510-1410	16.	6.7	9.3	58.1%	15.8	.2	1.4%	4.8	29.8%
		570-1470	16.3	13.7	2.5	15.6%	18.6	-2.4	-14.6%	.1	0.5%
	1800	330-1230	19.1	14.1	5.1	26.5%	18.	1.1	5.9%	3.1	16.2%
		390-1290	19.4	14.1	5.2	27.0%	15.9	3.4	17.7%	4.3	22.3%
		510-1410	19.6	14.1	5.5	28.0%	17.8	1.8	9.3%	3.7	18.7%
		570-1470	19.9	18.4	1.5	7.5%	30.3	-10.4	-52.4%	-4.5	-22.5%



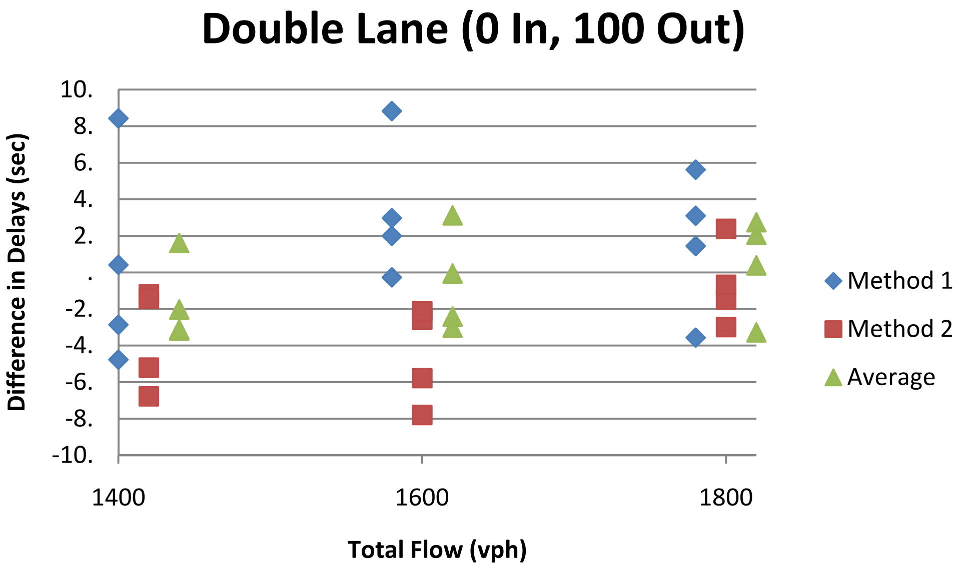
C.9 Double Lane Driveway without Sensors (50 In, 100 Out)

	Total Flow (vph)	Simulation Time Period (Sec)	Matched Travel Time Delay (Sec / Veh)	Method 1 Estimated Delay (Sec / Veh)	Method 1 Difference in Delays (Sec / Veh)	Method 1 Difference in Delays %	Method 2 Estimated Delay (Sec / Veh)	Method 2 Difference in Delays (Sec / Veh)	Method 2 Difference in Delays %	Average Difference in Delays (Sec / Veh)	Average Difference in Delays %
Double Lane (50 In, 100 Out)	1400	330-1230	13.3	15.2	-1.9	-14.1%	8.8	4.5	33.6%	1.3	9.8%
		390-1290	13.4	4.3	9.1	68.1%	16.5	-3.1	-23.3%	3.	22.4%
		510-1410	13.6	15.1	-1.5	-11.3%	20.2	-6.6	-48.5%	-4.1	-29.9%
		570-1470	13.7	17.7	-4.	-29.3%	17.8	-4.1	-29.7%	-4.	-29.5%
	1600	330-1230	13.8	12.9	1.	6.9%	14.5	-.7	-4.7%	.2	1.1%
		390-1290	15.	10.9	4.1	27.2%	20.1	-5.1	-33.8%	-.5	-3.3%
		510-1410	15.9	6.4	9.6	60.1%	20.2	-4.3	-26.8%	2.6	16.6%
		570-1470	16.1	11.	5.1	31.8%	18.5	-2.4	-14.9%	1.4	8.5%
	1800	330-1230	18.	13.6	4.3	24.0%	18.1	-.1	-0.7%	2.1	11.7%
		390-1290	18.2	15.7	2.5	13.8%	17.1	1.1	5.9%	1.8	9.9%
		510-1410	18.6	10.1	8.6	46.0%	16.9	1.7	9.2%	5.1	27.6%
		570-1470	18.9	18.2	.7	3.6%	21.3	-2.4	-12.5%	-.8	-4.4%



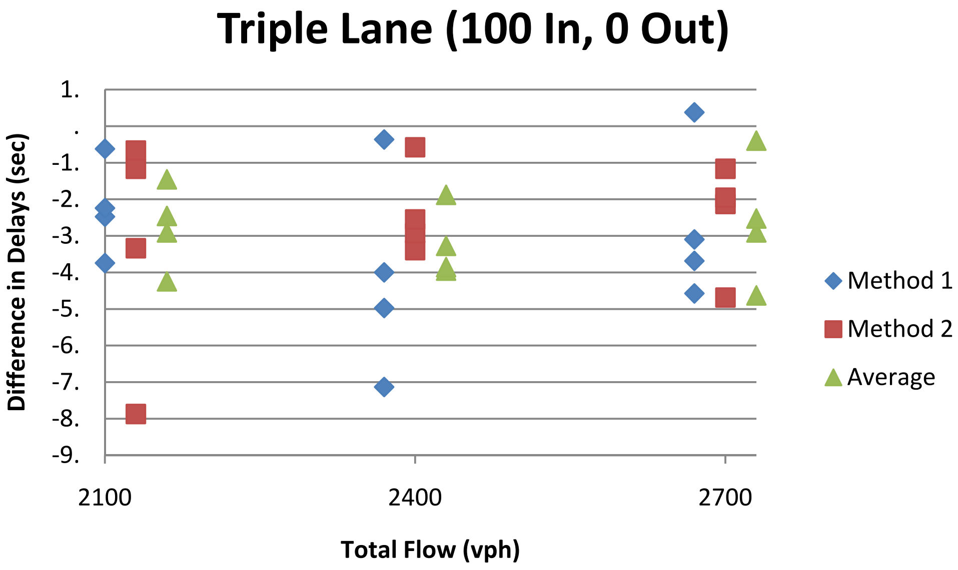
C.10 Double Lane Driveway without Sensors (0 In, 100 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Double Lane (0 In, 100 Out)	1400	330-1230	12.9	15.7	-2.9	-22.2%	14.1	-1.2	-9.2%	-2.	-15.7%
		390-1290	12.9	4.4	8.4	65.5%	18.1	-5.2	-40.5%	1.6	12.5%
		510-1410	13.	12.6	.4	3.2%	19.8	-6.8	-52.1%	-3.2	-24.5%
		570-1470	13.	17.8	-4.8	-36.7%	14.5	-1.5	-11.1%	-3.1	-23.9%
	1600	330-1230	12.9	13.1	-.3	-2.1%	18.7	-5.8	-44.9%	-3.	-23.5%
		390-1290	14.1	11.2	3.	21.1%	21.9	-7.8	-55.2%	-2.4	-17.0%
		510-1410	14.9	6.	8.8	59.4%	17.4	-2.6	-17.4%	3.1	21.0%
		570-1470	15.1	13.1	2.	13.3%	17.2	-2.1	-14.0%	-.1	-0.4%
	1800	330-1230	17.6	12.	5.6	31.9%	19.1	-1.5	-8.5%	2.1	11.7%
		390-1290	17.8	16.4	1.4	8.1%	18.5	-.7	-3.8%	.4	2.2%
		510-1410	17.6	14.5	3.1	17.6%	15.2	2.4	13.5%	2.7	15.6%
		570-1470	17.3	20.9	-3.6	-20.6%	20.3	-3.	-17.3%	-3.3	-18.9%



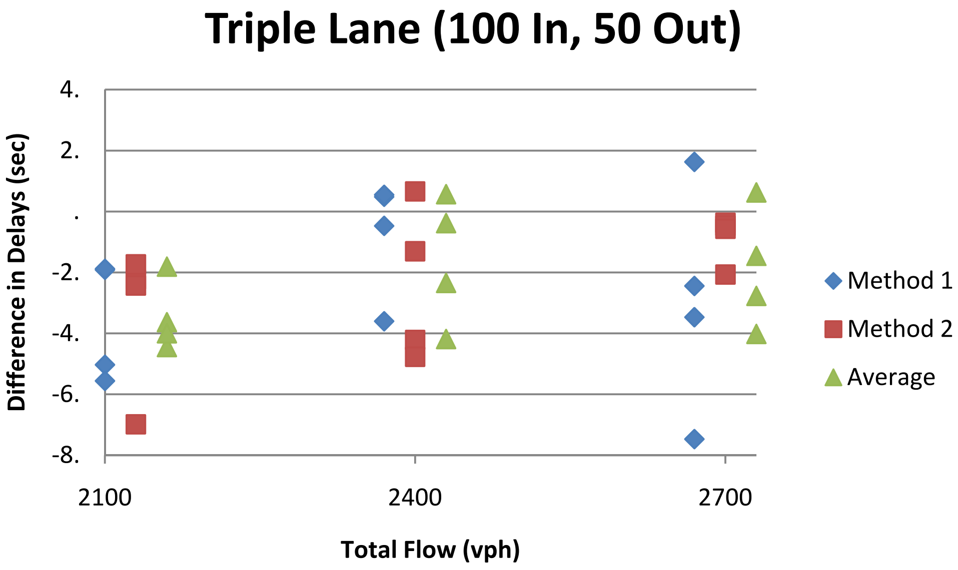
C.11 Triple Lane Driveway without Sensors (100 In, 0 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Triple Lane (100 In, 0 Out)	2100	330-1230	13.1	16.9	-3.7	-28.5%	14.3	-1.2	-8.9%	-2.5	-18.7%
		390-1290	12.9	13.5	-.6	-4.8%	20.7	-7.9	-61.1%	-4.2	-33.0%
		510-1410	12.7	15.2	-2.5	-19.4%	16.1	-3.3	-26.2%	-2.9	-22.8%
		570-1470	12.9	15.2	-2.2	-17.3%	13.6	-.7	-5.1%	-1.5	-11.2%
	2400	330-1230	15.2	15.6	-.4	-2.4%	18.6	-3.4	-22.3%	-1.9	-12.3%
		390-1290	15.2	20.2	-5.	-32.6%	18.2	-2.9	-19.2%	-4.	-25.9%
		510-1410	14.8	21.9	-7.1	-48.3%	15.4	-.6	-3.9%	-3.9	-26.1%
		570-1470	14.7	18.7	-4.	-27.2%	17.3	-2.5	-17.3%	-3.3	-22.2%
	2700	330-1230	17.6	17.2	.4	2.2%	18.7	-1.2	-6.6%	-.4	-2.2%
		390-1290	17.7	21.4	-3.7	-20.8%	19.8	-2.1	-12.0%	-2.9	-16.4%
		510-1410	17.3	20.4	-3.1	-17.9%	19.3	-2.	-11.3%	-2.5	-14.6%
		570-1470	17.3	21.9	-4.6	-26.4%	22.	-4.7	-27.0%	-4.6	-26.7%



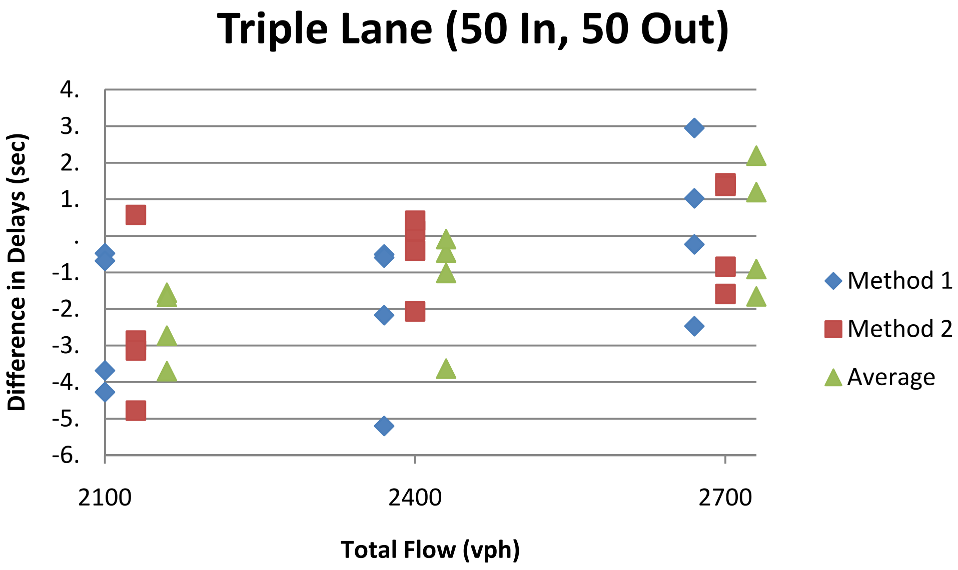
C.12 Triple Lane Driveway without Sensors (100 In, 50 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Triple Lane (100 In, 50 Out)	2100	330-1230	13.3	18.3	-5.	-37.9%	15.5	-2.2	-16.8%	-3.6	-27.4%
		390-1290	13.	14.9	-1.9	-14.7%	20.	-7.	-53.8%	-4.4	-34.2%
		510-1410	12.8	18.3	-5.6	-43.6%	15.2	-2.4	-19.1%	-4.	-31.3%
		570-1470	13.	14.9	-1.9	-14.5%	14.7	-1.7	-13.4%	-1.8	-13.9%
	2400	330-1230	14.9	15.4	-.5	-3.2%	19.1	-4.2	-28.3%	-2.3	-15.7%
		390-1290	14.9	18.5	-3.6	-24.2%	19.7	-4.8	-32.0%	-4.2	-28.1%
		510-1410	14.5	14.	.5	3.3%	13.9	.7	4.5%	.6	3.9%
		570-1470	14.4	13.9	.5	3.8%	15.7	-1.3	-9.0%	-.4	-2.6%
	2700	330-1230	17.3	15.7	1.6	9.4%	17.7	-.4	-2.1%	.6	3.6%
		390-1290	17.3	19.7	-2.4	-14.1%	17.7	-.5	-2.7%	-1.5	-8.4%
		510-1410	16.6	24.1	-7.5	-44.9%	17.2	-.6	-3.4%	-4.	-24.2%
		570-1470	16.7	20.1	-3.5	-20.8%	18.7	-2.1	-12.4%	-2.8	-16.6%



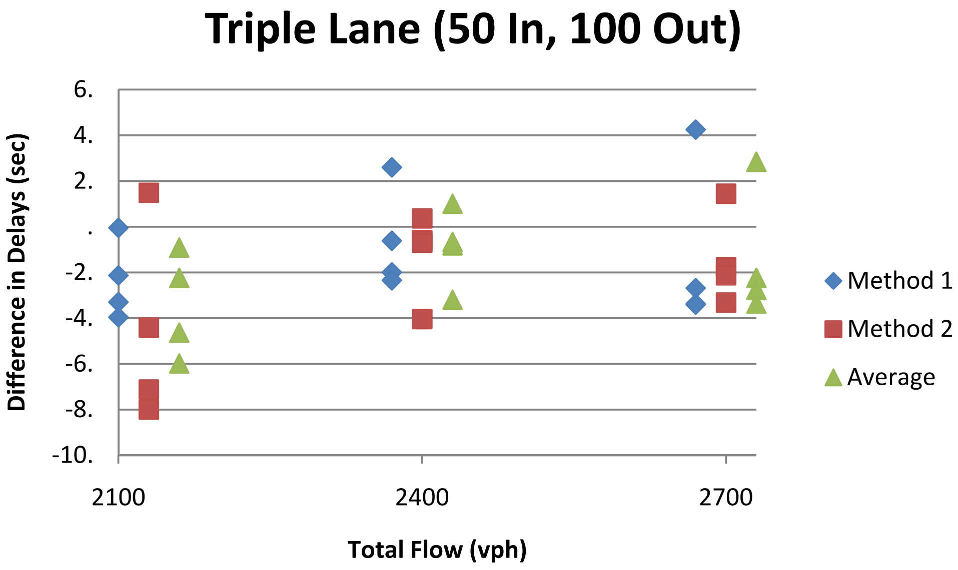
C.13 Triple Lane Driveway without Sensors (50 In, 50 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Triple Lane (50 In, 50 Out)	2100	330-1230	12.7	16.4	-3.7	-28.9%	12.2	.6	4.5%	-1.6	-12.2%
		390-1290	12.5	13.	-.5	-3.8%	15.4	-2.9	-22.9%	-1.7	-13.4%
		510-1410	12.4	16.6	-4.3	-34.5%	15.5	-3.1	-25.3%	-3.7	-29.9%
		570-1470	12.6	13.3	-.7	-5.4%	17.4	-4.8	-37.9%	-2.7	-21.7%
	2400	330-1230	14.5	15.	-.5	-3.5%	14.9	-.4	-2.8%	-.5	-3.1%
		390-1290	14.6	16.8	-2.2	-14.8%	14.5	.1	0.9%	-1.	-7.0%
		510-1410	14.6	15.2	-.6	-4.1%	14.1	.4	2.8%	-.1	-0.6%
		570-1470	14.5	19.7	-5.2	-35.8%	16.6	-2.1	-14.2%	-3.6	-25.0%
	2700	330-1230	16.7	13.7	3.	17.7%	15.2	1.4	8.6%	2.2	13.2%
		390-1290	16.7	19.2	-2.5	-14.8%	17.5	-.8	-5.1%	-1.7	-9.9%
		510-1410	16.4	15.4	1.	6.3%	15.	1.4	8.3%	1.2	7.3%
		570-1470	16.6	16.9	-.2	-1.4%	18.2	-1.6	-9.5%	-.9	-5.5%



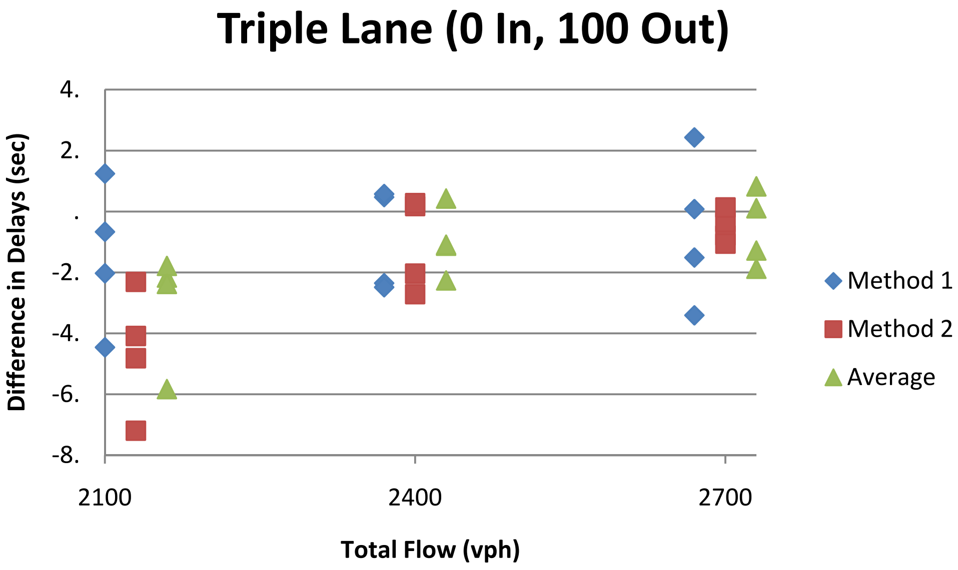
C.14 Triple Lane Driveway without Sensors (50 In, 100 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Triple Lane (50 In, 100 Out)	2100	330-1230	13.	16.3	-3.3	-25.5%	11.5	1.5	11.5%	-.9	-7.0%
		390-1290	12.7	12.8	.	-0.4%	17.1	-4.4	-34.7%	-2.2	-17.6%
		510-1410	12.5	16.5	-4.	-31.7%	20.5	-8.	-63.9%	-6.	-47.8%
		570-1470	12.7	14.8	-2.1	-16.8%	19.8	-7.1	-56.2%	-4.6	-36.5%
	2400	330-1230	14.4	11.8	2.6	18.1%	14.9	-.6	-4.1%	1.	7.0%
		390-1290	14.5	16.5	-2.	-13.8%	14.1	.4	2.5%	-.8	-5.6%
		510-1410	14.4	15.	-.6	-4.3%	15.1	-.7	-4.9%	-.7	-4.6%
		570-1470	14.4	16.7	-2.3	-16.3%	18.4	-4.	-28.1%	-3.2	-22.2%
	2700	330-1230	18.2	14.	4.2	23.3%	16.8	1.4	7.9%	2.8	15.6%
		390-1290	18.2	20.9	-2.7	-14.8%	20.	-1.8	-9.7%	-2.2	-12.2%
		510-1410	17.6	21.	-3.4	-19.2%	19.8	-2.1	-12.0%	-2.7	-15.6%
		570-1470	17.9	21.3	-3.4	-19.1%	21.2	-3.3	-18.6%	-3.4	-18.8%



C.15 Triple Lane Driveway without Sensors (0 In, 100 Out)

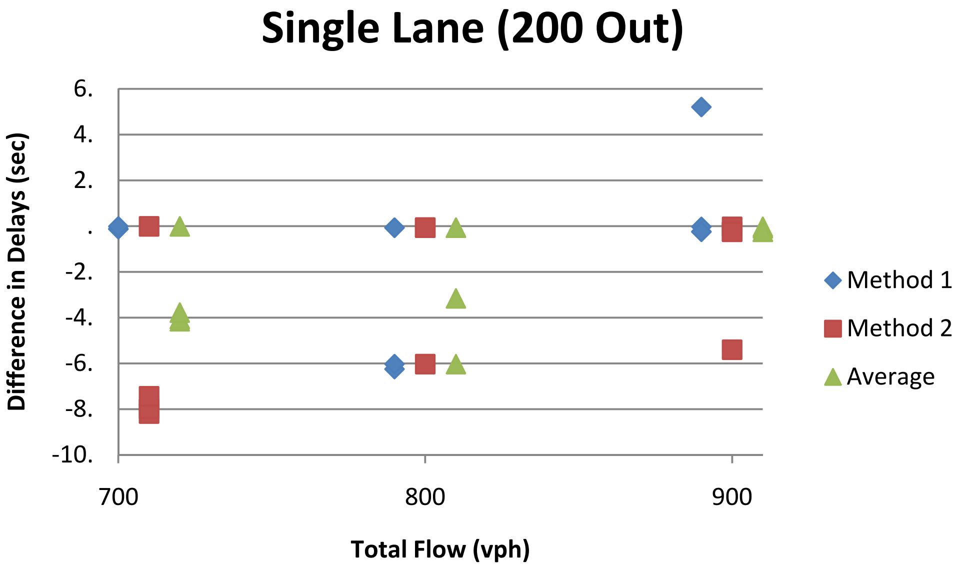
			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Triple Lane (0 In, 100 Out)	2100	330-1230	12.6	14.7	-2.	-16.1%	14.9	-2.3	-18.3%	-2.2	-17.2%
		390-1290	12.3	11.1	1.2	10.1%	17.1	-4.8	-39.0%	-1.8	-14.5%
		510-1410	12.2	16.7	-4.5	-36.6%	19.4	-7.2	-59.0%	-5.8	-47.8%
		570-1470	12.4	13.	-.7	-5.4%	16.5	-4.1	-33.0%	-2.4	-19.2%
	2400	330-1230	14.2	13.7	.5	3.3%	16.9	-2.7	-19.2%	-1.1	-7.9%
		390-1290	14.2	16.6	-2.4	-16.5%	14.1	.2	1.2%	-1.1	-7.6%
		510-1410	14.	13.4	.6	4.1%	13.7	.3	2.0%	.4	3.0%
		570-1470	14.	16.5	-2.5	-17.7%	16.1	-2.	-14.5%	-2.3	-16.1%
	2700	330-1230	16.2	13.7	2.4	15.0%	16.9	-.8	-4.9%	.8	5.1%
		390-1290	15.9	19.3	-3.4	-21.4%	16.2	-.3	-2.2%	-1.9	-11.8%
		510-1410	15.2	15.1	.1	0.5%	15.1	.1	0.9%	.1	0.7%
		570-1470	15.3	16.8	-1.5	-9.9%	16.3	-1.1	-6.9%	-1.3	-8.4%



APPENDIX D: Charts and Graphs

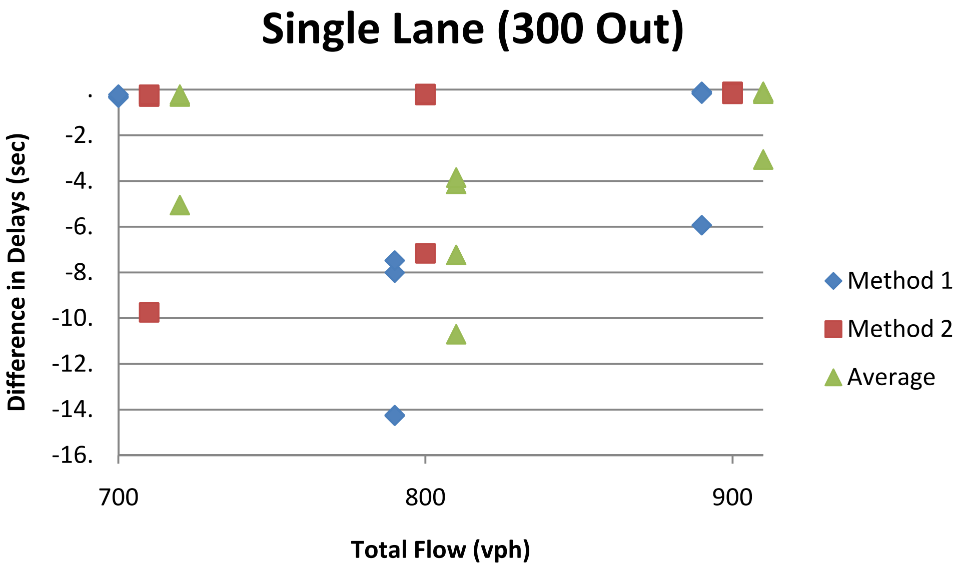
D.1 Single Lane with Turning Bay (0 In, 200 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Single Lane (200 In)	700	330-1230	11.9	12.	-.1	-1.0%	20.1	-8.2	-69.0%	-4.2	-35.0%
		390-1290	12.5	12.6	-.1	-1.0%	20.4	-8.	-64.2%	-4.1	-32.6%
		510-1410	12.3	12.5	-.1	-1.0%	19.8	-7.4	-60.3%	-3.8	-30.6%
		570-1470	13.	13.	.	-0.1%	13.	.	-0.1%	.	-0.1%
	800	330-1230	11.1	11.2	-.1	-0.6%	11.2	-.1	-0.6%	-.1	-0.6%
		390-1290	12.7	18.9	-6.3	-49.4%	12.7	-.1	-0.5%	-3.2	-24.9%
		510-1410	13.	13.1	-.1	-0.5%	13.1	-.1	-0.5%	-.1	-0.5%
		570-1470	13.2	19.2	-6.	-45.8%	19.2	-6.	-45.8%	-6.	-45.8%
	900	330-1230	10.8	5.6	5.2	48.3%	16.2	-5.4	-50.0%	-.1	-0.9%
		390-1290	11.8	11.9	.	-0.2%	11.9	.	-0.2%	.	-0.2%
		510-1410	12.7	12.9	-.2	-1.9%	12.9	-.2	-1.9%	-.2	-1.9%
		570-1470	12.5	12.7	-.2	-2.0%	12.7	-.2	-2.0%	-.2	-2.0%



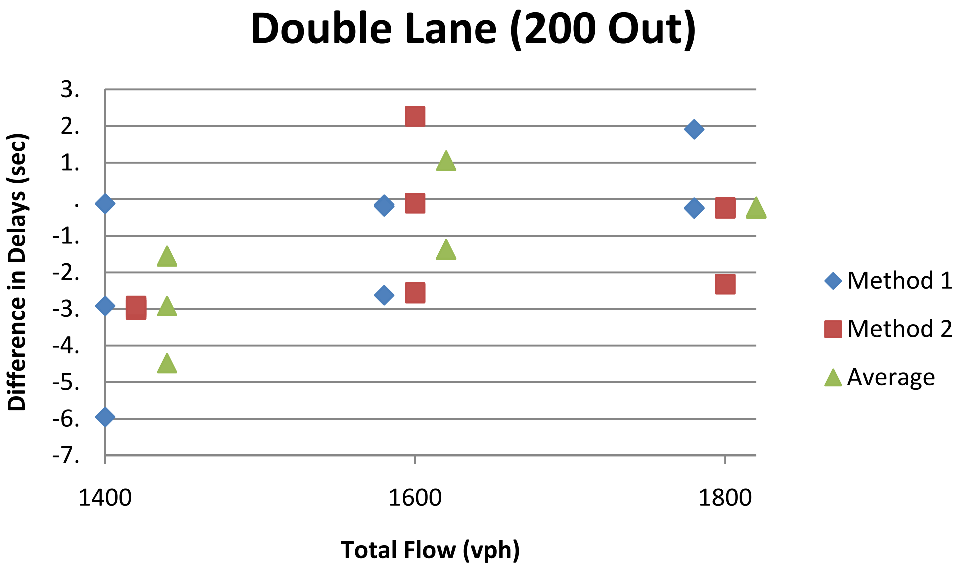
D.2 Single Lane with Turning Bay (0 In, 300 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Single Lane (300 In)	700	330-1230	10.9	11.2	-.3	-2.8%	11.2	-.3	-2.8%	-.3	-2.8%
		390-1290	11.4	11.7	-.3	-2.6%	11.7	-.3	-2.6%	-.3	-2.6%
		510-1410	11.3	11.6	-.4	-3.2%	21.	-9.7	-86.7%	-5.1	-44.9%
		570-1470	11.8	12.	-.2	-1.9%	12.	-.2	-1.9%	-.2	-1.9%
	800	330-1230	10.4	18.4	-8.	-76.9%	10.7	-.2	-2.3%	-4.1	-39.6%
		390-1290	12.3	19.8	-7.5	-60.6%	12.6	-.2	-1.8%	-3.9	-31.2%
		510-1410	12.8	27.1	-14.2	-111.2%	20.	-7.2	-55.9%	-10.7	-83.6%
		570-1470	13.3	27.5	-14.3	-107.7%	13.4	-.2	-1.4%	-7.2	-54.6%
	900	330-1230	9.9	10.	-.1	-1.0%	10.	-.1	-1.0%	-.1	-1.0%
		390-1290	11.2	11.3	-.1	-0.9%	11.3	-.1	-0.9%	-.1	-0.9%
		510-1410	11.8	17.7	-5.9	-50.4%	12.	-.2	-1.6%	-3.1	-26.0%
		570-1470	11.5	11.7	-.2	-1.6%	11.7	-.2	-1.6%	-.2	-1.6%



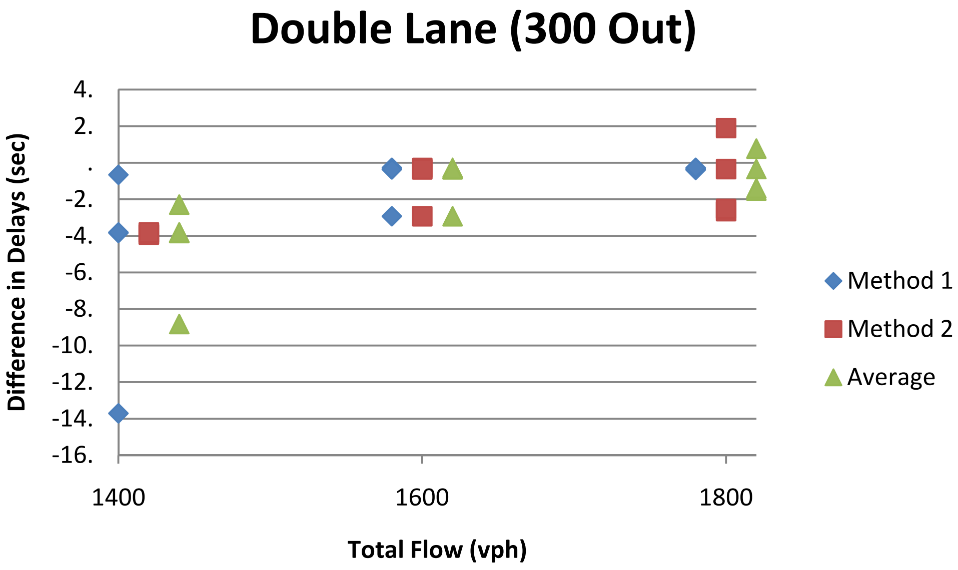
D.3 Double Lane with Turning Bay (0 In, 200 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Double Lane (200 In)	1400	330-1230	12.4	18.3	-6.	-48.0%	15.4	-3.	-24.2%	-4.5	-36.1%
		390-1290	12.7	12.8	-.1	-0.9%	15.7	-3.	-23.8%	-1.6	-12.3%
		510-1410	12.5	12.6	-.1	-1.0%	15.4	-3.	-23.7%	-1.5	-12.4%
		570-1470	12.4	15.3	-2.9	-23.6%	15.3	-2.9	-23.6%	-2.9	-23.6%
	1600	330-1230	12.3	14.9	-2.6	-21.3%	12.4	-.1	-0.9%	-1.4	-11.1%
		390-1290	13.	13.2	-.1	-1.1%	10.7	2.3	17.4%	1.1	8.1%
		510-1410	13.3	13.5	-.2	-1.4%	15.9	-2.6	-19.3%	-1.4	-10.3%
		570-1470	13.7	13.9	-.2	-1.4%	16.3	-2.5	-18.6%	-1.4	-10.0%
	1800	330-1230	15.9	16.2	-.2	-1.4%	16.2	-.2	-1.4%	-.2	-1.4%
		390-1290	16.2	16.5	-.3	-1.5%	16.5	-.3	-1.5%	-.3	-1.5%
		510-1410	16.	16.3	-.3	-1.6%	16.3	-.3	-1.6%	-.3	-1.6%
		570-1470	15.8	13.9	1.9	12.1%	18.2	-2.3	-14.6%	-.2	-1.3%



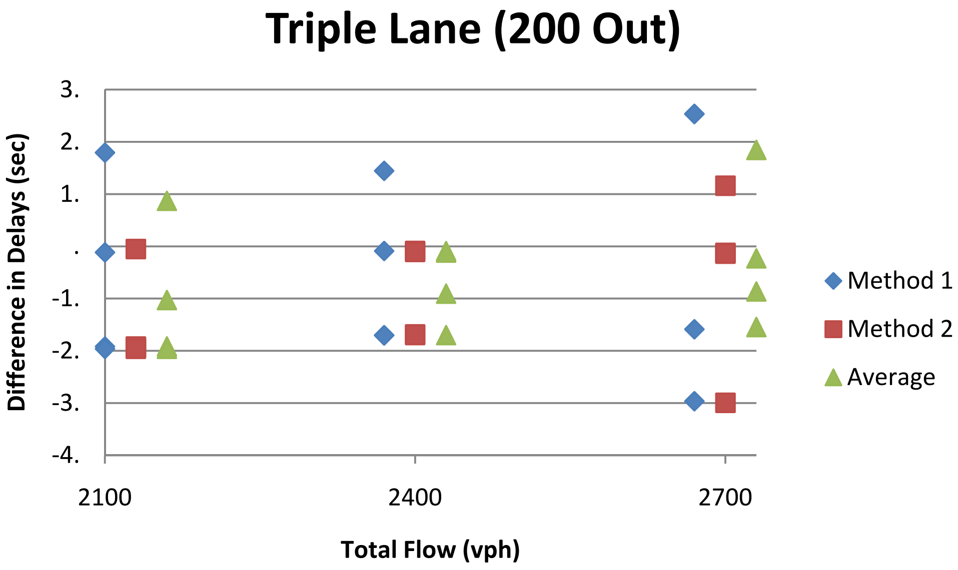
D.4 Double Lane with Turning Bay (0 In, 300 Out)

				Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Matched Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Double Lane (300 In)	1400	330-1230	11.5	25.2	-13.7	-119.2%	15.4	-3.9	-34.2%	-8.8	-76.7%
		390-1290	11.5	12.2	-.7	-5.7%	15.5	-3.9	-34.0%	-2.3	-19.9%
		510-1410	11.6	15.5	-3.8	-33.1%	15.5	-3.8	-33.1%	-3.8	-33.1%
		570-1470	11.6	15.4	-3.8	-33.0%	15.4	-3.8	-33.0%	-3.8	-33.0%
	1600	330-1230	11.8	12.1	-.3	-2.4%	12.1	-.3	-2.4%	-.3	-2.4%
		390-1290	12.3	12.7	-.4	-3.0%	12.7	-.4	-3.0%	-.4	-3.0%
		510-1410	12.7	13.	-.4	-2.9%	13.	-.4	-2.9%	-.4	-2.9%
		570-1470	12.9	15.8	-2.9	-22.8%	15.8	-2.9	-22.8%	-2.9	-22.8%
	1800	330-1230	14.	14.4	-.3	-2.5%	14.4	-.3	-2.5%	-.3	-2.5%
		390-1290	14.3	14.7	-.4	-2.8%	16.9	-2.7	-18.6%	-1.5	-10.7%
		510-1410	14.5	14.8	-.4	-2.5%	12.6	1.9	13.1%	.8	5.3%
		570-1470	14.6	14.8	-.3	-1.9%	17.1	-2.5	-17.3%	-1.4	-9.6%



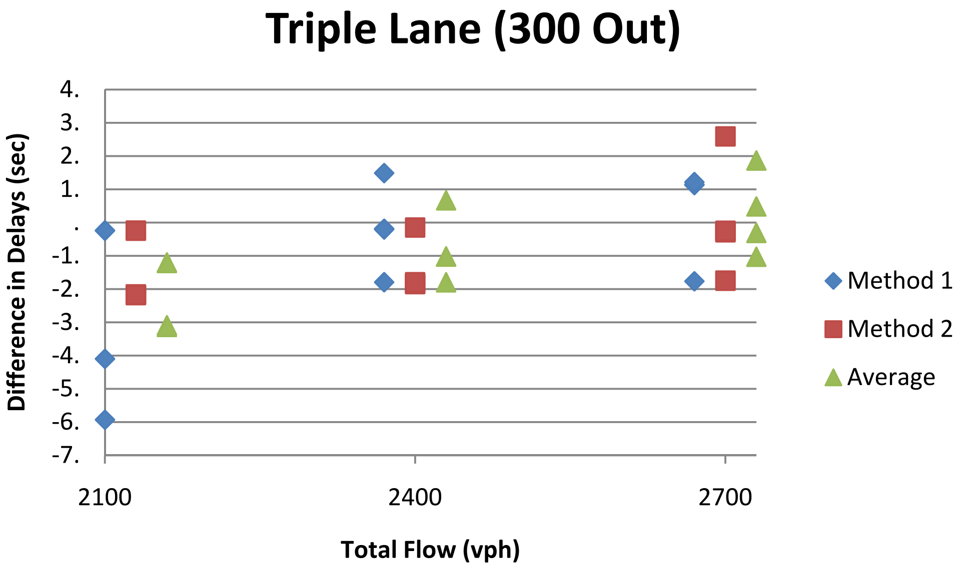
D.5 Triple Lane with Turning Bay (0 In, 200 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Triple Lane (200 In)	2100	330-1230	11.8	13.7	-1.9	-16.2%	13.7	-1.9	-16.2%	-1.9	-16.2%
		390-1290	11.6	11.7	-.1	-1.0%	13.5	-1.9	-16.8%	-1.	-8.9%
		510-1410	11.4	13.3	-2.	-17.3%	13.3	-2.	-17.3%	-2.	-17.3%
		570-1470	11.6	9.8	1.8	15.4%	11.7	-.1	-0.4%	.9	7.5%
	2400	330-1230	13.7	13.8	-.1	-0.7%	13.8	-.1	-0.7%	-.1	-0.7%
		390-1290	13.8	12.4	1.4	10.5%	15.5	-1.7	-12.2%	-.1	-0.9%
		510-1410	13.7	15.4	-1.7	-12.4%	15.4	-1.7	-12.4%	-1.7	-12.4%
		570-1470	13.7	15.4	-1.7	-12.4%	13.8	-.1	-0.8%	-.9	-6.6%
	2700	330-1230	15.6	13.	2.5	16.3%	14.4	1.2	7.5%	1.8	11.9%
		390-1290	15.5	12.9	2.5	16.4%	18.5	-3.	-19.4%	-.2	-1.5%
		510-1410	14.7	17.6	-3.	-20.2%	14.8	-.1	-0.9%	-1.5	-10.5%
		570-1470	14.7	16.3	-1.6	-10.8%	14.9	-.1	-1.0%	-.9	-5.9%



D.6 Triple Lane with Turning Bay (0 In, 300 Out)

			Matched	Method 1			Method 2			Average	
	Total Flow (vph)	Simulation Time Period (Sec)	Travel Time Delay (Sec / Veh)	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Estimated Delay (Sec / Veh)	Difference in Delays (Sec / Veh)	Difference in Delays %	Difference in Delays (Sec / Veh)	Difference in Delays %
Triple Lane (300 In)	2100	330-1230	11.5	17.4	-5.9	-51.8%	11.7	-.2	-2.1%	-3.1	-26.9%
		390-1290	11.2	15.3	-4.1	-36.4%	13.4	-2.2	-19.3%	-3.1	-27.9%
		510-1410	11.2	11.4	-.2	-2.1%	13.3	-2.2	-19.4%	-1.2	-10.7%
		570-1470	11.4	11.6	-.2	-2.2%	13.6	-2.2	-19.2%	-1.2	-10.7%
	2400	330-1230	12.7	12.9	-.2	-1.4%	14.6	-1.9	-14.5%	-1.	-8.0%
		390-1290	12.8	13.	-.2	-1.6%	14.6	-1.8	-14.4%	-1.	-8.0%
		510-1410	13.	11.5	1.5	11.4%	13.2	-.1	-1.1%	.7	5.2%
		570-1470	13.1	14.9	-1.8	-13.7%	14.9	-1.8	-13.7%	-1.8	-13.7%
	2700	330-1230	14.7	13.6	1.1	7.8%	12.1	2.6	17.6%	1.9	12.7%
		390-1290	14.8	13.7	1.1	7.6%	16.5	-1.7	-11.8%	-.3	-2.1%
		510-1410	14.9	16.7	-1.8	-11.8%	15.2	-.3	-1.9%	-1.	-6.9%
		570-1470	15.2	14.	1.2	8.0%	15.5	-.2	-1.6%	.5	3.2%



APPENDIX E: Data CD

The enclosed CD contains the following items: 1) VISSIM simulation files, 2) VISSIM output files, and 3) Microsoft Excel files containing macros.