# Development of an Advanced Loop Event Data Analyzer (ALEDA) System for Dual-Loop Detector Malfunction Detection and Investigation

**Patikhom Cheevarunothai[1*], Yinhai Wang[2], and Nancy L. Nihan[3]**

1* Graduate Research Assistant, Department of Civil & Environmental Engineering, University of Washington, Seattle, WA 98195-2700, Tel: (206) 335-2516, Fax: (206) 543-5965, Email: num@u.washington.edu

2 Assistant Professor, Department of Civil & Environmental Engineering, University of Washington, Seattle, WA 98195-2700, Tel: (206) 616-2696, Fax: (206) 543-5965, Email: yinhai@u.washington.edu

3 Professor and Director, Transportation Northwest (TransNow), Department of Civil & Environmental Engineering, University of Washington, Seattle, WA 98195-2700, Tel: (206) 543-9639, Fax: (206) 543-5965, Email: nihan@u.washington.edu

**ABSTRACT**

Dual-loop detector systems are widely deployed in Washington State freeway networks to collect traffic data. The Traffic Systems Management Center (TSMC) aggregates traffic volume, occupancy, speed, and length data from dual-loop detectors into 20-second intervals and stores them to save storage space of archived data and preserve the data format compatible with the control system algorithms of Washington State Department of Transportation (WSDOT). Because of the data aggregation, valuable information of individual vehicle is missing. This makes the detection and in-depth investigation of causes of dual-loop errors complicated or impossible. Since high-resolution event data preserves individual vehicle information, they are an excellent data source for such analyses. For example, our study using event data has found that the main cause of dual-loop malfunction in Washington State is the loop sensitivity discrepancy. Since event data is typically not available from TSMC, a data collection system is desired for collecting loop event data. This paper describes such a system called Advanced Loop Event Data Analyzer (ALEDA). ALEDA is a portable event data collection and real-time analysis system which can be installed on a laptop computer. Besides its capability to collect and record event data at 60 Hz or higher without interfering the operation of controllers, ALEDA analyzes the event data at dual-loop station, displays individual vehicle information, and points out sensitivity problems with solutions based on passing vehicle statistics. Consequently, ALEDA facilitates the on-site real-time identification and correction of loop sensitivity problems to improve data quality.

**KEYWORDS**
ALEDA, loop inductive detectors, detector malfunction, event data, freeway application

## INTRODUCTION

Inductive loop detectors have been widely deployed in the Washington State roadway networks to provide traffic data for Advanced Traffic Management Systems (ATMS) and Advanced Traveler Information Systems (ATIS). Two types of loop detectors are currently installed on freeways: single-loop detectors and dual-loop detectors (also called a speed trap). A dual-loop detector is formed by two single loops located several feet apart in the same traffic lane. A single-loop detector collects traffic volume and occupancy data, while a dual-loop detector measures vehicle speed and length in addition to the single-loop measurements. A loop detector's raw signals are inputs to a controller. Typically, a controller housed in a control cabinet scans a loop detector at 60 Hz. A controller measures two levels of logic signal: high and low logic level. The high logic level (12 VDC) represents the situation of an unoccupied loop detector. The low logic level (0 VDC) denotes the state when the loop detector is occupied by a vehicle. To save disk space for data storage and bandwidth for data transmission to the WSDOT traffic control center, loop detector data are aggregated into 20-second intervals. As a result, useful information of individual vehicles is lost. This makes the detection and in-depth investigation of loop detector errors more complicated or at times impossible [1].

Loop event data refer to the high-resolution data typically collected at 60 Hz (or higher) from a loop detector. Individual vehicle information, such as presence time, arrival time, and departure time, can be extracted from loop event data. Members of the Berkeley Highway Laboratory (BHL) and research groups at the University of Washington (UW) have extensively collected loop event data for various research purposes. Since the standard detector station in California uses a Model 170 controller, the event data collection software developed by the California Department of Transportation (Caltrans) for the I-880 Field Experiment collects and stores event data in the field by using processing power of the Model 170 controller [2]. Because of the limited processing capability in a Model 170 controller, outputting 60 Hz event data may obstruct the normal operation of the controller. The Detector Event DAta Collection (DEDAC) system developed by the TransNow (Transportation Northwest Center) ITS Group at the UW uses external processing power of a desktop computer to avoid the interruption of controller operations [3]. A digital input/output (I/O) Peripheral Component Interconnect (PCI) card is used and the card is connected directly to the Input File of a control cabinet. As a consequence of requiring a bulky desktop computer, the DEDAC system cannot be fit in a control cabinet and hence makes the on-site data collection work very difficult.

Considering that loop event data are essential for loop detector malfunction diagnoses, traffic data extractions, and advanced analyses, a better loop detector event data collection and analysis system is desired. This paper describes such a system developed by the Smart Transportation Applications and Research Laboratory (STAR Lab) at the UW. This new portable system is called Advanced Loop Event Data Analyzer (ALEDA). ALEDA is a computer application executable on a laptop computer with Windows 2000 or XP operating systems. It combines the new digital Input/Output (I/O) technologies and object-oriented programming techniques to serve as a user-friendly, portable, and practical tool for event data collection and analysis.

## SYSTEM DESIGN AND COMPONENTS

According to the Traffic Detector Handbook [4], a controller collects loop detector data by reading the voltage signals from the Input File of the controller cabinet: a high voltage level (12VDC) represents the situation when no car is on top of a loop detector ("OFF" condition), and a low voltage level (0 VDC) denotes the situation with a car on a loop detector ("ON" condition).

To detect signal voltage and transform them into binary values, the digital I/O adapter is directly connected to the Input File as shown in Figure 1. By this connection, ALEDA taps loop event data from the Input File without disturbing the normal operation of the controller. The digital I/O adapter [5] uses 3.8 VDC to separate voltage signals into high or low levels. For instance, the 2 VDC signal is at low level. ALEDA can poll the data address in the digital I/O adapter at 60 Hz or higher. The collected data are managed in an internal array. These data can serve as inputs for real-time calculations and analyses of individual vehicle on-time, speed, length, and on-time difference or be recorded to a user-specified text file for permanent preservation as shown in Figure 2.

ALEDA was designed to contain the following three hardware components:

- Laptop computer with Universal Serial Bus (USB) ports.
  Recommended configurations of a laptop computer include Windows 2000 or Windows XP operating system, a Pentium 4 processor, and 512 MB of Double Data Rate Synchronous Dynamic Random Access Memory (DDR SDRAM).

- Digital Input/Output (I/O) Adapter.
  This adapter is required to connect a laptop computer with a USB port at one end and to connect the Input File housed in a control cabinet at the other end. In our design, we selected the SeaLINK ISO-16 Isolated Inputs Digital Interface Adapter (please refer to [5] for details). It has two ports with 8 input channels for each port. The turn-on logic voltage is 3.8 VDC.

- Cable Connections
  The normal 24-guage cables are used to connect the laptop computer, the digital I/O adapter, and the Input File in a control cabinet.

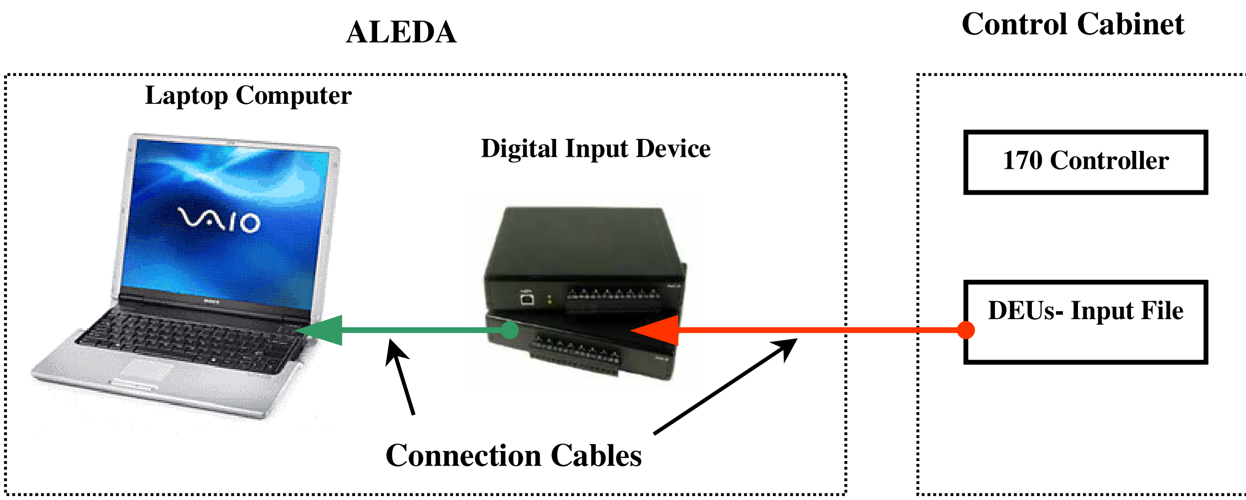


**Figure 1 - ALEDA Graphical Connection Structure**

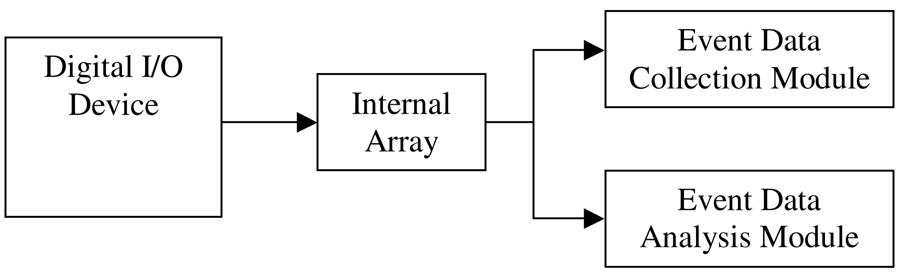


**Figure 2 - ALEDA Design Architecture**

## SYSTEM IMPLEMENTATION

The ALEDA computer application was developed in the C# programming language with the help of the Visual C# .NET technologies [6] and the additional Universal Library documents [5] from the manufacturer of the digital I/O adapter. The computer application is executable on a laptop computer installed with Windows 2000 or XP operating system.

Since a controller scans a loop detector at 60 Hz, the computer application needs to poll the data addresses from the digital I/O adapter at 60 Hz or higher to record the event data identical to what are seen by the controller. A high-resolution timer raising an event at user-defined time intervals is required to fulfill this requirement. The multimedia timer optimized for use in Windows in the Visual C#.NET technology was applied in ALEDA. The multimedia timer services provide the greatest degree of timing accuracy. They allow applications to schedule timing events at a high resolution. The resolution on the hardware platform tested can precisely collect event data up to 80 Hz.

## SYSTEM FUNCTIONS

The data collection and the data analysis functions are two main functions in ALEDA.

### Data Collection Function

The main objective of the data collection function is to collect, process, and store the event data containing individual vehicle information, e.g., vehicle arrival time, departure time, and presence time, in American Standard Code for Information Interchange (ASCII) format. The ASCII file also stores the calculated data from the event data, such as estimated vehicle speed, length, volume, and on-time differences. The flow chart of the speed and length estimation algorithm is shown in Figure 3. Event data being collected are displayed in real-time on the user interface as shown in Figure 4.

The speed is calculated from the distance between the upstream loop (M loop) and the downstream loop (S loop), and the time difference between the arrival time at the M loop ($t_{m\text{-}on}$) and that at the S loop ($t_{s\text{-}on}$), as shown in Equation (1). The default value of the distance between the leading edge of the M loop and the leading edge of the S loop is 16 feet (4.8 meters) in the loop detection system of the Washington State Department of Transportation (WSDOT). Since lane-changing vehicles at the dual loop location may not have the right arrival time measured by each single loop, they should be discarded from speed calculation. To avoid the lane changing problem, the speed & length algorithm will match $t_{m\text{-}on}$ with $t_{s\text{-}on}$ using a set-of-conditions check. In the first condition, if a vehicle occupies both the M loop and the S loop, ALEDA will match the latest $t_{m\text{-}on}$ with the next $t_{s\text{-}on}$. The second condition is that if a vehicle occupies only the M loop but not the S loop, the $t_{m\text{-}on}$ will be rejected because of having no $t_{s\text{-}on}$ matched. In the third condition, if a vehicle occupies only the S loop but not the M loop, the $t_{s\text{-}on}$ will also be rejected because of no matched $t_{m\text{-}on}$. Therefore, non-paired $t_{m\text{-}on}$ or $t_{s\text{-}on}$ will be disregarded.

$$Speed = \frac{16}{\left(t_{s\text{-}on} - t_{m\text{-}on}\right)} \qquad (1)$$

The individual vehicle length is estimated immediately after its speed is calculated. Equation (2) shows how the vehicle length is estimated with the assumed 6 feet (1.8 meters) loop width. Vehicle length is estimated from speed and the averaged on-times on the M loop and the S loop. The on-times on the M loop are calculated from the arrival time ($t_{m\text{-}on}$) and the departure time ($t_{m\text{-}off}$). Similarly, the S loop's on-time is obtained from $t_{s\text{-}on}$ and $t_{s\text{-}off}$. Since the length is calculated from the average on-time and the on-time depends largely on the loop's sensitivity level, the sensitivity setting plays a big role in the accuracy of vehicle length estimation. To accommodate more general situations, ALEDA provides the function for users to specify the distance between the M loop and the S loop, as well as the loop width (Figure 4).

$$Length = \left( Speed \times \frac{\left(t_{s-off} - t_{s-on}\right) + \left(t_{m-off} - t_{m-on}\right)}{2} \right) - 6 \qquad (2)$$

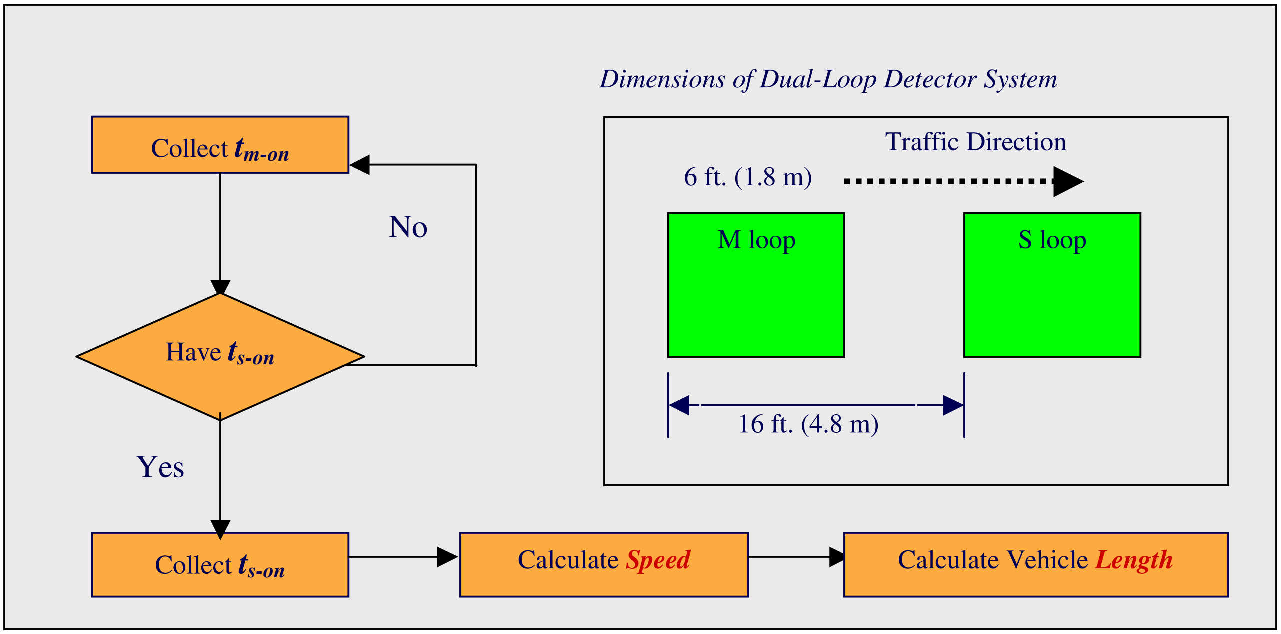


**Figure 3 - ALEDA Speed & Length Algorithm**


**Figure 4 - ALEDA Program User Interface**

**Data Analysis Function**

The main objective of ALEDA's data analysis function is to identify the causes of dual-loop detector errors and provide suggestions for fine tuning the dual-loop detector. This is very important for improving data quality at dual-loop stations.

In the current WSDOT dual-loop algorithm, only vehicles with an on-time difference of less than 10% between the M loop and the S loop are included in calculating individual vehicle speed and length. "On-time" refers to the time period in which a car is visible by a loop detector. The on-time of a passing vehicle depends significantly on the sensitivity level of a loop detector. If the sensitivity levels of the M loop and the S loop differ significantly, a vehicle traversing the two single loops at a constant speed may be measured very differently in terms of on-times. If the on-time difference is more than 10%, the WSDOT algorithm drops the vehicle from vehicle speed and length calculation. The sensitivity inconsistency between the two single loops that form a dual-loop detector has been identified as a major cause of the under-classification problem of vehicle volumes [7].

Therefore, the on-time has been used as a primary factor for checking sensitivity related malfunctions of dual-loop detectors in ALEDA. The on-time difference between the M loop and the S loop could represent the sensitivity discrepancy of the two single loops in a dual-loop detector. In addition, the length of individual vehicle calculated from the on-time could also be examined to identify the suitable sensitivity level for a single-loop detector.
After the sensitivity discrepancy is eliminated, the next question is to decide the suitable sensitivity level for both single-loop detectors in a dual-loop system so that it can measure vehicle length accurately. Since vehicle lengths follow some statistical distribution when sample size is large enough, we can use the features of vehicle length distribution to identify the right sensitivity level. From the 24-hour data, the median length of every one hundred short vehicles (defined as those shorter than 26 feet or 7.81 meters) was calculated and plotted in Figure 5. It is obvious that the calculated median vehicle lengths of different lanes are dissimilar. Lane 1 has unrealistically short median lengths. This results from the unsuitable sensitivity level setting in the dual-loop system. This problem is under investigation to find its best solution. At the current stage, ALEDA has the capability to detect this problem.

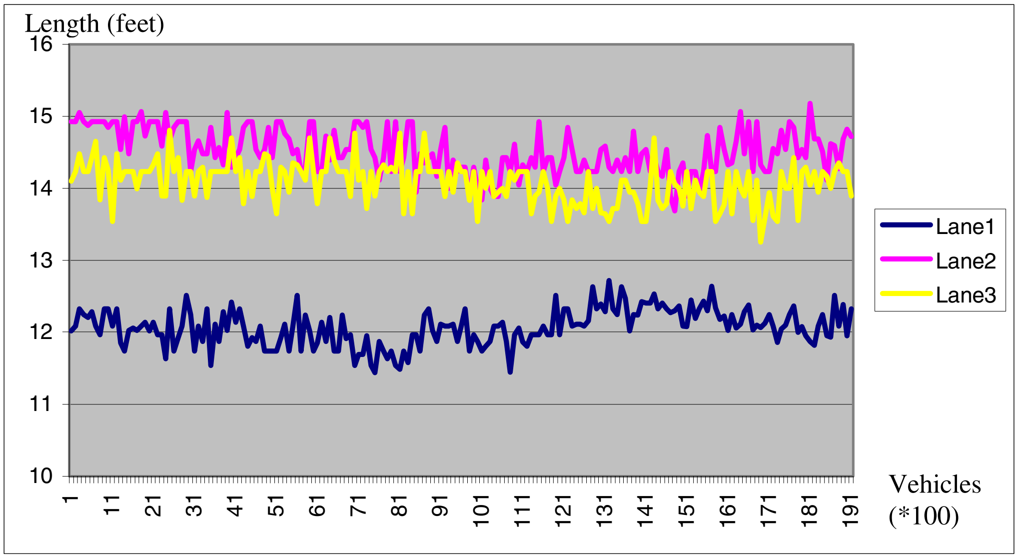


**Figure 5 - Estimated Short Vehicle Median Length at ES-167D (SB I-5 & NE 145th St.)**

## SYSTEM TESTING

### Test Site Selection

A previous study [3] has shown that the dual-loop detector is vulnerable to sensitivity discrepancy and vehicle changing lane problems. This results in the undercount of classified vehicle volumes. The loop detector errors caused by traffic lane changing under unpredictable drivers' behavior are unavoidable but can be minimized by selecting a dual-loop detector station with low likelihood of lane changes.

Following the intensive search and data analysis in the Traffic Data Acquisition and Distribution (TDAD) database [8] and the consultation with WSDOT technical supervisors, three traffic stations were selected for the system test: 1) ES-167D (located at SB I-5 & NE 145th St.); 2) ES-168R (located at NB I-5 & NE 145th St.); and 3) ES-172R (located at NB I-5 & Metro Base).

The traffic volumes at the test stations from the TDAD database are listed in Table 1(a) – 1(c). Only the general purpose lanes are included in this study. Lane 1 is the rightmost lane. The lane number increases from the right to the left. Traffic volumes from the M loop, the S loop, and the dual-loop detector (ST – Speed Traps) are shown in the second, third, and fourth columns, respectively. The last column displays the percent difference (DIFF%) between the volumes counted by the M loop and the dual-loop system. The DIFF% column shows the severity of the bin-volume undercount problem. As a result, lane 3 at ES-167D, all the lanes at ES-168R, and lane 3 at ES-172R have DIFF% more than 10% and are considered to have serious sensitivity problems. The dual-loop stations with good lanes (DIFF% less than 10%) and bad lanes (DIFF% more than 10%) are preferable for comparison purposes in this study.

**Table 1(a) - TDAD data at ES-167D (SB I-5 & NE 145$^{th}$ St.)**

| Volume | M loop | S loop | ST | DIFF% |
|---|---|---|---|---|
| Lane 1 | 10592 | 10510 | 9576 | 9.59 |
| Lane 2 | 15909 | 15933 | 14902 | 6.33 |
| Lane 3 | 16097 | 15975 | 13027 | **19.07** |

**Table 1(b) - TDAD data at ES-168R (NB I-5 & NE 145$^{th}$ St.)**

| Volume | M loop | S loop | ST | DIFF% |
|---|---|---|---|---|
| Lane 1 | 7108 | 7206 | 5697 | **19.85** |
| Lane 2 | 12523 | 12361 | 4306 | **65.62** |
| Lane 3 | 12460 | 12334 | 8796 | **29.41** |

**Table 1(c) - TDAD data at ES-172R (NB I-5 & Metro Base)**

| Volume | M loop | S loop | ST | DIFF% |
|---|---|---|---|---|
| Lane 1 | 15778 | 15872 | 14954 | 5.22 |
| Lane 2 | 14082 | 14686 | 12845 | 8.78 |
| Lane 3 | 10025 | 11186 | 567 | **94.34** |

The Detector Electronic Units (DEUs) at the test stations are EDI's and Sarasota's that have 8 levels of sensitivity (from level 0 to 7). The sensitivity level of all single-loop detectors in the dual-loop systems were set at level 2 except one single loop on lane 3 at ES-172R (NB I-5 & Metro Base) having sensitivity level set at 5. As shown in Table 1(c), the DIFF% on lane 3 at ES-172R is almost 95%. The dual-loop detector on this lane calculated speed and length information on only 5% of the total traffic. The sensitivity setting is at level 2 and level 5 for the M loop and the S loop, respectively. This result emphasizes the importance of sensitivity setting in the dual-loop detector system.

## A Case Study of Field Test Results and Discussions

Since event data are high-resolution data containing information of an individual vehicle, dual-loop malfunctions may readily be identified and investigated with such event data. The use of programming data structure techniques in a computer application makes the storage of certain amounts of the event data for the real-time dual-loop data analysis simple. As previously mentioned, the individual length estimation relies significantly on the setting of sensitivity level. The distribution of vehicle length will be utilized in solving the dual-loop sensitivity problem. ALEDA is capable of providing analysis results of dual-loop malfunction detection, investigation, and recommended solutions to users onsite by examining the event data of a few passing vehicles. Typically, the algorithms produce reasonably accurate results after the data of one hundred vehicles are examined. Here we show the detection and investigation of sensitivity problems as an example of the analysis processes in ALEDA.

As mentioned earlier, sensitivity inconsistency is the primary cause of the WSDOT dual-loops' undercount of classified volumes. The on-time difference represents the sensitivity discrepancy in a dual-loop detector. The on-time differences of all individual vehicles detected in a 15-minute interval have been plotted in Figure 6(a)-6(c) for in-depth investigation of the sensitivity problem at the study stations.

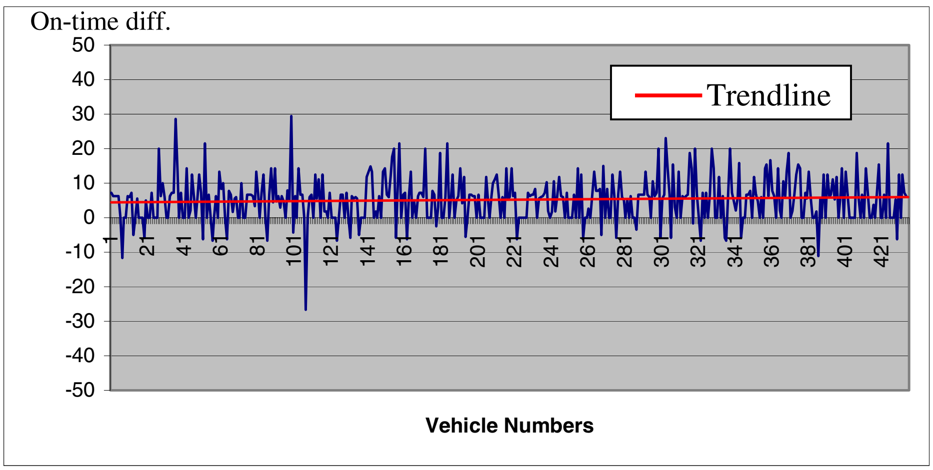


**Figure 6(a) - Lane 2 at ES-167D (SB I-5 & NE 145th St.)**

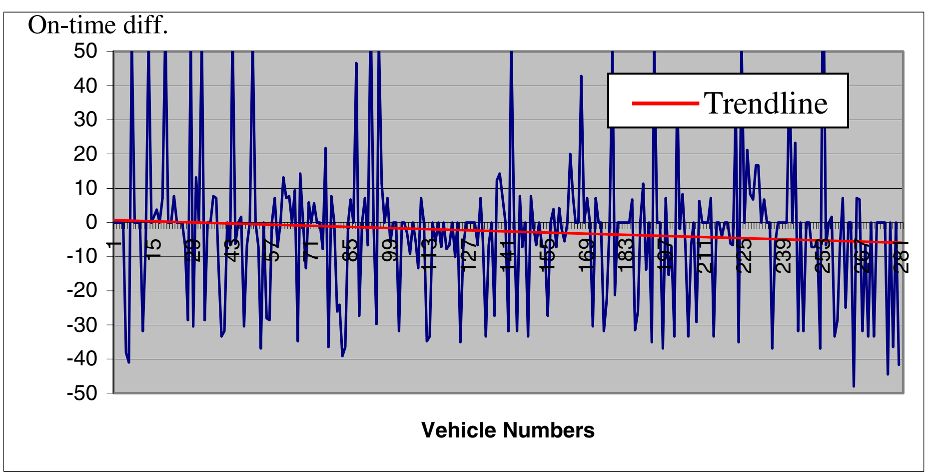


**Figure 6(b) - Lane 3 at ES-168R (NB I-5 & NE 145th St.)**

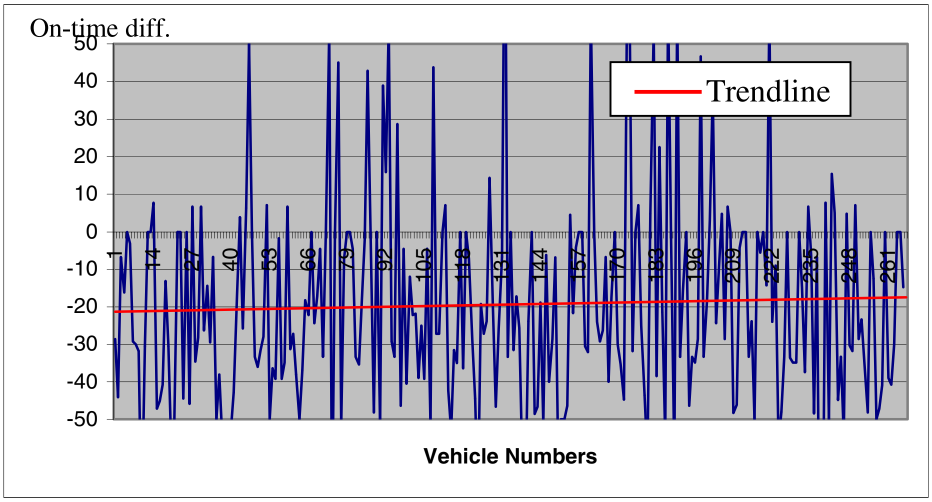


**Figure 6(c) - Lane 2 at ES-168R (NB I-5 & NE 145th St.)**

To show the detection of sensitivity problem with different severity levels, the plots of on-time differences in some traffic lanes are shown in Figure 6(a)-6(c). In Figure 6(a), the plotted on-time differences in lane 2 at the ES-167D station are within ±10% the majority time, according to the trendline. This conforms to the small value of DIFF% (6.33%). The sensitivity problem of this lane is minor. At the same station, the trendline of lane 3's on-time difference is within ±10% as well, but the fluctuation of the on-time differences is obvious, as displayed in Figure 6(b). This implies that the on-time difference is low the majority of the time. The sensitivity discrepancy is not the issue here; instead the intermittent fluctuation may arise from the cross talk problem. The cross talk results in more numbers of on-time differences that are outside ±10% region and thus shifts the DIFF% to 19.07%. At the ES-168R station, lane 2 has the trendline of the on-time differences outside the ±10% region (Figure 6(c)). This implies that sensitivity inconsistency is a major problem. The fluctuation of the on-time differences is also obvious. The DIFF% in this lane went up to as high as 65.62%. This may indicate the severity of the issue when the sensitivity discrepancy problem is coupled with the cross talk problem. However, the sensitivity discrepancy is clearly the main problem here since the DIFF% went up from 19.07% to 65.62% (about 45% higher) from lane 3 at ES-168R (only cross talk problems) to lane 2 at ES-172R (sensitivity discrepancy and cross talk problems). The cross talk only intermittently causes large on-time differences, but not regularly.

The sensitivity discrepancy problem should be solved by adjusting the sensitivity levels of the DEU following the results of the analysis function in ALEDA. Likewise, the cross talk problem would be eliminated by adjusting the single-loop frequency. Speed estimates should be reasonably accurate when no sensitivity discrepancy and cross talk problems present in a dual-loop detector system.

## CONCLUSIONS AND FUTURE WORK

Dual-loop detectors are a primary speed and classified-vehicle volume data source in Washington State. However, most dual-loop detectors have malfunctions caused by sensitivity discrepancy between the two single loop detectors, and the malfunctions have resulted in erroneous data. ALEDA is proposed to fix this problem by collecting and analyzing the loop detector event data. The main objective of ALEDA is to collect event data, identify detector sensitivity problems, and provide quick remedy solutions based on the analysis of the event data. Detection, investigation, and correction of sensitivity discrepancy and cross talk problems in the dual-loop system were given as an example of the analysis functions in ALEDA. As a consequence of ALEDA, the dual-loop system could provide accurate traffic data for advanced traffic management systems and advanced traveler information systems.

Future research efforts on ALEDA include: 1) improving the data collection functions; 2) developing the analysis function for error identification and solution recommendations; and 3) testing the system with detector electronic units from different manufacturers and under different weather conditions.

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