Improved Dual-Loop System for Collecting Real-Time Truck Data

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Abstract

The Washington State Department of Transportation (WSDOT) has a loop detection system on its Greater Seattle freeway network to provide real-time traffic data. The dual-loop detectors installed in the system are used to measure vehicle lengths and then classify each vehicle into one of four categories according to its length. The dual-loop's capability of measuring vehicle length makes the WSDOT dual-loop detection system a potential real-time truck data source for freight movement study in that truck volume estimates by basic length category can be developed from the vehicle length measurements produced by the dual-loop detectors. However, a previous study found the WSDOT dual-loop detection system was not consistently reporting accurate truck volumes. The problems included significant miscounts and misclassifications.

As an extension of the previous study, this research project determined possible causes of dual-loop miscounts and misclassifications under non-forced-flow traffic conditions. A new dual-loop algorithm that can address these error causes and therefore tolerate erroneous loop actuation signals was developed to improve the performance of the WSDOT loop detection system. A quick remedy method was also recommended to improve the performance of the dual-loop detection system without replacing any part of the existing system hardware or software. As a byproduct of the research, a laptop-based detector event data collection system (DEDAC) was also developed to help collect loop event data for the research.

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Keywords: freeway traffic, inductive loop detectors, event data collection, error detection, truck data.

INTRODUCTION

In the past decade, with the increasing emphasis on just-in-time inventories and the growing impact of freight mobility on our regional economy, vehicle-classification data, especially accurate up-to-the-minute data on truck movements have become essential to our regional growth and market competitiveness. Also, because of heavy weights and large turning radii, the characteristics of truck movements are very different from those of passenger cars and should be considered in transportation planning and traffic analysis models. Continuous collection of truck volume data along our region's freeways is imperative for a variety of purposes. For example, traffic operators need these data for real-time traffic management operations; the trucking industry needs these data for route selection and fleet monitoring; transportation researchers need these data to develop real-time algorithms or systems for analysis of freight movements. Therefore, a traffic data collection system that can continuously collect and deliver real-time truck volume data is very desirable.

As one of the most popular automated traffic data collection methods, inductive loop detector technology was first introduced for detection of vehicles in the early 1960's (1), and today, after a 40-year evolution, it has become a ubiquitous means for collecting traffic data from freeways in the United States. Inductive loop detectors are frequently deployed as single-loop detectors, i.e., one loop per lane, or as speed traps (also called dual-loop detectors, dual loops, or T loops) formed by two consecutive single-loop detectors placed several meters apart in each lane. Single-loop detectors are used to measure volume and lane occupancy, while dual-loop detectors measure speed and vehicle length.

The Washington State Department of Transportation (WSDOT) has a network of loop detectors on its Greater Seattle freeway network that provides real-time traffic data to its Advanced Traffic Management System (ATMS) and its Advanced Traveler Information System (ATIS). There are 620 loop stations installed along the freeway network. In total, there are 4800 single-loop detectors and 1020 dual-loop detectors embedded beneath the pavement for traffic data collection. Most of the loop detectors deployed on the Greater Seattle freeway network are square-shaped detectors with a dimension of 6 feet in length and 6 feet in width. In recent years, some damaged square-shaped loop detectors were replaced by circle-shaped detectors with a diameter of 6 feet.

Current WSDOT Single-Loop and Dual-Loop Algorithms

When there is no vehicle present on a single-loop detector, the detector rests in the "off" state. The detector changes its state from "off" to "on" when a vehicle arrives at the leading edge of the detector and from "on" to "off" when the vehicle departs from the rear edge of the detector. This change of state from "off" to "on" and then back to "off" represents the passage of a vehicle. The duration during which a vehicle occupies a single-loop detector is called the detector on-time, which can be aggregated to calculate lane occupancy for a particular interval. This is how a single-loop detector collects volume and lane occupancy data.

When a vehicle passes two single-loop detectors spaced a few meters apart (a dual-loop detector), it first activates the upstream detector (the M loop) and then the downstream detector (the S loop). The time it takes for the vehicle to travel from the upstream detector to the downstream detector is called the elapsed time. If the distance from the rear edge of the upstream detector to the leading edge of the downstream detector is known, the speed at which the vehicle traverses the dual-loop detector can be calculated by dividing the distance by the elapsed time. The calculated speed can then be used to calculate vehicle length using the detector on-time collected from either of the two single-loop detectors (M or S loop). In the current WSDOT system, vehicles are classified according to their lengths by assigning each identified vehicle to one of four bins: (a) Bin 1 - PCs and smaller vehicles (length 26 ft or less); (b) Bin 2 - small trucks, etc. (26 ft to 39 ft); (c) Bin 3 - larger trucks and buses (39 ft to 65 ft); and (d) Bin 4 - largest trucks and articulated buses (length greater than 65 ft). Vehicles that fall inside Bins 2, 3, and 4 are considered recreation vehicles, trucks, or buses. Therefore, the dual-loop detector's capability of measuring vehicle lengths makes the WSDOT dual-loop detection system a potential real-time truck data source for freight movement study. This is how a dual-loop detector collects speed and vehicle length data. To save disk space, the collected individual vehicle data are then aggregated into 20-second intervals of flow, occupancy, velocity, and vehicle length data.

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Problem Statement

Since the overwhelming majority of vehicles in Bins 2 through 4 represent trucks, correct vehicle counts and bin assignment would yield a ubiquitous means of obtaining truck flow data along the freeway network. However, a preliminary study (2) on Interstate 5 (I-5) found the WSDOT dual-loop detection system was not consistently reporting accurate truck volumes. In that study, the accuracy of dual-loop vehicle classification data was evaluated using video ground-truth data, and the major findings are summarized as follows:

- Dual-loop detectors undercounted vehicle volumes. This was a very common problem in the WSDOT dual-loop detection system. More than 80% of the dual-loop detectors had significant under-count errors.
- Dual-loop detectors misclassified vehicles across bins, especially between Bin1 and Bin2, and Bin3 and Bin4. For the data collected during the off-peak hour period, observed errors in truck misclassifications ranged from 30% to 41% and, for the data collected during peak-hour period, observed errors in bin assignment for trucks ranged from 33% to 55%.

Admittedly, dual-loop detectors were primarily designed and implemented for measuring vehicle speeds rather than classification and bin volume data; nonetheless, if the capability of measuring vehicle length could be improved and fully utilized, they would become a widespread and cost-efficient truck data source for freeway freight movement study and economic analysis for the Seattle Metropolitan Region. This then raises the issue of the need for more accurate dual-loop bin volume data.

Research Objective

Inductive loop detection systems are subject to errors, which can be caused by system hardware and software. Embedded beneath the pavement, after enduring long-term impact from the load of the passing vehicles and stress resulting from pavement deformation, loop detectors become very vulnerable to malfunctions. Causes for loop malfunctions include moisture, loop sealant deterioration, pavement cracking, broken wires, deteriorated insulation, corroded splices, detuned amplifiers, transmission errors, etc (1).

As an extension of the previous study (2), this research, sponsored by Transportation Northwest (TransNow), the USDOT University Transportation Center for Federal Region 10, aimed at identifying possible causes of WSDOT freeway dual-loop miscounts and misclassifications and developing a new dual-loop algorithm that could tolerate erroneous loop actuation signals to radically improve the WSDOT dual-loop detection system's ability to provide accurate real-time truck data.

PREVIOUS WORK

Because of the vulnerability of the loop detectors, a means to timely identify loop errors, investigate causes of malfunction, and apply remedial methods has been of a great interest to transportation professionals. Consequently, error detection and correction techniques have continued to evolve in the past three decades.

The loops operate in presence mode (that is, they turn on and stay on as long as a vehicle is occupying the loop). At each station, the field microprocessor (usually a Model 170 controller, an 8-bit 6808-based machine) checks or scans the loop actuations 60 times each second. Typical freeway loop detection systems, under normal operation, aggregate individual-loop detector actuations sampled at 60 Hz into 20-second or 30-second flow, and occupancy measurements. So, there are two types of loop data, raw loop actuation signals and aggregated loop data, available for malfunction inspection. Accordingly, based on the type of data being inspected, two approaches have been explored for erroneous loop data detection and malfunction identification. One is aggregate-data-based malfunction detection, and the other is raw-actuations-based malfunction detection.

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Aggregate-data-based malfunction detection applies reliability checks to the aggregate traffic measurements attempting to ensure the validity of traffic data prior to their use in traffic management and information system applications. Some commonly used tests establish certain thresholds beyond which the data cannot be said to reflect actual traffic operations. Maximum and minimum acceptable values for volume, speed, and occupancy are of this type. More sophisticated tests make use of the inherent relationships among traffic parameters such as speed, volume, and occupancy by applying traffic flow theory principles (3-7).

The raw-actuations-based malfunction detection method processes the raw loop actuation signals from a loop directly. Individual vehicle information, such as vehicle arrival, departure, and presence times, can be calculated from the loop's "on" and "off" indications. This approach was first pursued by the Institute of Transportation Studies at the University of California, Berkeley, and the resulting algorithms were described by Chen and May (8). Their methodology examines the distribution of vehicles' on-time, i.e., the time the detector is occupied by each vehicle. They developed a diagnostics scheme in which the average vehicle on-time is examined as a test statistic. By comparing this value against the average on-times for a station of detectors, the validity of detector operation could be checked. Coifman (9) compared the measured on-times from each loop in a dual-loop detector on a vehicle-by-vehicle basis because, at free flow velocities, the two single-loop on-times should be virtually identical. Congested periods were not considered in his analysis because, at lower velocities, vehicle acceleration could cause the two on-times to differ significantly even though both loops were functioning properly. He also presented eight new detector validation tests that employ event data to identify detector errors. Five of these tests can be applied to single-loop detectors or non-invasive sensors that aggregate data using similar techniques. All of the tests can be applied to dual-loop detectors (10).

In addition to the loop error detection techniques, various erroneous data correction techniques have been proposed to correct loop errors. Daily and Wall (11) developed an algorithm for correcting errors in archived freeway loop data that are the result of poorly calibrated sensors. Calibration errors create difficulties when trying to use archived data in offline analysis. In their work, they used the consistency of vehicle counts to judge the validity of the data; if vehicle counts were balanced the data were considered to be valid, if vehicle counts were not balanced the data were not considered to be valid. The method could also determine a correction factor, which was used to create a time series. The time series could be combined with the original data to adjust the volume to create a consistent data set.

Payne and Thompson (3), after examining the malfunction rates of I-880 data by applying 14 validity tests, developed a repairing algorithm from the I-880 database utilizing historical traffic distributions as well as current measurements from surrounding sensors. The resulting measurement estimates were shown to be unbiased for short-term malfunctions. This data-repair algorithm is suitable for applications that do not rely on the absolute accuracy of individual measurement data.

Chen, et al. (12), developed a diagnostics algorithm to detect malfunctioning single-loop detectors from their volume and occupancy measurements. Unlike previous approaches, the algorithm employed a time series of many samples, rather than basing decisions on a single sample. They then developed a linear regression imputation algorithm using the linear relationship between neighboring loops to estimate the value of missing or bad samples.

Previous research has been focused on checking the validity of loop data and correcting errors in the data, and little has been done to identify where the errors occur in the loop detecting process so that the error source could be eliminated. Therefore, in this research the loop detecting process was examined to identify possible causes of loop errors.

DETERMINING ERROR CAUSES IN THE CURRENT WSDOT LOOP DETECTION SYSTEM

Typical freeway inductive loop detection systems, under normal operations, aggregate individual loop detector actuations sampled at 60 Hz into 20- or 30-second flow and lane occupancy measurements. While such aggregations are appropriate for serving as inputs to control system algorithms and save disk space for archiving loop data, useful data regarding individual vehicles are lost. For single-loop detectors, the lost information includes individual vehicle arrival, departure, and presence times. For speed traps, the lost information also includes the calculated individual vehicle speed and length. Yet this information about individual vehicles is very desirable for in-depth investigation of dual-

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loop miscounts and misclassifications. Therefore, before the error causes investigation could happen, a detector event data collection (DEDAC) system, which provides loop event data for subsequent data analysis, needed to be developed. A previous study developed a desktop-based DEDAC system that can collect loop event data without interrupting a controller's normal operation (13). Although the desktop-based DEDAC system is a reliable and practical system for loop detector event data collection, integrating a bulky desktop computer in the system significantly limits its usability and effectiveness. Because of the large size of the desktop computer and monitor, the desktop-based DEDAC system cannot be placed inside the traffic cabinet, so data collection personnel must be present beside the cabinet during the data collection. With such a cumbersome system, it would be extremely inconvenient for long-duration data collection, especially in inclement weather. Therefore, in this research, efforts were made to develop a laptop-based DEDAC in order to improve the system's portability, usability, transferability, and effectiveness.

Development of a Laptop-Based DEDAC System

A laptop-based DEDAC system was successfully developed in this research. An overview of the system design is illustrated in Figure 1. As can be seen in Figure 1, there are two significant differences between the desktop-based DEDAC and the laptop-based DEDAC. One difference is that the bulky desktop computer is replaced by a portable laptop. The other difference is that the data acquisition card is replaced by a USB digital Input/Output (I/O) adapter. System reliability tests conducted at WSDOT ITS laboratory indicated that the laptop-based DEDAC system was able to accurately collect loop detector actuation signals with high sampling rates under a variety of traffic conditions for long periods of data collection (14).

The laptop-based DEDAC system greatly improves the DEDAC system's portability, usability, transferability, and effectiveness. The physical dimensions of the USB adapter used to build the interface between the Input File and a laptop computer are 17.78 cm (7.0 in) in length, 13.34 cm (5.25 in) in width, and 3.81 cm (1.5 in) in height. The volume of the adapter is 0.9×10^{-3} m^3 (60 in^3). The physical dimensions of a regular laptop computer are 38 cm (15 in) in length, 30 cm (12 in) in width, and 6.5 cm (2.5 in) in height. The volume of a regular laptop computer is about 0.7×10^{-2} m^3 (450 in^3). So, the space the laptop-based DEDAC system occupies is only 0.8×10^{-2} m^3 (510 in^3). Because the size is so small, the laptop-based DEDAC system is portable and can be easily placed in a traffic cabinet for event data collection.

The improved portability in turn improves the usability and effectiveness of the DEDAC system. The system can now be placed in any cabinet for long-duration event data collection regardless of weather conditions. Data collection personnel are no longer required to be present beside the traffic cabinet after they set up the equipment. The laptop-based DEDAC can be used to collect event data for days and weeks as long as the capacity of the hard disk is not exceeded.

Procedure to Identify Loop Error Causes

As previously stated, a tremendous amount of the dual-loop detectors have miscount and misclassification errors that can be caused by any problematic step involved in the dual-loop detecting process. Therefore, a systematic examination of the whole process through which dual-loop detectors detect vehicles and produce measurements is needed to identify possible causes of dual-loop data errors. The WSDOT loop detecting process is simplified in Figure 2.

As shown in Figure 2, the Model 170 controller samples individual loop detector actuation signals at 60 Hz to get loop event data, which are then processed by applying the WSDOT dual-loop algorithm to get individual vehicle information such as length and speed. The individual vehicle information is aggregated into 20-second average velocity and length measurements and then sent to the Traffic System Management Center (TSMC). If any step of the process fails, the data collected will be erroneous.

The examination focuses on factors such as hardware malfunction, defects in the dual-loop algorithm, bugs in the code implementing the dual-loop algorithm, insufficient computing power of the cabinet controller, and any combination of these factors. Depending on these factors that need to be examined, the following tasks need to be performed.

First, collect loop detector event data. As previously mentioned, at each loop station, the field microprocessor checks or scans the loop actuation signals 60 times each second, and this 60 Hz data are called loop detector event data. The event data collection should not interrupt any loop detector's normal operation because the 20-second dual-loop data are still needed for analysis purposes. Traffic should also be recorded using a video camera when the event data collection is conducted. The recorded traffic is then processed to get ground-truth data, such as individual vehicle presence time, vehicle length, and volume information. The collected event data may feed three processing modules. These three modules are illustrated in Figure 3. The first module is the existing 170 controller programmed with the current WSDOT dual-loop algorithm. The second module is the simplified single-loop and dual-loop algorithms developed based on the current WSDOT dual-loop working mechanism, but without implementing any on-time validity checks in the dual-loop algorithm. These two algorithms can be used to process the loop detector event data to get individual vehicle data. The third module is the new generation of controllers that has more computing power than the existing 170 controller.

Next, compare WSDOT 20-second dual-loop data with video ground-truth data to evaluate its accuracy. The suspicion that the current dual-loop algorithm has flaws or the code that implements the algorithm may have bugs could, to some extent, be addressed through the comparison.

If the difference between the WSDOT 20-second aggregate data and the video ground-truth data is noticeable, the collected loop event data should be input into the simplified single-loop and dual-loop algorithms to get individual vehicle arrival and departure times, speed, and length information. The calculated information is first compared with video ground-truth data. If they agree, it can be concluded that: (1) the collected event data are sound; (2) the WSDOT dual-loop working mechanism is correct; and (3) the current WSDOT dual-loop algorithm implementation has problems. Otherwise the calculated information is compared with the WSDOT aggregate 20-second loop measurements. If they agree, it can be concluded that the current dual-loop algorithm module is reliable, but the loop event data have problems. If they do not agree, then both the algorithm module and the loop event data are suspicious.

If there are remarkable problems in the current WSDOT dual-loop algorithm module, one more test must be conducted to conclude whether the problems are caused by the aged Model 170 controllers. Input the collected loop event data into a new Model 170-compatible controller that has much stronger computing power than the current Model 170 controller to get 20-second aggregated vehicle length and speed data. The suspicion that the current Model 170 controller is deficient in computing power can be addressed by comparing the output from the new Model 170 controller with that from the current Model 170 controller.

Identified Error Causes

One-hour event data were collected from five dual-loop detectors located on I-5 at NE 130th Street in Seattle from 2:00 p.m. to 3:00 p.m. on May 16, 2002. A WSDOT surveillance camera was also employed to record traffic during the event data collection. The videotape provided by the WSDOT that had recorded the one-hour traffic was manually processed to obtain individual vehicle class information and arrival time. The number of vehicles that passed during the 60-minute period was counted for each of the five lanes. The traffic data obtained by processing the video data were the video ground-truth data for this research. The aggregate 20-second dual-loop bin-volume data for the same 60-minute period were downloaded from WSDOT Traffic Data Acquisition and Distribution (TDAD) website at http://www.its.washington.edu/tdad/. For convenience, these aggregate 20-second data, which were output from the current WSDOT dual-loop algorithm, are called TDAD-based traffic data. All the information obtained was then analyzed by following the research procedure designed to determine possible causes of dual-loop data errors. The main findings from our data analysis are summarized as follows:

1. When both M and S loops seem to work properly, the relatively large difference of measured on-times between the two single-loop detectors that form a dual-loop detector is the main cause of the WSDOT dual-loop miscounts and misclassifications.
   - Sensitivity discrepancy between paired M and S loops is a direct cause of large on-time differences between the loops, which in turn considerably affects a dual-loop detector's performance.
   - A wrong mode setting that causes large on-time percentage differences between paired M and S loops significantly affects a dual-loop detector's performance.
   - Under non-forced-flow traffic conditions, paired M and S loops' sensitivity discrepancies are the direct cause of large on-time differences. Therefore, due to the inconsistency and changeability of loop detectors' sensitivities, a fixed on-time difference threshold value (±10%) set in WSDOT dual-loop algorithm may be inappropriate or too strict.
2. The WSDOT dual-loop algorithm provides reasonable results when the on-time differences are within the allowable range (±10%). When the difference exceeds the threshold, the performance of the WSDOT dual-loop algorithm is noticeably different from the simplified dual-loop algorithm implemented in this research.

3. From the tests and analysis performed on the data collected from the data collection site in this research, no malfunctions were found that might indicate the insufficiency of computing power in the Model 170 controllers. Further research may be needed to investigate the sufficiency of computing power of the current WSDOT 170 controllers.

DEVELOPMENT OF A NEW DUAL-LOOP ALGORITHM

The WSDOT current loop cabinet uses a Model 170 controller, an 8-bit 6808-based machine that was a product first released in 1975 by Motorola, Inc. The current WSDOT dual-loop algorithm was coded in Assembly (a low-level programming language) in order to efficiently utilize the limited hardware resources (memory, central processing unit, etc.). Since the software was coded in Assembly, it is difficult to understand and update. Also perhaps because of the limited computing power of the 170 controllers, erroneous loop actuation signals were simply screened out by the current WSDOT dual-loop algorithm with flags signaled. This screening process filtered out a tremendous amount of erroneous loop actuation signals that could have otherwise been corrected to give acceptable speed and vehicle length information.

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The New Dual-Loop Algorithm

Nowadays, with advances in technologies, the computing power of controllers has been dramatically increased. The new generation of controllers is now capable of executing more involved applications. Therefore, based on the identified error causes, a new dual-loop algorithm was developed in this research to handle erroneous raw loop actuation signals. The new dual-loop algorithm is designed to filter out all the noise and keep as much individual vehicle information as possible despite some unreliability in the raw loop actuation signals. It begins with a de-noise filter and a postprocessor that screen out noise and correct erroneous actuation signals. The algorithm then matches downstream on-times to their upstream on-times. The matched on-time pairs are then used to calculate individual vehicle speed and length with appropriate error flags where needed. When calculating speed and vehicle length, various checks are applied to test the validity of the data. If any of the checks fails, an appropriate error will be flagged, but the individual vehicle data are not discarded from the total count (14).

Evaluating the Effectiveness of the New Dual-Loop Algorithm in Counting Vehicles

In order to evaluate the effectiveness of the new dual-loop algorithm in counting vehicles, one-hour loop event data were collected from three dual-loop detectors located on SR167 at 34th Street NW in Auburn from 10:00 a.m. to 11:00 a.m. on November 21, 2003. Two of the dual-loop detectors were embedded in general purpose (GP) lanes and one was embedded in a high occupancy vehicle (HOV) lane. The one-hour loop event data were processed to get single-loop (M and S) and dual-loop volumes. The traffic data obtained by applying the new dual-loop algorithm to the collected loop event data are called event-data-based traffic data hereafter in the paper. One-hour TDAD-based single-loop and dual-loop volumes were also downloaded for comparison purposes. These two sets of one-hour volume data, together with one-hour video-ground-truth volume data obtained by processing the video data provided by WSDOT are summarized in Table 1. The event-data-based and TDAD-based single-loop volume data were each then compared to the video-ground-truth volume data to calculate over-count rates for each of the three lanes. The results are summarized in Table 2.

Table 1 shows that the event-data-based one-hour single-loop volume was almost equal to the video-ground-truth one-hour volume for each of the two GP lanes. During this one-hour period, the M and S loops on Lane 1 only over counted one and four vehicles respectively. The M loop on Lane 2 correctly counted all the passing vehicles, while the S loop only over-counted two vehicles. The M and S loops on the HOV lane correctly counted all the passing vehicles. As can be seen in Table 2, the highest event-data-based over-count rate was only 0.32% during this one-hour period.

In contrast to the event-data-based single-loop volumes, shown in Table 1, the TDAD-based one-hour single-loop volumes were consistently higher than the video-ground-truth volumes. The M and S loops on Lane 1 over-counted 46 and 53 vehicles, respectively. The M and S loops on Lane 2 over-counted 61 and 71 vehicles, respectively. The M and S loops on the HOV lane over-counted 16 and 13 vehicles, respectively. As can be seen in Table 2, the over-count rate ranged from 3.65% to 4.79%, which was much higher than the event-data-based over-count rate. The difference between event-data-based single-loop over-count rates and TDAD-based over-count rates were calculated and the results were also summarized in the last two columns of Table 2. The over-count rate reductions indicated that the de-noise filter and the postprocessor effectively filtered out noise and corrected raw loop actuation signals when processing this one-hour period of event data.

One-hour event-data-based dual-loop volume and one-hour TDAD-based dual-loop volume were compared to the one-hour video-ground-truth volume to calculate the undercount rate for each of the three lanes. The results are summarized in Table 3. As shown in Table 3, during this one-hour period, the number of passing vehicles and each individual vehicle’s arrival time, calculated by applying the new dual-loop algorithm using event data, exactly matched that of video-ground-truth data except for one occasion when a dump-pup truck (the combination of a dump truck and a pup trailer) was counted as two vehicles by the new dual-loop algorithm due to the long drawbar that connected the dump truck and the pup trailer. The TDAD-based dual-loop volumes, in contrast, consistently undercounted vehicles that passed the detector zone during the one-hour period. The dual-loop detectors on Lanes 1, 2, and HOV undercounted 93, 146, and 14 vehicles, respectively. The undercount rate was as high as 9.22%. These results proved that the new dual-loop algorithm was able to improve the detection rate of the dual-loop detectors for this one-hour period.

It can be concluded that the de-noised filter, the postprocessor, and the improved dual-loop algorithm considerably reduced the single-loop positive false alarm rate while noticeably improving the dual-loop detector detection rate.

Evaluating the Effectiveness of the New Dual-Loop Algorithm in Classifying Vehicles

In order to evaluate how accurately the new dual-loop algorithm classifies vehicles, one-hour video-based vehicle classification data were compared to the same one-hour event-data-based vehicle classification data. The length ranges used by the current WSDOT dual-loop algorithm to classify vehicles into one of four bins were also adopted to classify observed vehicles when processing the video data to classify vehicles detected by the new dual-loop algorithm. When observing the video, if the researcher was certain about the bin class of an observed vehicle, the vehicle was then assigned to that bin; if the researcher was not certain about the bin class of a vehicle because the length of the vehicle was close to one of the bin threshold values, the vehicle was dropped from the ground-truth sample. In other words, only vehicles classified by the researcher with 100% confidence (for the ground-truth sample) were used to evaluate the accuracy of vehicle classification data calculated by the new dual-loop algorithm. The results are summarized in Table 4.

As shown in this table, 1144 (91% of the total number of vehicles that passed Lane 1), 1519 (96% of the total number of vehicles that passed Lane 2), and 328 (98% of the total number of vehicles that passed Lane HOV) vehicles that passed Lane 1, Lane 2, and Lane HOV respectively were classified into bins when manually processing the video ground-truth data. The selected samples accounted for an overwhelming majority of the vehicles that passed the dual-loop detection zone during that one-hour period and this sample was used to evaluate the accuracy of the new dual loop algorithm and the current WSDOT algorithm. Of these vehicles, all but one were classified into the same bins as the ground-truth sample by the new dual-loop algorithm for all three lanes. The vehicle that was misclassified by the new dual-loop algorithm was a dump-pup truck which was incorrectly separated into two vehicles due to the long drawbar that connects the two parts.

In order to evaluate how much the new dual-loop algorithm improved the quality of the vehicle classification data, the one-hour TDAD aggregate data were also examined to identify the vehicles that were correctly classified by the current WSDOT dual-loop algorithm. The results are also summarized in Table 4. As shown in this table, the WSDOT dual-loop algorithm correctly classified the majority of the vehicles for each of the three lanes. For Bin1, more than 90% of the vehicles were correctly classified. For Bin2, 77% and 58% of the vehicles were correctly classified for Lane 1 and Lane 2, respectively. For Bin3, 80% and 70% of the vehicles were correctly classified for Lane 1 and Lane 2, respectively. For Bin4, 83% and 67% of the vehicles were correctly classified for Lane 1 and Lane 2, respectively.

By comparing the number of vehicles what were correctly classified by the new dual-loop algorithm to that by the current WSDOT dual-loop algorithm, one can find that the new dual-loop algorithm correctly classified significantly more vehicles than the current WSDOT dual-loop algorithm, especially Bin2, Bin3, and Bin4 vehicles where the new algorithm correctly classified up to 42% more vehicles than the current WSDOT algorithm.

It can be concluded from the above results that the new dual-loop algorithm correctly classified the overwhelming majority of the vehicles that were classified into bins when processing the video data for this one-hour period. The new dual-loop algorithm considerably increased the capability of dual-loop detectors to accurately classify vehicles.

CONCLUSIONS

In this research, the WSDOT dual-loop detection system was systematically examined and possible error causes were identified. There are a variety of loop error causes. When both single-loop detectors seem to work properly under non-forced-flow traffic conditions, the main cause for the dual-loop undercount problem is the large on-time difference caused by the sensitivity discrepancy between the two single (M and S) loops because the current WSDOT dual-loop algorithm discards vehicles detected with on-time difference greater than the 10% threshold value.

Based on the identified error causes, a new dual-loop algorithm that can handle erroneous raw loop actuation signals was developed in this research. The new dual-loop algorithm is much more flexible than the current WSDOT dual-loop algorithm in that it is capable of recovering erroneous raw loop actuation signals and outputting acceptable volume and vehicle classification information (14). The data analysis conducted in this research verified the effectiveness of the de-noise filter, the postprocessor, and the improved dual-loop algorithm.

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The dual-loop detection system could become a good truck data source after implementing the new dual-loop algorithm if the sensitivity discrepancy between paired single-loop detectors can be adjusted so that the on-time difference of the two single-loop detectors that form a dual-loop detector falls within a reasonable range.

RECOMMENDATIONS FOR FUTURE RESEARCH

As identified in the data analysis, the relatively large sensitivity discrepancy between the two single-loop detectors that form a dual-loop detector is the main cause for the WSDOT dual-loop system’s miscounts and misclassifications. A quick remedy method that does not involve replacing any of the system hardware or software would be to adjust the sensitivity levels of the two single-loop detectors so that the mean on-time difference is less than 10% for the passing vehicles under non-forced-flow traffic conditions.

With the availability of the laptop-based DEDAC system, this sensitivity level adjustment becomes possible. Therefore, a follow-up research is to develop a program to integrate into the current laptop-based DEDAC system to calculate the sensitivity adjustment needed to calibrate every dual-loop detector that has sensitivity discrepancy between the two single-loop detectors. Although such sensitivity adjustment is a necessary but not sufficient condition for complete dual-loop accuracy, it should still improve the system so that the dual-loop detectors will be able to collect a majority of the passing vehicles without replacing any part of the current WSDOT dual-loop detection system.

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List of Figures and Tables

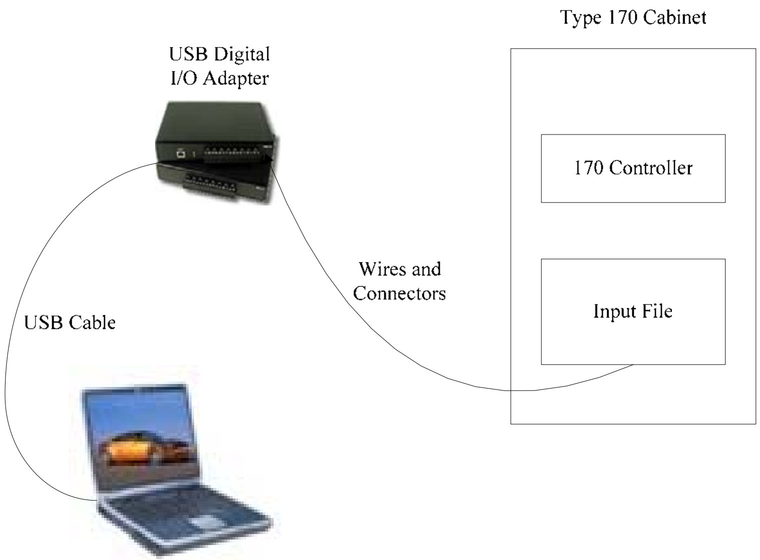

Figure 1. Overview of the laptop-based DEDAC system design

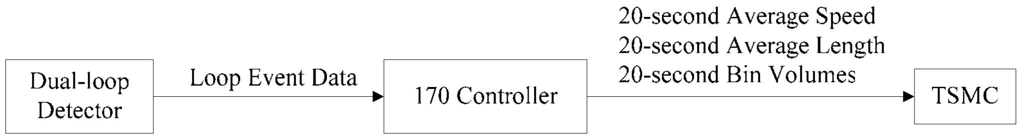

Figure 2. Diagram of the process through which dual-loop detectors detect vehicles and produce measurements

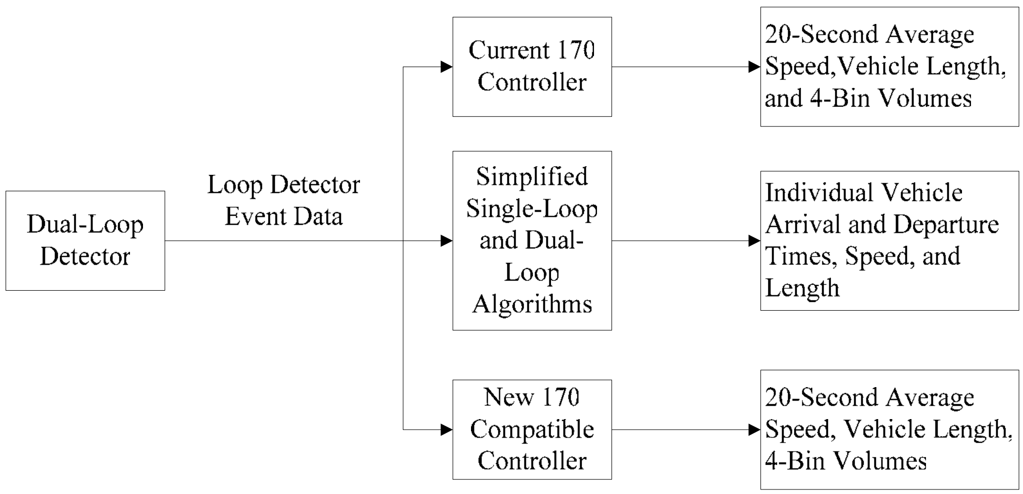

Figure 3. Data flow diagram for proposed research approach

Table 1. One-Hour TDAD-Based and Event-Data-Based Single-Loop Volumes, and Video-Ground-Truth Volumes

Lane No	TDAD-Based		Event-Data-Based		Video-Ground-Truth
	V_M	V_S	V_{EM}	V_{ES}	V_v
Lane 1	1308	1315	1263	1266	1262
Lane 2	1644	1654	1583	1585	1583
Lane HOV	350	347	334	334	334

V_M = TDAD-based M loop volume
V_S = TDAD-based S loop volume
V_{EM} = Event-data-based M loop volume
V_{ES} = Event-data-based S loop volume
V_V = Video-ground-truth volume

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Table 2. One-Hour TDAD-Based and Event-Data-Based Single-Loop Volume Over-Count Rates

Lane No	TDAD-Based		Event-Data-Based		Over-Count Rate Reduction	
	M loop $\frac{V_M - V_V}{V_V}$	S loop $\frac{V_S - V_V}{V_V}$	M loop $\frac{V_{EM} - V_V}{V_V}$	S loop $\frac{V_{ES} - V_V}{V_V}$	M loop $\frac{V_M - V_{EM}}{V_V}$	S loop $\frac{V_S - V_{ES}}{V_V}$
Lane 1	3.65%	4.19%	0.08%	0.32%	3.57%	3.87%
Lane 2	3.85%	4.49%	0.00%	0.13%	3.85%	4.36%
Lane HOV	4.79%	3.89%	0.00%	0.00%	4.79%	3.89%

V_M = TDAD-based M loop volume
V_S = TDAD-based S loop volume
V_{EM} = Event-data-based M loop volume
V_{ES} = Event-data-based S loop volume
V_V = Video-ground-truth volume

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Table 3. One-Hour Event-Data-Based and TDAD-Based Dual-Loop Volume Undercount Rates

Lane No	V_T	V_{ET}	V_V	$\frac{V_T - V_V}{V_V}$	$\frac{V_{ET} - V_V}{V_V}$
Lane 1	1169	1263	1262	-7.37%	0.08%
Lane 2	1437	1583	1583	-9.22%	0.00%
Lane HOV	320	334	334	-4.19%	0.00%

V_T = TDAD-based dual-loop volume
V_{ET} = Event-data-based dual-loop volume
V_V = Video-ground-truth volume

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Table 4. One-Hour Video-Based, Event-Data-Based, and TDAD-Based Vehicle Classification Data

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Bin No.	Lane 1					Lane 2					Lane HOV				
	V_V	V_E	V_T	$\frac{V_E}{V_V}$	$\frac{V_T}{V_V}$	V_V	V_E	V_T	$\frac{V_E}{V_V}$	$\frac{V_T}{V_V}$	V_V	V_E	V_T	$\frac{V_E}{V_V}$	$\frac{V_T}{V_V}$
Bin1	973	973	914	100%	94%	1463	1463	1326	100%	91%	328	328	306	100%	93%
Bin2	39	39	30	100%	77%	12	12	7	100%	58%	0	0	0	----	----
Bin3	44	44	35	100%	80%	20	20	14	100%	70%	0	0	0	----	----
Bin4	88	87	73	99%	83%	24	24	16	100%	67%	0	0	0	----	----
Subtotal	1144	1143	1052	99.9%	92.0%	1519	1519	1363	100.0%	89.7%	328	328	306	100%	93.3%

V_v = Number of vehicles that were classified into bins when processing the videotape
V_E = Number of vehicles that were classified into the same bins by the new dual-loop algorithm and by processing the videotape
V_T = Number of vehicles that were classified into the same bins by the current WSDOT dual-loop algorithm and by processing the videotape

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Video-Based vs. Event-Data-Based