DEPARTMENT OF TRANSPORTATION

Improve Traffic Volume Estimates from MnDOT's Regional Traffic Management Center

Taek Kwon, Principal Investigator
Department of Electrical Engineering
University of Minnesota Duluth

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Research Project
Final Report 2020-02

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16. Abstract (Limit: 250 words) The Regional Transportation Management Center (RTMC) at the Minnesota Department of Transportation (MnDOT) deploys a large number of traffic detectors in the Twin Cities' freeway network and continuously collects traffic data. While RTMC mainly uses the data for traffic and incident management, the TFA (Traffic Forecasting and Analysis) office uses the same data for monitoring, forecasting, planning, and reporting of transportation applications. RTMC provides current and historical volume data generated from its freeway network, but it does not provide quality information on that data. The objective of this project was to develop a new tool that can quickly explore the quality of detector data. To allow exploration of data quality, 13 detector-health parameters were computed using raw volume and occupancy data and then they were stored in a relational database. The final detector-health system was implemented as a client server-based system, in that a single server served many remote clients through the Internet. This report provides descriptions of the detector-health parameters, principles applied, server implementation, client software, and some analyses and application examples.			
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IMPROVE TRAFFIC VOLUME ESTIMATES FROM MNDOT'S REGIONAL TRAFFIC MANAGEMENT CENTER

FINAL REPORT

Prepared by:

Taek M. Kwon
Department of Electrical Engineering
University of Minnesota Duluth

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LIST OF ABBREVIATIONS

MnDOT	Minnesota Department of Transportation
FHWA	Federal Highway Administration
AASHTO	American Association of State Highway and Transportation Officials
RTMC	Regional Transportation Management Center
TMC	Traffic Management Center
TFA	Traffic Forecasting and Analysis
AADT	Annual Average Daily Traffic
CC	Continuous Count
CSV	Comma Separated Values
SC	Short-Duration Count
GUI	Graphical User Interface

EXECUTIVE SUMMARY

The Regional Transportation Management Center (RTMC) at the Minnesota Department of Transportation (MnDOT) manages the Twin Cites' (St. Paul and Minneapolis) freeway network and aggregates traffic data from a large number of vehicle detectors (about 7,830 detectors in 2019 and growing every year). Two types of vehicle detectors are mainly deployed, inductive loop detectors and microwave radar detectors. RTMC saves detector data consisting of volume, occupancy, and speed (when available) at a data rate of every 30 seconds from all detectors. MnDOT offices, such as Traffic Forecasting and Analysis (TFA), use this data for Federal Highway Administration (FHWA) reporting, traffic forecasting, and multiple planning applications.

One of the MnDOT TFA office's challenges in using RTMC detector data has been unavailability of quality information. Knowing which detectors have been producing high-quality data is critical for TFA, since choosing a set of good detectors leads to better or higher-quality design outcomes. For example, a continuous count (CC) station requires a set of detectors that provide good-quality data throughout the entire year, from which parameters like seasonal adjustment factors are more accurately computed. Consequently, quality control of traffic data has been an important issue to TFA. FHWA has also emphasized the same issue for many years, evidenced by TMG-2016 Section 2.6, which specifically states, "The TMG recommends that each agency improve the quality of reported traffic data by establishing quality assurance processes for traffic data collection and processing."[1] This project was created to develop a tool for TFA analysts to quickly explore RTMC detector data and identify bad or good detectors for a given period.

This project was started by reviewing an extensive list of literatures available on traffic detector diagnostic algorithms and erroneous data detection techniques, and then 13 diagnostic parameters were adopted. These parameters, which are named detector-health parameters, form the basis for quality control in this project, and they are all derived from raw 30-second detector volume and occupancy data. The parameters are computed every day for each detector and then stored in a relational database. The same parameters for each day are also fed into a classifier that outputs a health-level of the detector for the day. To simplify quality representation, four health levels were defined, which are: healthy, tolerable, impaired, and nonfunctional. Detectors in the healthy class were recommended for vehicle counting programs while the detectors in the tolerable class were recommended only if no healthy class detectors were available for the same location. The detectors in impaired or nonfunctional classes were not recommended for counting applications and considered targets for maintenance operations.

The final detector-health system was implemented as a client-server system, in which a single server supplies data to many remote clients through the Internet. The server contains a relational database, and a software tool called "detHealth_Daily.exe" that computes and loads detector-health parameters to the detector-health database. This software tool connects to a data server called IRIS (Intelligent Roadway Information System) managed by RTMC, obtains raw volume and occupancy data for each detector, and then computes all detector-health parameters. For the relational database engine, a free version of MySQL is used. Currently, only one client program called "detHealth_App" is available, which

is installed on the user's personal computer. This application software provides detector-health classification in a pie chart per day, retrieval of health parameters, parameter visualization, station AADT computation, etc.

This report includes few data analysis examples that were part of testing and development of the detector-health system (summarized in Chapter 4). Histograms of all detector-health parameters on interstate highway I-694 were computed, plotted, and analyzed to understand the frequency of occurrence. In histograms, most parameters exhibited an exponential distribution with a heavy concentration in the first few bins, which suggests that a majority of detectors were healthy for most of the time.

RTMC maintains an incident database that stores reported incidents on the Twin Cities' freeway network. Part of this data, which was provided to the research team, was a collection of incident data from the I-694 and I-94 interstate highway systems for the period, from January 1, 2015, to December 31, 2016. In this data, RTMC classified incidents into four categories, which were stall, roadwork, hazard, and crash. Each incident was recorded as a single database record and its location was specified using latitude and longitude but without detector IDs. Since incidents were not directly tied to detector IDs, the research team had to study all potential detectors near the incident location and then figure out how each incident affected the corresponding detector data. It was found that roadwork and hazard incidents increased consecutive zero-volume counts, but crash and stall incidents did not noticeably affect zero-volume counts or daily traffic volumes.

TESLA is a legacy RTMC maintenance logging system that recorded loop maintenance work orders. RTMC transitioned to a new maintenance logging system called TAMS in the fall of 2016 but provided the research team with the old TESLA data for 2015 and 2016 for study. As the basic methodology of investigating this data in relation to detector-health parameters, all stations on I-694 and I-94 were investigated. For all detectors in every station, whether they have had a record or records in the TESLA log from January 2015 to December 2016 was checked. If a maintenance record was found, then all detector-health parameters for that station were investigated. The research team found that detector repairs resulted in a sequence of event patterns. More specifically, all detectors in the station of repair event typically stopped producing data for few days before the repair, followed by a large number of negative volume counts for a few days, and then a normal pattern of traffic data was returned.

In conclusion, this project was born out of the need for quality information on the detector-volume data provided by RTMC. Since RTMC does not provide quality information on its traffic data, the research team had to create a wide range of detector-health parameters to use as a quality measure. A database of these health parameters provided a new tool for exploring quality information of detectors. During the project period, TFA reported that this new tool was used on several occasions and was effective in exploring reported problems of some continuous or short-duration count stations, as well as for a specific detector.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Modern transportation systems rely heavily on many traffic sensors and the data they generate. Traffic management centers (TMCs) in major cities across the U.S. are one example; they typically manage tens of thousands of traffic detectors installed on their city's freeways. The data produced from such a large system are often referred to as ITS (Intelligent Transportation Systems) generated data, because they are part of a large-scaled, sophisticated ITS network deployed throughout major cities. State transportation departments in planning and traffic forecasting offices use this available data for transportation monitoring, forecasting, planning, and reporting applications [1].

ITS-generated traffic data are generally sampled at a higher time resolution than that of traditional traffic counting devices (such as pneumatic tube counters or piezo-sensor stations) because they are mainly used for real-time traffic and incident managements. Data are typically recorded every 15 to 30 seconds. Due to a huge number of detectors deployed in TMC-managed freeway networks, it is often hard to maintain all of them to work in their full capacity, and thus some bad detectors are likely to be present in the system. The causes could be hardware malfunctions, road constructions, communication failures, power-supply problems, calibration errors, etc. Since a TMC's mission is mainly in real-time traffic management, once the real-time data has been used for applications such as ramp metering or incident managements, the quality of past data is of less concern and their operations simply move on to the next phase. However, if the same data are used for transportation planning applications, accuracy of past traffic data, especially volume, becomes extremely important, because it can affect the outcomes of analyses, projections, or designs. Although a huge amount of traffic data is available from TMCs, information on which portion of the data is good or bad is rarely available. Therefore, there is a need to measure, label, and assure the quality of data before they are used in transportation applications.

In Minnesota, the Regional Transportation Management Center (RTMC) within the Minnesota Department of Transportation (MnDOT) manages freeway traffic and incidents in the Twin Cites (St. Paul and Minneapolis) and aggregates data from about 7,830 detectors (in 2019 and this number grows every year) installed on the cities' freeway network. Two types of detectors have mainly been deployed, which are loop detectors and microwave radar detectors. RTMC daily saves the detector data consisting of volume, occupancy, and/or speed if it is available, at a data rate of every 30 seconds from all detectors. Within MnDOT, offices involving transportation planning and forecast, such as Traffic Forecasting and Analysis (TFA), use this data to produce short-duration and continuous count data for various Twin Cities' freeway locations. However, one of the major issues to TFA has been how to know (or discover) a set of good detectors without availability of data quality information. This project was created to improve quality of volume data by utilizing some form of detector quality parameters computed from 30-second volume and occupancy data available from RTMC. A strategy developed in this project was to create a database for detector-health parameters for each detector per day.

It should be mentioned that the effort of establishing a quality-control process at MnDOT TFA goes in parallel with the FHWA's efforts in introducing quality control into traffic data collection and processing. TMG-2016 (Section 2.6) states, "The TMG recommends that each agency improve the quality of reported traffic data by establishing quality-assurance processes for traffic data collection and processing." [2]

1.2 LITERATURE REVIEW

A large volume of research work has been done in the area of understanding faults in loop detectors and detecting consequential errors from the data. This section reviews literatures available on traffic detector diagnostic algorithms and erroneous data-detection techniques. Major sources used for this literature review were from the *Transportation Research Record* on-line database and Google scholar searches.

Although numerous vehicle detection technologies, which include magnetic sensors, magnetometers, inductive loop detectors, video image processors, microwave radars, ultrasonic, acoustic, passive infrared sensors, etc., have been developed and commercially available for many years, inductive loop detectors have been by far the most widely used vehicle sensing technology in modern traffic control systems (*Traffic Detector Handbook* [2]). Similarly, traffic detectors in the Twin Cities' freeway network managed by MnDOT RTMC also consist predominantly of inductive loop detectors. Therefore, this literature review focuses on loop detector diagnostics, but many of the same techniques could be used in other types of sensors.

In general, loop detector diagnostic approaches are classified into two levels: microscopic and macroscopic, initially coined by Jacobson et al. [3]. Microscopic-level diagnostic tests concern individual vehicle actuation signals or diagnostic indicators output by detector electronics in the field cabinet. Macroscopic-level diagnostic tests, on the other hand, refer to quality-control algorithms executed at TMCs after the data have been aggregated from field sensors.

A comprehensive treatment in microscopic-level information on inductive loop detectors can be found from the *Traffic Detector Handbook* [2]. It includes detailed descriptions of the underlying physics of inductance changes by a vehicle passage, proper installations of loop wires and lead-in cables, electronic units (detector board), acceptance tests, maintenance, and standards. This reference mainly provides information on basic failure tests at a control cabinet where individual loop detectors are connected. The tests include open/grounded-loop tests, presence/pulse mode tests, crosstalk detection tests, and sensitivity setup checks. An example of this type of basic loop signal test can be found from the methods developed in California, which established loop-detector installation acceptance criterion and maintenance techniques, as early as in mid-1970s [4].

A large volume of work on microscopic-level loop diagnostics has been developed at the Berkeley Highway Laboratory (BHL) that uses vehicle actuation signals (event data) in the detector card [5]. Loops operate in presence mode for freeway operation applications. That is, they turn on and stay on as long as a vehicle is present on the loop detection zone. This actuation signal, consisting of on-times and off-times, is sampled at 60 Hz through a controller such as model 170. What is distinctive at BHL was that

the on-time/off-time event data were transferred to the central sever located in their TMC and the event data was then used for developing loop-detector diagnostic algorithms [5]. The main advantage of tapping into this on-time/off-time vehicle actuation signal is fidelity available for individual vehicle measurements. For example, Chen and May [6] examined individual vehicle on-time of single loops against the statistical vehicle on-time data and determined validity of the detector operations. Their approach was sensitive to additional errors such as pulse breakups, where a single vehicle registers multiple actuations. Loop diagnostics utilizing on-time of dual loops was devised by Coifman [7]. The assumption he used was that at free-flow traffic, the on-times from the two loops should be virtually identical regardless of vehicle length. Loop errors were reported when two on-times differed over a preset threshold level. Coifman and Dhoorjaty [8] extended this result to include several more detector-validation tests such as a headway versus on-time ratio test, feasible range of vehicle lengths test, cumulative distribution of vehicle lengths, etc. Another interesting work was done by Lee and Coifman [9], in which they devised an algorithm that could detect pulse breakup errors. Diagnosis of pulse breakup was possible by examining short off-times and then differentiating between pulse breakups and tailgating. Following BHL studies, a similar detector-event data-collection system was implemented by the TransNow research team at the University of Washington (UW) [10].

In loop detectors, crosstalk is typically caused by inductive or capacitive coupling between closely placed loops or closely spaced lead-in wires operating at similar frequencies and leads to false detection and counting [2]. The *Traffic Detector Handbook* [2] suggests detailed instructions on how to avoid crosstalk errors by selecting different frequencies and carefully wiring the lead wires, but it does not provide information on how to detect them. A systematic approach in detecting crosstalk from loops proposed by Ernst et al. [11] developed a crosstalk detection algorithm based on a spectral analysis of vehicle inductance signatures in the frequency domain computed by Fast Fourier Transform (FFT).

Another type of detector error not discussed frequently but important is the segmentation error. Because loop detector event (actuation) data requires extra storage and bandwidth, controllers in a cabinet typically aggregate data in a preset interval, such as 30 seconds, into two values, volume and lane occupancy, which are then sent to TMC. A segmentation error may occur when a vehicle is present on the loop when the current interval terminates. In this case, the vehicle is counted toward the following interval, but part of its scan counts for occupancy are mistakenly assigned to the current interval. This incorrect count of scan in computing occupancy is referred to as a segmentation error. Yu et al. [12] developed a segmentation error detection algorithm based on loop-detector event data and was able to use that information to improve speed estimation from single loop detectors. They found that more than 15% of intervals are, in general, contaminated by segmentation errors [12].

Until now, microscopic-level or control-cabinet level loop-diagnostic techniques have been reviewed. Next macroscopic-level diagnostics techniques are considered, in which detectors are diagnosed using a large amount of volume and occupancy data collected at a TMC. Macroscopic algorithms may be further divided into algorithms based on a single location analysis and a system-level analysis of multiple locations. As an example of single location analysis, Jacobson et al. [3] devised a diagnostic algorithm based on an “acceptable region” in the k-q plane, declaring the data good if they fall inside the acceptable region. The boundaries of the acceptable region are defined by a set of parameters, which

are calibrated from historical data. Cleghorn et al. [14] extended the work of Jacobson et al. by tightening the upper bound for the k-q ratio through the application of traffic-flow theory. Chen et al. [14] devised an algorithm based on daily statistics of detector error conditions, which is basically another way of testing acceptable regions of the k-q plane. More specifically, they tested daily statistics of four conditions: (1) occupancy and flow are mostly zero, (2) non-zero occupancy and zero flow, (3) very high occupancy, and (4) constant occupancy and flow. In addition, they devised an imputation algorithm for missing data points. Another algorithm for testing a single location was developed by Kwon and his students, which tested 10 parameters through a large decision tree [15].

The second type of macroscopic-level diagnostic is based on spatial relations of traffic flow at the system level, involving multiple detector stations. A detector station here refers to a control cabinet that aggregates and processes loop signals from all lanes at that location and transfers the aggregated data (volume and occupancy) to TMC. The most frequently applied principle for system-level analysis is called the conservation-of-vehicles (COV) principle [16]. It states that, if the total number of vehicles counted by two consecutive detector stations is observed over a period, the difference in the cumulative counts at any time should not exceed the number of vehicles that can be accommodated in that length of the road under the jam density [17]. When the traffic volumes of two consecutive stations violate this principle, the cause is under or over counts of vehicles in the stations involved. Vanajakshi and Rilett successfully applied this principle in freeway traffic to diagnose bad loop-detector data [17]. Wall and Daily [20] used the same principle to adjust highway traffic volumes. Weijermars and Van Berkum [18] further extended and applied the COV principle in detecting invalid traffic data produced by single loop detectors at signalized intersections. In Minnesota, Kwon and MnDOT applied the COV principle in determining equivalent detector sets referred to as primary, secondary, and tertiary detector sets for computing annual average daily traffic (AADT) of a location [19]. In this approach, when errors were detected from the primary detector set, AADT was computed using the secondary detector set; when errors were present in the secondary set as well, AADT was computed from the tertiary detector set. If all three sets failed, the current data for the corresponding station were thrown away. This approach was implemented and used by MnDOT.

In California, macroscopic-level diagnostics were applied through a large data aggregation system called PeMS (Performance Measurement System) [21]. With so much detector data (over 25,000 loops) collected to one location, many loop detector locations were mislabeled as an error in lane direction. Kwon et al. [22] developed an approach that can detect incorrect configuration information about the loop locations. Their method relies on the fact that flow, occupancy, or speed measurements between a pair of loops that are spatially close must show higher correlations than when they are farther apart. They found that 15.6% of loops had incorrectly assigned labels on the stretch of road they studied. Another interesting effort was introduction of a dashboard concept into TMC operations. Hranac and Petty [23] proposed digital dashboards representing detector health within the framework of PeMS. A dashboard is a collection of graphical visualizations of key metrics for decision makers. For example, it could display the percentage of bad detectors in a district, such as 65% of detectors are good and 34% of detectors are bad. The user can then drill down into the data to discover more details and validate the data interpretation.

Many loop-data screening tests at a macroscopic level are available as summarized above [17-23]. Most of them focus less on identification of the maintenance-required detectors and more on imputing or correcting the bad data. One of the interesting approaches might be integrating many of the studies and practices available into a single integrated solution. This research attempts to identify and integrate many of the past diagnostic tools into one integrated system to develop a quality-control software tool.

CHAPTER 2: DETECTOR-HEALTH PARAMETERS

This chapter describes detector-health parameters and health-level classification developed as a representation of quality in this project. All diagnostic parameters are integrated into a single database, and then a system level algorithm is explored using application of the Conservation-Of-Vehicles (COV) principle.

2.1 DETECTOR-HEALTH PARAMETERS

The raw data available from RTMC detectors are 30-second volume and occupancy data. Occupancy data are not available for all detectors but volume data are. Each parameter presented in this section may be classified into one of the four cases: (1) computed from volume data only, (2) computed from occupancy data only, (3) computed using the relationship between volume and occupancy, and (4) spatial relation of volume data. Most of the parameters described below are a collection of well-known detector diagnostic parameters in literatures surveyed in Section 1.2. Some parameters are unrelated to detector-health measure but included for future utility of the database. Each parameter is described with its definition and the actual short name used in the database. The short name was the database column name and is shown as italic letters inside the corresponding parenthesis.

2.1.1 Consecutive zero volume (*conZeroVol*)

This value is an integer and represents a total number of 30-second time slots comprising a collection of consecutive zero volumes for 10 or more minutes. More specifically, there are 2,880 30-second time slots in a day (24 hours), and *conZeroVol* is obtained by counting the number of time slots only if zero volumes consecutively occur and it lasts longer than 10 minutes (i.e., zero volumes are found from more than 20 consecutive 30 second time slots). If the duration of consecutive zero-volumes is less than 10 minutes, it is ignored. A small *conZeroVol* value may not directly correlate to a faulty condition but when its value becomes very large, it indicates a potential problem in the sensor or system. For example, if a detector has consecutive zero volumes for more than 24 hours, it is highly likely that the detector is experiencing a faulty condition or a lane closure (construction or special event). This parameter has been used by MnDOT as a quality factor in the past, and it was particularly used as one the main measures to replace primary set volumes with secondary or tertiary equivalent volumes [19].

2.1.2 Negative Volume Counts (*negVolCnt*)

Total number of 30-second time slots with negative volumes. Volume values cannot be a negative number, but it is often used by the system to indicate an error condition. RTMC also places a negative volume number in 30-second time slots if an error condition was discovered in that slot.

2.1.3 Consecutive zero occupancy (*conZeroOcc*)

Total number of 30-second time slots comprising a collection of continuous time spans with consecutive zero occupancies for 10 or more minutes. The same reasoning described in the consecutive zero volumes is applicable to consecutive zero occupancies.

2.1.4 Negative Occupancy Counts (*negOccCnt*)

Total number of 30-second time slots with negative occupancies. Occupancy values cannot be a negative number, but it is used by the system or detector to indicate an error condition.

2.1.5 Occupancy lock-on sequence (*occLockOn*)

Total number of 30-second time slots comprising a collection of time spans of consecutive occupancy lock-on conditions (i.e., 99<occupancy≤100) for 10 or more minutes. Occupancy values greater than 99 percent are possible in real-world traffic under congestion, but lasting many long hours (such as consecutive 24 hours) imply an error condition.

2.1.6 Zero-volume on non-zero occupancy (*zvolOnOcc*)

Total number of 30-second time slots in which zero-volumes were detected on non-zero-occupancy. Ideally, zero volume should only exist under zero occupancy within each time slot. However, zero volume on non-zero occupancy may occur if a partial vehicle presence was captured at the end of the current time slot, and then the same vehicle is again captured and counted in the subsequent time slot. This problem is often referred to as a segmentation error [12]. If zero volumes persist on non-zero occupancies, a faulty condition in the detector may be the cause.

2.1.7 Volume-over-count (*overCnt*)

Total number of 30-second time slots in which volume is greater than 25 but less than 128 (25<vol<128). The theoretical limit of a single-lane volume for 30 seconds is around 25. If a 30-second volume exceeds this limit, it is likely caused by a fault such as mutual coupling in which vehicles in adjacent lanes are counted.

2.1.8 Very-high-occupancy (*highOcc*)

Total number of 30-second time slots with occupancy greater than 35%. This parameter correlates to detection of congestion, but it may provide additional information when it is used along with other parameters. If *highOccs* are present for a long period, it may be caused by a faulty condition in detector.

2.1.9 Constant volume (*constVol*)

Total number of consecutive 30-second time slots in which volume values remain constant in the range (0<vol<128) for 10 or more minutes. In normal traffic conditions, volume counts at consecutive time slots rarely repeat, except for zeroes in low traffic hours. If a non-zero constant volume repeats for more than 10 minutes from a detector, it is likely caused by a faulty condition in the detector.

2.1.10 Constant occupancy (*constOcc*)

Total number of consecutive 30-second time slots in which occupancy values remain constant in the range (0.2<vol<100) for 10 or more minutes. The same reasoning described in the constant volume is applied to *constOcc*.

2.1.11 Volume on low occupancy (*volOnLowOcc*)

Total number of 30-second time slots in which volume is greater than one when occupancy is in the range occ≤0.2%. In a 30-second time slot, 0.2 percent occupancy can be measured on a 6x6 feet loop by a single vehicle passage of one feet in length with 80 mph speed. Therefore, an occupancy that is less than 0.2 percent is unrealistic, and it is only possible by a passage of a segment of a vehicle [12]. This condition occurs when vehicle on-time is present between two adjacent time slots. Such a low occupancy should not be counted as a complete vehicle since it is a fragment of a vehicle. Existence of multiple time slots with volumes greater than one when occ≤0.2% indicates a potential faulty condition in that detector.

2.1.12 Correlation Coefficient (*CorrCoef*)

The Correlation Coefficient (*CorrCoef*) between volume and occupancy of a detector indicates a degree of linearity between them, and it is computed using the following formula.

$$CorrCoef = \frac{\sum_{i=0}^{2879}[(Vol(i)-Vol_{avg})(Occ(i)-Occ_{avg})]}{\sqrt{\sum_{i=0}^{2879}(Vol(i)-Vol_{avg})^2}\sqrt{\sum_{i=0}^{2879}(Occ(i)-Occ_{avg})^2}} \quad (1)$$

where *i* is an index of 30-second time slots, *occ(i)* is the occupancy at the *ith* time slot, *vol(i)* is the volume of the *ith* time slot, and subscription *avg* indicates an average. If *CorrCoef* is close to one, it means that the relation between volume and occupancy is almost perfectly linear, which is only possible by a “pulse mode” in a loop detector card. Pulse mode does not affect volume counts but affects speed estimates. Therefore, this parameter is included mainly for detection of pulse modes in loop cards.

2.1.13 Vol/occ ratio (*volOccRatio*)

The volume and occupancy ratio (vol/occ) of a 30-second time slot on a healthy detector should stay inside the theoretical acceptable bounds. This theory was originally developed by Jacobson et. al [3] and adopted in this research as one of the detector-health parameters. The vol/occ ratio for a 30-second data follows the relation [3],

$$vol/occ = (u * g)/120 \quad (2)$$

where *vol* is the 30-second volume, and *occ* is the 30-second occupancy in percent, *u* is speed in mph, and *g=K*/(vehicle length + detector length) where K is a conversion factor. Simply speaking, *g* is a parameter that makes a speed estimation possible using only volume and occupancy, and thus it is a function of vehicle length. At RTMC, this value is called field length. Table 1 shows the acceptable ranges of *vol/occ* under four different ranges of occupancies. It was constructed by only modifying the speed limits (min and max speeds) of the original table derived by Jacobson et. al [3] to adapt to speed limits of the TC freeways but using the same *g* values. If a *vol/occ* ratio is outside this range, the data is considered erroneous.

Table 1: Vol/Occ Ratio Thresholds for 30 Second Loop Data

	Occupancy Ranges (%)			
	0.2 – 7.99	8.0 – 25.99	26.0 – 35.99	36.0+
Min g	2.322	2.024	1.754	.980
Max g	3.832	2.526	2.462	1.868
Min speed (mph)	24.22	18.63	8.69	6.83
Max speed (mph)	95	88	50	40
Min Vol/Occ	.469	.314	.129	.056
Max Vol/Occ	3.033	1.852	1.026	.623

2.1.14 Conservation-of-vehicles principle

The conservation-of-vehicles (COV) principle is stated as: “the total number of vehicles counted by the upstream station should be counted by the downstream station at some future point in time if there are no exits and entrances between them.” [16]

Consider a pair of upstream and downstream stations on the same road with all detectors in the same direction, and no exits or entrances exist between them. The configuration of this pair of stations must satisfy the conservation-of-vehicles principle since there are no entrances or exits between them. Let the cumulative difference of volumes at the *k-th* 30-second time slot between the pair be denoted *D(k)*. Then the differences are:

$$D(k) = T_u(k) - T_d(k + \tau) \qquad k = 1 \dots K - \tau \quad (3)$$

where T_u is the total volume at upstream, T_d is the total volume at downstream, and τ is the time lag to catch the vehicles coming from upstream. If *D(k)* increases over time, it implies that some vehicles counted at upstream are not counted at downstream. If *D(k)* decreases over time, it implies that some vehicles not counted at upstream are counted at downstream. If *D(k)* is zero or near zero, it implies that vehicles are counted at the same time from both stations, which also indicates an error condition.

A normalized difference ratio (*diff_ratio*) of volumes between a pair of stations is measured as:

$$diff\_ratio(v1, v2) = |v1 - v2|/(\frac{v1+v2}{2}) \quad (4)$$

where *v1* and *v2* are the cumulative station volumes for a single day ending at midnight.

If this ratio is very small such as less than 0.01 when it is computed for the entire day (midnight-to-midnight), it indicates that the station traffic volumes between the two stations obey the COV rule. This in turn suggests that all detectors in both stations are working correctly since it is extremely hard to satisfy COV if any of the detectors in the two consecutive stations are not properly functioning. Therefore, COV tests are preferably used to detect a set of healthy detectors. This project computes volumes at three consecutive, equivalent stations and then compares them using *diff_ratio* in Eq. (4) to determine a satisfactory condition of COV.

2.2 DETECTOR-HEALTH-LEVEL CLASSIFICATION

This project defines four levels of detector health: *healthy, tolerable, impaired, and nonfunctional*. A graphical representation may be expressed using a simple pie chart as shown in Figure 1. Such a chart could quickly show or summarize the health status of the whole detectors in a system, from which further information may be queried upon selecting one of the classes, similarly to the dashboard concept developed in [23].

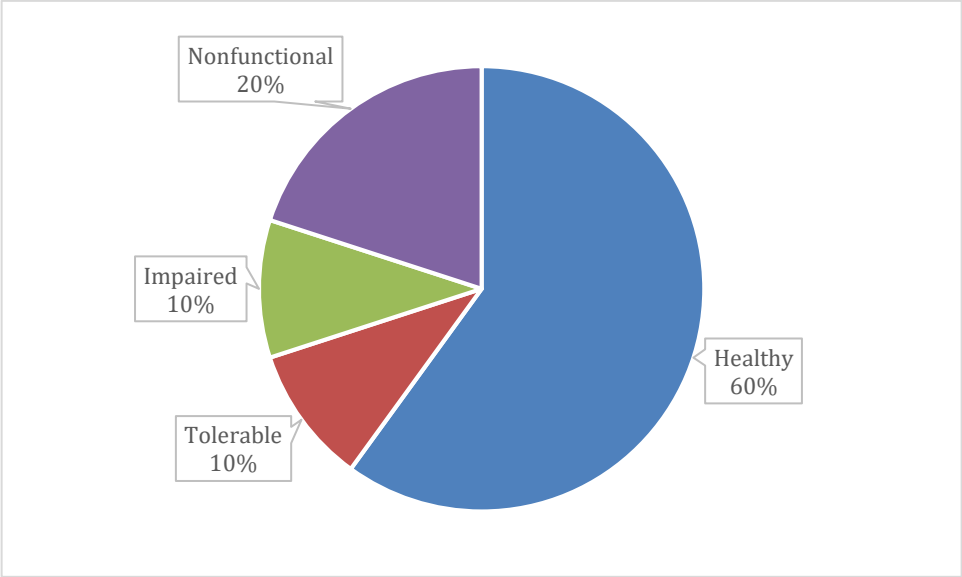


Figure 2.1 A Pie-Chart Representation of Detector-Health Classification (This pie chart was not generated from real data, and it is only used for illustration)

In this classification scheme, detectors in *Healthy* class are more desirable for vehicle counting programs, since the detectors in *Healthy* category provide the highest quality of counting data. Detectors in *Tolerable* should be used for counting only if the detectors in *Healthy* class are no longer available for the given location.

The detectors in *Impaired* or *Nonfunctional* are targets for maintenance operations and not recommended for vehicle counting programs. *Nonfunctional* class is assigned to detectors that are completely broken and do not generate any useable data. These detectors should be considered as the highest priority targets for maintenance. Detectors in *Impaired* class generate data that may include a large portion of them missing or erroneous, and thus considered not accurate enough for use in vehicle counting programs.

The health level of a detector is determined using a classifier algorithm that takes in *N* acceptance tests using the parameters described in Section 2.1. Figure 2 illustrates the concept of this classifier. Presently, 12 parameters are fed into the algorithm, and threshold levels set by user (user programmable) determines the classification.

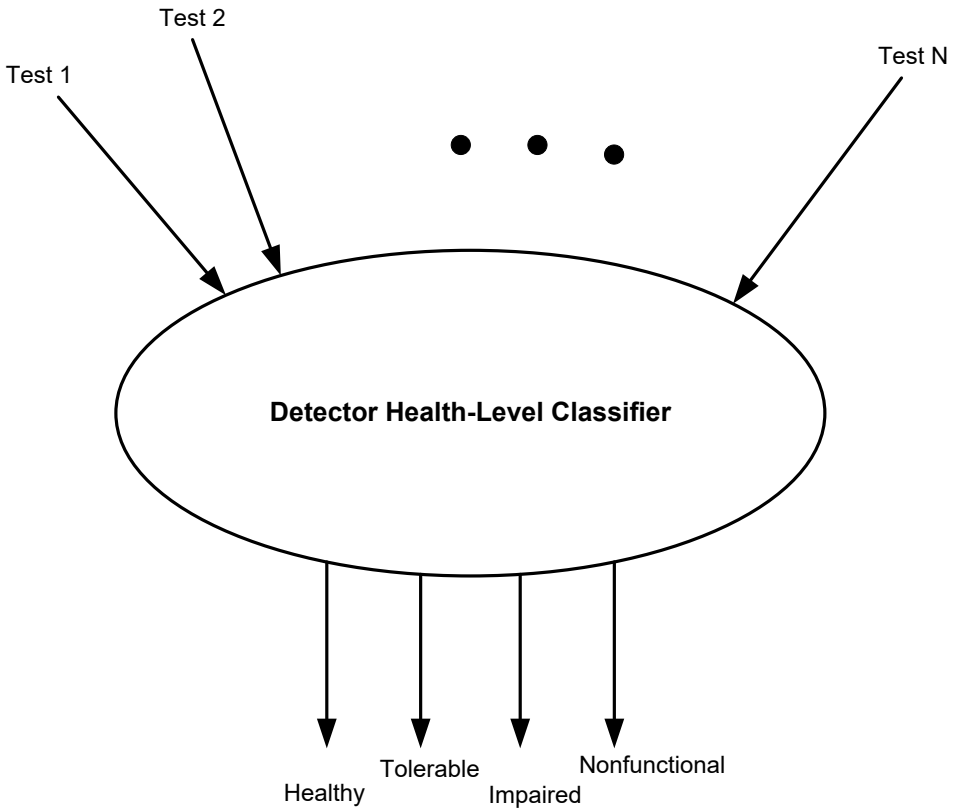


Figure 2.2: Detector-health-level classifier

2.3 COV APPLICATION IN STATION VOLUME

The COV principle described in Section 2.1.14 could be applied between two consecutive stations, even if entrances and/or exits between them may exist. Consider Figure 3 that has one entrance and one exit between each pair of two consecutive stations. The station in the middle is named Cur_Sta (current station), and its relations to upstream is called Up_Sta (upstream station) and downstream to Dn_Sta (downstream station). A simple COV rule is that entrances add while exits reduce the total volume at the downstream station. Suppose that we wish to estimate Cur_Sta volume in terms of the Up_Sta volume, and call this volume *Equiv_Up_Sta_vol*. Then, *Equiv_Up_Sta_vol* is computed by adding the Entrance_1 volume and subtracting the Exit_1 volume from the Up_Sta volume, i.e., the Eq. (5) holds for cumulative volumes ending at midnight.

$$Equiv\_Up\_Sta\_vol = Up\_Sta\_vol + Entrance\_1\_vol - Exit\_1\_vol \approx Cur\_Sta\_vol \quad (5)$$

Similarly, the equivalent downstream volume (*Equiv_Dn_Sta_vol)* can be calculated using current station volume as:

$$Equiv\_Dn\_Sta\_vol = Dn\_Sta\_vol - Entrance\_2\_vol + Exit\_2\_vol \approx Cur\_Sta\_vol \quad (6)$$

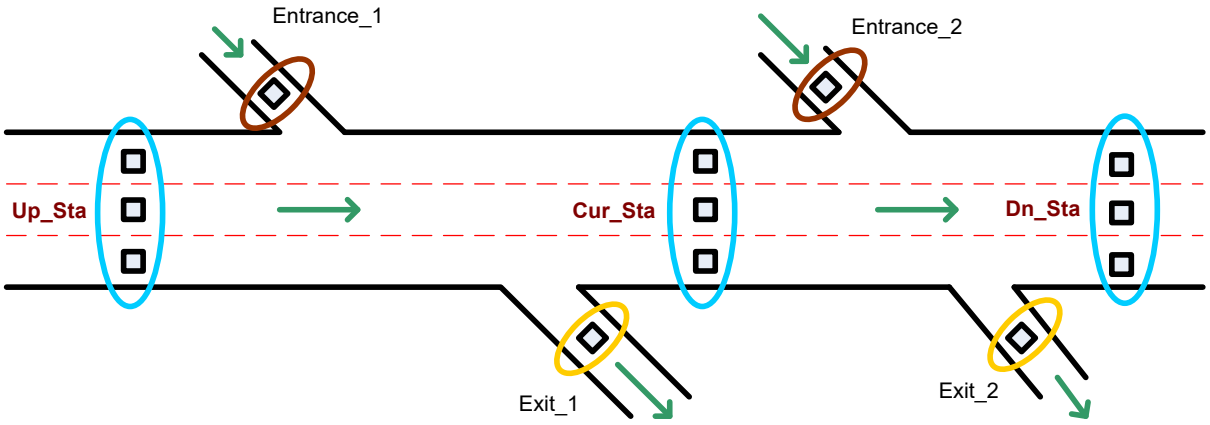


Figure 2.3: Equivalent volume relations of a station with presence of entrance and exit nodes between upstream and downstream stations

This leads to a condition for healthy station as:

$$Cur\_Sta\_vol \approx Equiv\_Up\_Sta\_vol \approx Equiv\_Dn\_Sta\_vol \quad (7)$$

The basic reasoning for using Eq. 7 as the acceptance condition for a healthy station is that, if one or more malfunctioning detectors exist in any of the stations under test, it will affect the total volume of the station and is unlikely to hold COV relations on three equivalent stations. Reviews on actual RTMC traffic data showed that less than 1 percent of differences exist when all detectors involved are working correctly. When detector errors exist, the differences were typically higher than 5 percent.

The COV principle may also be applied to detectors in an entrance ramp. Figure 4 illustrates multiple types of detectors installed in a typical entrance ramp on the Twin Cities' freeway network. This particular example has a passage detector (labeled P), a bypass detector (labeled B), a merge detector (labeled M), and two queue detectors (labeled Q). Queue detectors are used to detect if the vehicles queued at an entrance ramp are stretched beyond the queue detectors or not. A bypass lane allows bypass of high-occupancy vehicles (HOVs) where a B detector is placed. Merge detectors count all vehicles entering the highway from the entrance node where the M detector was installed, resulting in equal to the sum of traffic volumes in passage and bypass lanes. Therefore, the equivalency relation for daily volumes of detectors in an entrance ramp is given by:

$$Vol(all\ Q) \approx Vol(P + B) \approx Vol(M) \quad (8)$$

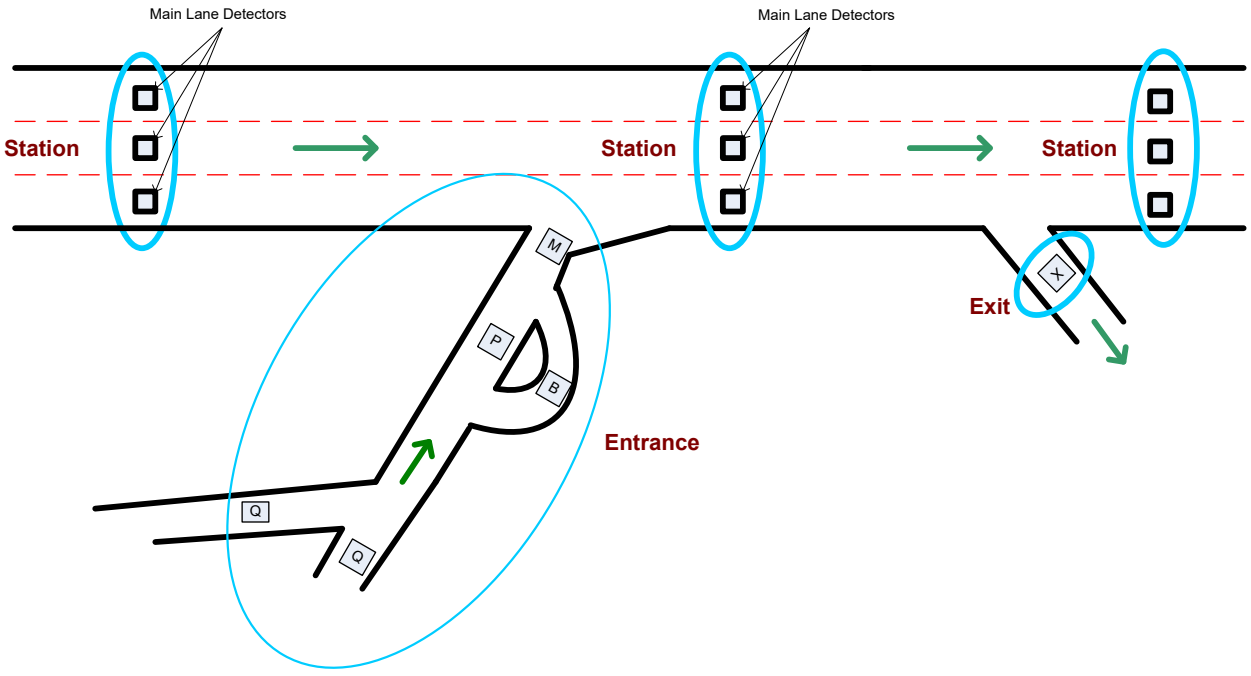


Figure 2.4: COV relations in an entrance ramp

Eq. (8) describes that volume sum of all Q detectors or M detector should be equal to the volume sum of P and B detectors. This relation was used to identify good detectors in entrance ramps in a similar manner as the COV rules applied on consecutive stations.

It should be noted that exit ramps in the Twin Cities' freeway network do not have redundant detectors installed, thus the COV principle cannot be applied in exit ramps. It is also important to note that the COV principle does not reveal information on which detector is bad or good, but it gives information on which station contains one or more bad detectors. Because of this limitation, it is only used for identifications of good stations.

2.4 STATION VOLUME SELECTION RULES FOR COMPUTING AADT

For each station, three equivalent station volumes are daily available for computing AADT [24] as illustrated Figures 3. Therefore, there must be a rule for choosing a station volume from the available three stations. This section describes the selection rules developed and implemented in this project.

Let the daily station volume be denoted for *i*-th station on day *k* as *Sta_vol(i, k)*. Define the equivalent upstream and downstream volumes as *Sta_vol(i+1, k)* and *Sta_vol(i-1, k)*, respectively, i.e.,

Sta_vol(i+1, k) = equivalent upstream station volume of station i on day k,

Sta_vol(i, k) = current station volume of station i, on day k,

Sta_vol(i-1, k) = equivalent downstream station volume of station i on day k,

When station volumes are computed, a missing percent of the daily volume is also computed by dividing the total number of 30-second time slots with missing values. For example, if volume data in a day include 360 missing slots, the missing percent would be (360/2880)*100=12.5 percent since a single day has 2,880 30-second time slots. Let the missing percent of a station be denoted as:

Miss_per(i+1,k) = missing percent of *Sta_vol(i+1, k)*

Miss_per(i,k) = missing percent of *Sta_vol(i, k)*

Miss_per(i-1,k) = missing percent of *Sta_vol(i-1, k)*

This missing percent information is used to select a daily station volume out of three available values. Selection rules were established for the following four cases, which would cover all possible cases.

Case 1: All three station volumes include missing values, i.e., (*Miss_per(i,k)>0%),* (*Miss_per(i+1,k)>0%), and* (*Miss_per(i-1,k)>0%)*

Select a station volume that has minimum missing percent.

Case 2: All three stations are healthy and their daily volumes include zero missing values.

Use the average of the three station volumes as the station volume, i.e.,

[Sta_vol(i, k) + Sta_vol(i+1, k) + Sta_vol(i-1, k)]/3

Case 3: Only one station volume has zero missing values and the other two have missing values

Use the station volume with zero missing values.

Case 4: Two station volumes have no missing values.

Use the average of the two station volumes with zero missing values.

In summary, the above rule selects a station volume with minimum missing percent if all stations have missing percent. If there exist more than one station volumes with zero missing values, average of them are used as the station volume.

2.5 AADT COMPUTATION ALGORITHM

The software implementation of AADT computation in this project follows the algorithm published by AASHTO in 1992 referred often to as "average of averages" [25] and described here for clarification.

1. Compute day-of-week (DOW) ADT (average daily traffic) for each month, i.e., average volume of Sunday, Monday, Tuesday, Wednesday, Thursday, Friday, and Saturday of the month. This produces seven values for each month. Call these values ADT_DOW (i,j) where i=1,2,…,12 are months and j=1,2,…,7 are day-of-week. This produces 84 (12 x 7) values.

2. Compute an average ADT for each day-of-week across 12 months, i.e.,

   Avg_ADT_DOW(j) = $[\sum_{i=1}^{12} \mathrm{ADT\_DOW}\ (\mathrm{i}, \mathrm{j})]/12$ for j=1,2,…,7.

3. AASHTO_AADT = $[\ \sum_{j=1}^{7} \mathrm{Avg\_ADT\_DOW(j)}]/7$

All AADT values implemented in the software were computed using the above algorithm. In the Stations tab of the software, the rule described in Section 2.4 was used. In the Detectors tab, a user provides a list of detector IDs, and the software computes combined AADT of all detectors listed, which is called a station. Daily station volumes were excluded from AADT computation if it meets any of the following conditions.

- Station volume = 0. Zero station volumes can only occur if detectors were faulty or no vehicles passed through any of the detectors for the whole day. Since either case would introduce a strong bias to the average, it is excluded from computing the average.

- Station volume = -1. Negative one indicates that all volume data are missing and thus no valid data is included in the data; it is excluded from the AADT computation.

- Missing percent ≥ 20%. If a station volume was computed using more than 20 percent of missing data, it is excluded from the AADT computation because it could introduce a bias in the average. (Note: A missing-percent threshold, 20%, was used as the default value, and no effort was made

to verify this value due to limited time in this project. This limit was recommended by one of the MnDOT analysts.)

CHAPTER 3: IMPLEMENTATION OF DETECTOR-HEALTH SYSTEM

3.1 OVERALL SYSTEM

The final detector-health system developed in this project was designed as a client-server model, in that a single server serves many remote clients through Internet. This relation is illustrated in Figure 5. The clients remotely query the detector-health database housed in the server through Internet and support data needs of the client application. One main advantage of separating between clients from a server is that both side software can independently evolve over time, as long as the table structure of the database remains compatible with the client-side applications.

The server-side software comprises of a relational database, archived files of detector-health parameters, and a data maintenance program. For the relational database engine, a free version MySQL was used. This version still allows remote access of its databases through Internet. A software tool called "detHealth_daily.exe" was developed for the server-side software management. This program acquires raw detector data from the IRIS (Intelligent Roadway Information System) server managed by RTMC, computes all detector-health parameters, and then loads them to the MySQL database.

Protection of server data is important and must be addressed as part of the overall system maintenance strategy. Presently, detector-health parameters are produced as CSV (Comma Separated Values) files, archived, and then loaded to the server database. The table column structures of the CSV files precisely match with the tables in the database, allowing simple uploading or downloading from one to the other. By this process, backup of the server database is automatically created and archived in the storage. If the CSV files were stored in a network attached storage (NAS) with a RAID (Redundant Array of Inexpensive Disks) configuration, the CSV files would be well protected and served as a backup. The tables of database can be directly restored using the CSV files stored in NAS. Another protection needed is robustness and high availability of the server itself. Presently, the server was installed on a regular personal computer (PC) and placed in an empty table in the office of MnDOT TFA (Traffic Data Forecast and Analysis). In order to prevent any accidental shut down or catastrophic failure of the server, MnDOT is considering an option to move the server to a virtual machine (VM). Keeping the server at a VM would provide a much higher reliability and availability.

Presently, only one client software-package that installs "detHealth_app" has been developed and distributed to MnDOT in this project. The detHealth_app program can be installed on any user PCs inside the MnDOT firewall by just few mouse clicks and is available for download from a webpage provided by the PI of this project. All user interfaces of this software tool were designed using graphic user interface (GUI) to make it easy to use. This software provides detector-health classification, retrieval of detector-health parameters, historic parameter retrievals and visualization, station AADT computation, hourly and daily volumes, station search in a road map, r_node search and information retrieval, and mapping in a Google map. This software is further described in Section 3.5.

It should be noted that the MnDOT Internet firewall prevents any client trying to connect to the server from outside MnDOT network. However, clients running on any of the PCs inside the MnDOT firewall should be able to connect to the server even if the office is located outside Twin Cities.

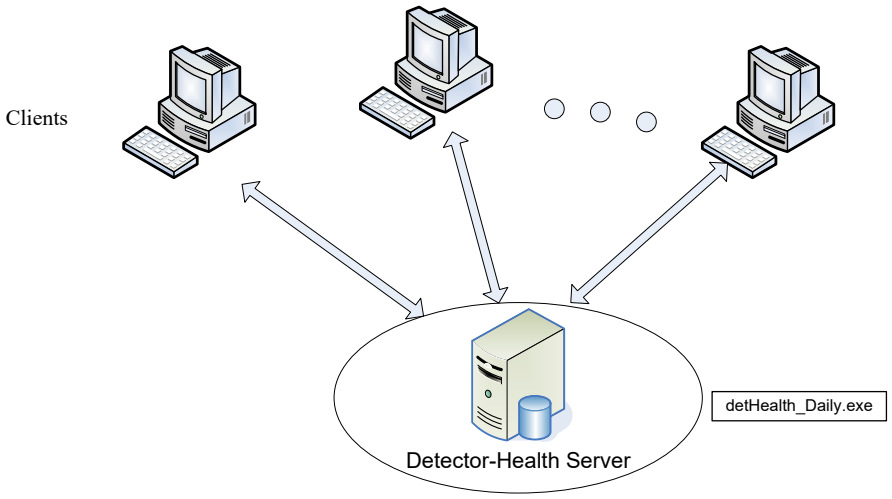


Figure 3.1: Client-server implementation of detector-health system

3.2 DATABASE IMPLEMENTATION AND TABLES

The database engine, MySQL, adopted for this project was an open-source relational database management system (RDBMS), presently owned and distributed by the Oracle Corporation. Among the various versions available, the MySQL Community Edition was installed in this project, which is free under General Public Licensing (GPL). Proprietary licensing versions include Oracle MySQL Cloud Service, MySQL Enterprise Edition, and MySQL Cluster CGE, which are all very powerful and used by many large corporations but not free.

MySQL allows creation of multiple databases, but only one database called “detectorhealth” was sufficient and created for this project. The main table of the database is the health_param table which consists of 25 columns defined in Table 2. In Table 2, each row corresponds to a column in the health_param database table. Each database record is equivalent to a single row in the equivalent CSV file and represents detector-health parameters of a single detector on a single day. The column indices 0 through 8 in Table 2 are used for identification of the detector and date, i.e., they consist of date, route, dir, station ID, r_node name, lane number, detector category, and currently abandoned or not. Uniqueness of the row is identified through three primary keys, which are date, r_node, and detector ID. Column indices 9 through 21 store the detector-health parameters for that day. Column 22 stores the traffic volume of the day and used for volume retrievals and AADT computations.

Column 24 stores healthLevel, which is a single character and initially determined by the user programmable threshold levels of health parameters. The entries of healthlevel are shown below; more details on the classification algorithm is described in subsection 3.3.3.

H=Healthy
T=Tolerable
I=Impaired
N=Nonfunctional
O=Offline (detectors currently offline)
G=Green counter (detector record used for green light counting of ramp)

Column 23, COV_ap, consists of two characters and keeps the status of how the COV principle application resulted in health level changes. The first character describes the result of health-level change by the first COV application, and the second character describes the result of second COV application using multiple r_nodes defined in COV_def. The first COV check is called r_node spatial-relation check. This process occurs within a single r_node and performs similarity checks of daily volumes when an r_node contains redundant detectors. For some r_nodes with n_type=Station, a single lane may contain multiple detectors within a close proximity. Examples include dual detectors installed for a speed trap or redundant installation due to construction or future uses. If multiple detectors in the same lane within a single r_node produce similar volumes after counting a whole day, the detectors are likely working correctly and the health-level is upgraded. Another case occurs when an r_node is an

Entrance node (n_type=Entrance). As shown in Figure 4, a fully configured Entrance node includes passage detectors (P), HOV bypass detectors (B), merge detectors (M), and queue detectors (Q). If all detectors were working correctly, the volume of P and B detectors combined should be close to the volume of Q detectors combined or M detectors combined. The test results are stored in the database using the characters defined by:

N = r_node spatial relation check or COV station test was not applicable.
S = health-level stayed same after checking r_node spatial relation or COV test
U = health-level was upgraded after checking r_node spatial relation or COV test
D = health-level was downgraded after checking r_node spatial relation or COV test
NN = Initialized default value.

The second COV test is performed when an r_node is a Station and has redundant equivalent upstream and downstream stations. The algorithm of this test was described in Section 2.3, and the result of the health-level change is specified in the second character of the COV_ap field using one of the four characters described above.

Table 2: Column Description of health_param Table

Column Index	Column Heading	Data Type	Null	Notes
0	det_date	date, primary key	Not null	Date of this detector-health parameter. Use format of "yyyy-MM-dd".
1	route	varchar(20), primary key	Not null	route name, e.g., "I-94"
2	dir	varchar(10)	null	route direction, e.g., "EB"
3	staID	varchar(20)	null	If n_type is not "Station", enter n_type, i.e., "Exit", "Entrance", "Intersection", or "Access", instead of station ID. If it is a Station but staID="", then fill in "Station"
4	r_node	varchar(20), primary key	Not null	r_node name, it is a string: ex, "rnd_87075"
5	detID	varchar(15), primary key	Not null	"name" attribute of detector in metro_config. T####=temporary detectors, R####=Rochester detectors, ####=TC normal detectors, where "####" denotes a numeric number
6	lane	varchar(1)	null	lane number, 1, 2, 3, ..., default="0"
7	det_cat	varchar(3)	null	detector category: A, B, G, M, P, Q, V, X, D, R, HT, CD, H, O, or default= ""
8	abandoned	varchar(1)	null	't' or 'f'

9	conZeroVol	int	Not null	Total number of 30sec time slots computed using consecutive zero-volumes extending 10 or more minutes. Assign -1 if vol file is missing.
10	negVolCnt	int	Not null	Total number of 30sec time slots with negative volumes. Special Case: -1= “missing vol file (offline)”
11	conZeroOcc	int	Not null	Total number of 30sec time slots computed using consecutive zero-occupancies extending 10 or more minutes. Assign -1 if occ file is missing.
12	negOccCnt	int	Not null	Total number of 30sec time slots with negative occupancies. Special Case: -1= “missing occ file (offline)”
13	occLockOn	int	Not null	Total number of consecutive 30sec time slots of 10 or more minutes in which occ is in the range of 99<occ≤100 percent. Special case: -1=“missing occ file (offline)”
14	zvolOnOcc	int	Not null	Total number of 30sec time slots in which the slots have zero-volume on a non-zero occupancy. -1= “missing vol or occ file (offline)”
15	overCnt	int	Not null	Total number of 30sec time slots with 25<vol<128. -1= “missing vol file (offline)”
16	highOcc	int	Not null	Total number of 30sec time slots with occ>35%. -1= “missing occ file (offline)”
17	constVol	int	Not null	Total number of consecutive 30sec time slots with (vol=Constant) where vol is in a valid range of 0<vol≤127. Consecutive time is defined as 10 or more minutes of continuous time for this parameter. -1= “missing vol file (offline)”
18	constOcc	int	Not null	Total number of consecutive 30sec time slots with (occ=Constant) where 0.2<occ<100. Consecutive time is defined as 10 or more minutes of continuous time (20 30sec slots). -1=”missing occ file (offline)”
19	volOnLowOcc	int	Not null	Total number of 30sec time slots with (vol>1 when 0≤occ≤0.2%). -1= “vol/occ file pair not available”

20	corrCoef	float4	Not null	Correlation Coefficient computed using 30sec vol and occ pairs. Assign corrCoef=0, if the denominator of the formula becomes zero. Assign corrCoef= -10 if vol/occ file pair not available.
21	volOccRatio	int	Not null	Total number of 30sec time slots violating the acceptable range of vol/occ ratio. -1= “vol/occ file pair not available”
22	detVol	int	Not null	Total detector-volume of the day. Exclude negative 30sec volumes (i.e., vol>127) in the total. -1= “missing vol file (offline)”
23	COV_ap	varchar(2)	null	COV application status. N= not applied or applicable, S=health level stayed same, U= health-level upgrade, D=health-level downgrade.
24	healthLevel	varchar(1)	null	H=Healthy, T=Tolerable, I=Impaired, N=Nonfunctional, O=Offline, G=Green counter

The second table the detectorhealth database is the COV_data table. This table stores the computational results of COV applied to r_nodes.

Table 3: Column description of "cov_data" Table in detectorhealth Database

Column Index	Column Heading	Data Type	Null	Notes
0	cov_date	date, primary key	Not null	format "yyyy-MM-dd"
1	r_node	varchar(20), primary key	Not null	r_node name
2	staID	varchar(15)	null	Station name
3	route	varchar(20)	null	route name, ex: "I-694"
4	dir	varchar(10)	null	route direction, ex: "WB"
5	cur_sta_vol	int	null	current station volume from selected detectors
6	cur_sta_conzero	int	null	conZeroVol added from the main station detectors
7	cur_sta_negcnt	int	null	negVolCnt added from the main station detectors
8	cur_offline	int	null	number of off-line detectors at the current station
9	cur_dets_selected	varchar(80)	null	list of detectors selected for curr_sta
10	up_sta_vol	int	null	upstream station volume
11	up_sta_conzero	int	null	conZeroVol added from the upstream detectors
12	up_sta_negcnt	int	null	negVolCnt added from the upstream station detectors
13	up_offline	int	null	number of off-line detectors at the upstream station
14	up_dets_selected	varchar(80)	null	list of detectors selected for up_sta
15	dn_sta_vol	int	null	downstream station volume
16	dn_sta_conzero	int	null	conZeroVol added from the downstream detectors
17	dn_sta_negcnt	int	null	negVolCnt added from the downstream station detectors
18	dn_offline	int	null	number of off-line detectors at the downstream station
19	dn_dets_selected	varchar(80)	null	list of detectors selected for dn_sta

20	lat	float8 (string)	null	current r_node latitude
21	lon	float8 (string)	null	current r_node longitude

Note:

9. The *cur_dets_selected* field follows the format of detector names separated by "/".

14. 19. The *up_dets_selected* and *dn_dets_selected* fields follow the detector list format used in the Table-4, COV_def table, columns 7 and 9.

3.3 DATA PROCESSING STEPS OF THE SERVER MANAGEMENT SOFTWARE (DETHEALTH_DAILY)

The server includes a MySQL database engine and a sever management program called detHealth_daily. This program is responsible for computing all detector-health parameters and then loading them to the detectorhealth database. This section describes how the raw detector data are internally processed by the server software, and then how the produced data are stored into the database. The details on user level description of this software are available from the user manual, "detHealth_daily: User Manual," which is available from the software download web page.

The detHealth_daily program is designed to run daily by a Windows scheduler. The server software is complex, and this section will attempt to describe the whole process by breaking them down to each process in subsections.

3.3.1 Step1: Download metro_config.xml

The first process of detHealth_daily is to download information related to all currently- available traffic detectors managed by RTMC. RTMC publishes most recent traffic detector information in their web site in a form of compressed file with filename, metro_config.xml.gz. This file is a well-structured xml file compressed using a gzip utility, which is a utility commonly available in UNIX or Linux operating systems (OS's). The record on when the content of this file changed is not available, and thus the history of new detector allocations or removal can only be kept track of by downloading and archiving the gzip file daily. Therefore, the first few steps are: download a metro_config.xml.gz file from the RTMC IRIS server, uncompress it, add a timestamp in the file, and save to a storage. The filename is given a format of

metro_config.yyyymmdd.xml

where yyyy is a four-digit year, mm is a two-digit month, and dd is a two digit day. The folder for storing this file can be set by user using the "Settings/Parameters" menu, but it is typically saved in the folder with name "~/traffic/defines/metro_config/" in a file system. If a NAS is available, it should be stored in a NAS since it is a critical file.

Each metro_config.xml file contains an xml data tree with hierarchically structured. At the top, the whole roadway network is defined by a set of corridors, and then each corridor is defined by a road name such as 'I-35E' and a direction attribute such as 'SB'. Consequently, each corridor represents only one direction of the road. The basic structure is described using an example, I-35E. The highway, I-35E, consists of two corridors, 'I-35E SB' and 'I-35E NB'. Each corridor is then defined using a set of r_nodes that represent the following types at a location on the corridor.

- "Station" (default and means Main),
- "Exit"
- "Entrance"
- "Intersection"
- "Access"
- "Interchange"

One of the useful attributes of r_node in developing application is the GPS location information, expressed in longitude and latitude. It can be used to pinpoint in a map where the r_node is and the detectors belong to that location. Each r_node is next defined through nested elements. The following xml shows an r_node defined for an entrance ramp in I-35E SB.

```
<r_node name='rnd_94495' n_type='Entrance' pickable='t' transition='Leg' label='Co Rd 14' lon='-
93.03155' lat='45.16164' lanes='1' shift='6' s_limit='70'>
   <detector name='4973' label='35E/CR14SG' category='G'/>
   <detector name='6412' label='35E/CR14SM' category='M' controller='ctl_95515'/>
   <detector name='6445' label='35E/CR14SB' category='B' controller='ctl_95515'/>
   <detector name='6446' label='35E/CR14SQ1' category='Q' lane='1' controller='ctl_95515'/>
   <detector name='6447' label='35E/CR14SQ2' category='Q' lane='2' controller='ctl_95515'/>
   <meter name='M35ES26' lon='-93.03196' lat='45.16266' storage='445'/>
 </r_node>
```

Detector categories summarized in Table 4 can be seen here as a category attribute in the xml statement. Detector category information is critical for the data processing and will be used in future descriptions. Another important information used is the lane numbers, which was used in deriving relationships of lanes for applying the COV principle.

Table 4: Detector Category

Category	Description
A	Auxilliary detector
B	HOV bypass
G	Count frame meter (number of greens)
M	Merge detector of ramp
P	Passage detector
Q	Ramp queue meter
V	Speed trap
X	Exit Detector of ramp
D	Shoulder
R	Reversible
HT	HOT lane
CD	Collector/Distributor lanes (local-express lanes)
H	HOV lane
O	Bus only lane
“”	Blank, main lane default or not defined

3.3.2 Step2: Derive three equivalent detector sets for each r_node

After downloading a metro_config.xml file for the day, the program analyzes each corridor and r_nodes in the corridor to determine equivalent detector sets. For each r_node with n_type=Station, equivalent upstream and downstream station volume relations described in Section 2.3 and Figure 3 are derived from the metro_config.xml file of the day. This result is saved as a CSV file with a timestamped filename given by:

COV_def.yyyymmdd.csv

This file is saved in the folder “~/traffic/defines/COV_def/” and the timestamp matches with the corresponding metro_config. yyyymmdd .xml file. The data processing is done by one corridor at a time, and the following rules are applied in deriving a COV_def file.

- Create a list of r_nodes in the order defined in the metro_config.xml file for the given route and direction. Exclude r_nodes with active=’f’. Exclude all n_type=’Station’ with no detectors. Include all n_type=’Entrance’ and ‘Exit’ even if they have no detectors. Exclude all r_nodes with n_type = ‘Intersection’ or ‘Access’.

- Pick three consecutive Station nodes. Label them upstream, current and downstream stations following the lane traffic direction.
- Derive r_node relations using Exit and Entrance nodes between consecutive Stations by following the COV principle described using Eq. (5) and (6) in Section 2.3. Create a list of the detectors corresponding to each r_node including signs determined by Eq. (5) and (6).

Table 5 describes each column of a COV_def CSV file. This table is constructed based on r_nodes, and the columns 0 – 4 are used as the identity of the current r_node, which are def_date, r_node name, station ID (staID), route, and direction (dir). To define upstream and downstream equivalent stations, a list of r_nodes are provided using a separator "&" and "+" or "-" sign, under the column headings of *up_rnodes* and *dn_rnodes*. For an r_node description, sign prefix is required even for "+". The following shows an example.

+rnd_2345&-rnd_34449&+rnd_0899

This string instructs that volumes of r_nodes, rnd_2345 and rnd_0899, must be added, while the volume of rnd_34449 must be subtracted to compute the total station volume. These r_node relations are translated into a list of detectors and then stored in column names: *cur_det_list, up_det_list*, and *dn_det_list*.

The data type of *cur_det_list* column is a text string, and it consists of detector names of the current station separated by "/". For example, if string of a current station was "2345/4567/2346", the station has detectors with names, "2345", "4567", and "2346". All of them are expressed without sign and takes positive sign by default, because the current node is always a station. If a lane has more than one detector, all detectors must be listed, but it does not have to follow the order of lane numbers.

Detector lists stored in *up_det_list*, and *dn_det_list* columns use a more complex syntax. Since station volumes are a function of r_nodes and its node types (n_type), it specifies n_type followed by a list of detectors of that r_node. The final n_type prefixes used are S= "Station", E= "Entrance", and X= "Exit" with all capital letters. Separator "&" divides r_nodes and "/" divides detectors. A plus sign ("+") indicates addition while a negative sign ("–") indicates subtraction in computing the r_node volumes from the total station volume, and the signs are only applied at the r_node level (i.e., not detector level). An example string of an equivalent station with two entrance nodes and one exit node is given by:

+S2456/3457/3458/T5687&-E456/457/458/T5687&-E678/8974/345&+X2456/3457

The volume of this station is computed by:
Station_volume = vol(2456) + vol(3457) + vol (3458) + vol(T5687) - vol (456) - vol (457) – vol(458) – vol(T5687) – vol(678)-vol(8974) – vol(345) + vol(2456) + vol(3457)
where vol(####) denotes a single day volume of detector name "####".

Some Exit and Entrance nodes may not have any detectors, and thus a syntax with no detectors are allowed. For example, "+S2435/345&-E&+X" is acceptable and indicates that the Entrance and Exit r_nodes do not have any detectors. For this specification, all "G" detectors are excluded in the detector list, since G detectors are not traffic detectors but counters used for storing a number of green light counts occurred in a freeway Entrance ramp.

Table 5: COV Defines Table

Column Index	Column Heading	Data Type	Null	Notes
0	def_date	date, primary key	Not null	the date of metro_config file used to produce this file
1	r_node	varchar(20), primary key	Not null	r_node name, only n_type=Station
2	staID	varchar(10)	null	Station name. If staID="", leave it as blank
3	route	varchar(20), primary key	not null	route name, ex: I-694
4	dir	varchar(10), primary key	not null	direction of the route
5	cur_det_list	varchar(80)	null	list of all detector names defined in the current station
6	up_rnodes	varchar(80)	null	list of equivalent upstream r_nodes
7	up_det_list	varchar(120)	null	detector list of equivalent upstream station
8	dn_rnodes	varchar(80)	null	list of equivalent downstream r_nodes
9	dn_det_list	varchar(120)	null	detector list of equivalent downstream station
10	lat	float8 (string)	null	current r_node latitude
11	lon	float8 (string)	null	current r_node longitude

3.3.3 Step 3: Compute all detector-health parameters

The parameters specified in the columns 9 -24 in Table 2 are computed using the raw volume and occupancy data queried and received from the IRIS server. For this computation, threshold values of the health-level classifier described in Figure 2 are first read in from a file. This table is user programmable and saved in a CSV format given in Table 6. The file is stored in the "~/traffic/defines/health_thresholds/" folder and has a timestamp in the middle of the filename; the file name takes the following format:

thresholds.yyyymmdd.csv

The same timestamp convention used in metro_config and COV_def files are applied here. The column headings of this table is specified in Table 6. Thresholds in columns 4-6 are illustrated in Figure 6. Notice that health levels, -1, 4, and 5 are not determined through the thresholding process.

Table 6: Column Headings of Health Parameter Thresholds

Column Index	Column Heading	Data Type	Null	Description
0	parameter	varchar(20), primary key	Not null	Detector-health parameter
1	ver_date	datetime, primary key	Not null	date of table valued entered
2	ver_num	int, primary key	Not null	threshold table version number
3	active	varchar(1)	Not null	't' or 'f' for active or inactive for the classification algorithm
4	th_3to2	int	null	level 3, if param>th_3to2, -1="do not use"
5	th_2to1	int	null	level 2, if param>th_2to1, -1= "do not use"
6	th_1to0	int	null	level 0, if param < th_1to0, -1= "do not use"

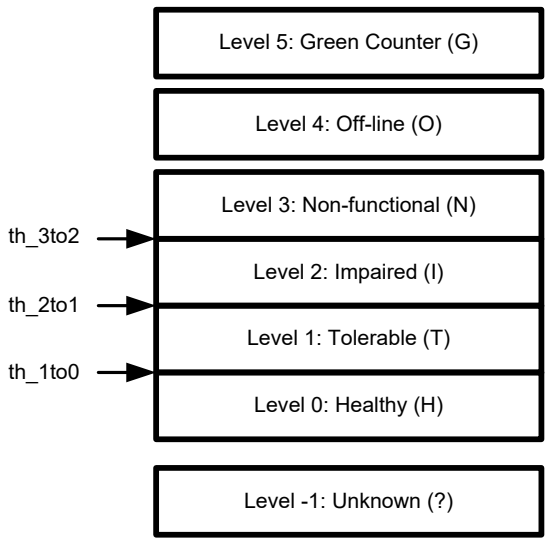


Figure 3.2: Numerical and a single-letter representation of Health levels and the three thresholds defined between four health levels

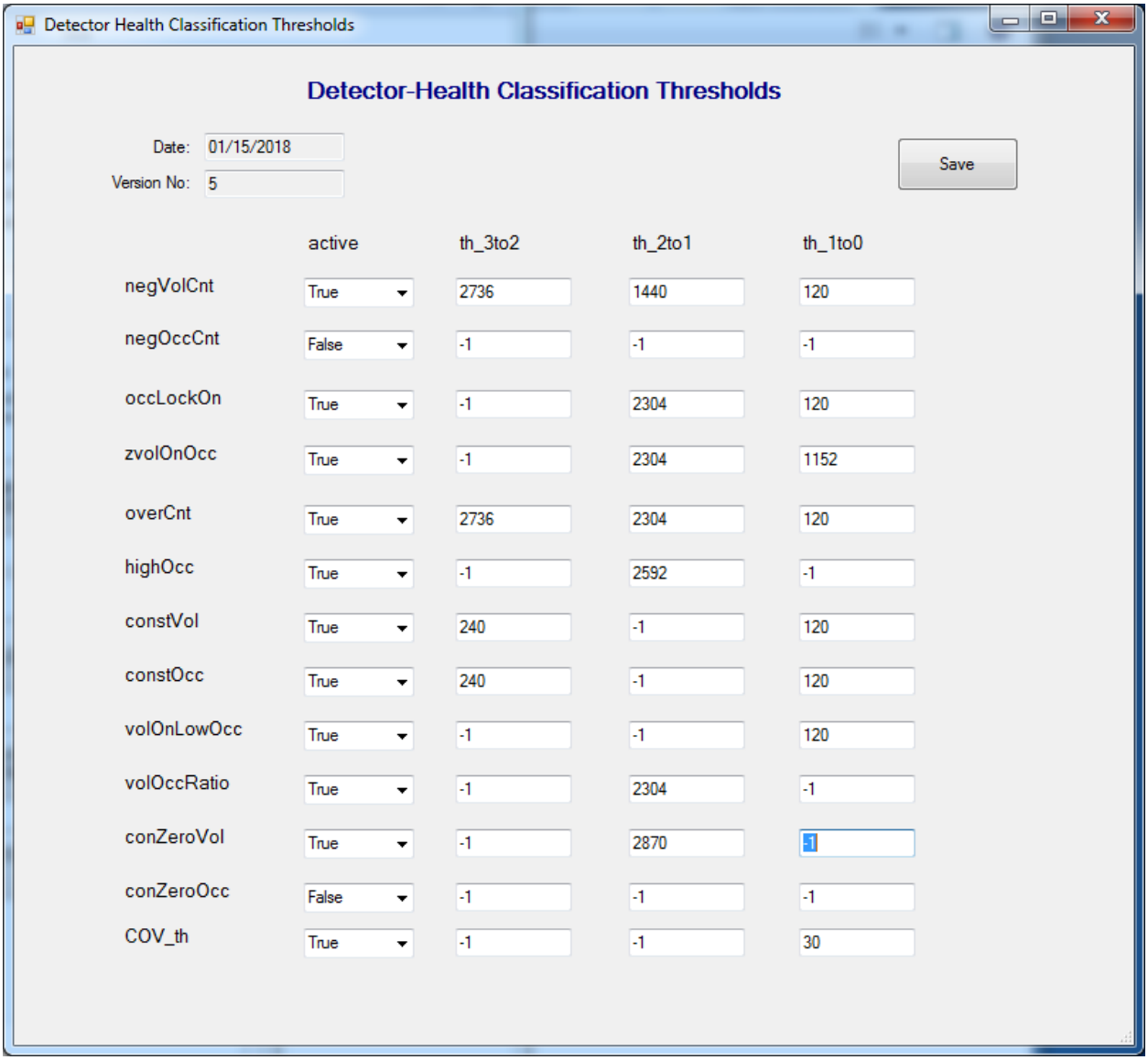


Figure 3.3: Settings window available in detHealth_daily for programming threshold levels

Threshold levels are designed to be programmable by user using the settings window shown in Figure 7. It should be noted that entry "-1" means that the corresponding threshold is not used. Below describes the actual implementation of the thresholding processes in the health level (HL) classification applied in detHealth_daily.exe. A general rule is given first and then then details of each case is described.

- Test is performed starting from HL=4 and then moved down to the next lower level. The cases survived the last test become HL=0 (healthy).
- All if-conditions per given HL are in OR relationship, i.e., if any of the listed conditions is met, it selects the assigned HL.

HL =5 (G), if

Detector category (det_cat) = G, special case, not programmable

else continue

HL =4 (O), if

negVolCnt=-1, special case, not programmable

else continue

HL =3 (N), if

1. zVolOnOcc=2880, special case, not programmable
2. conZeroVol=2880 for five or more days (not implemented yet)

else continue

HL =3 (N), if

1. negVolCnt > 2736 (95%), negVolCnt.th_3to2=2736
2. negOccCnt > 2736 (95%), negOccCnt.th_3to2=2736
3. occLockOn: not used, occLockOn.th_3to2= -1
4. zVolOnOcc: not used, zVolOnOcc.th_3to2= -1
5. overCnt > 2736 (95%), overCnt.th_3to2=2736
6. highOcc: not used, highOcc.th_3to2= -1
7. constVol >240 (2hr), constVol.th_3to2=240
8. constOcc > 240 (2hr), constOcc.th_3to2=240
9. volOnLowOcc: not used, volOnLowOcc.th_3to2= -1
10. volOccRatio: not used, volOccRatio.th_3to2= -1
11. conZeroVol: not used, conZeroVol.th_3to2= -1
12. conZeroOcc: not used, conZeroOcc.th_3to2= -1
13. COV_th: not used, COV_th.th_3to2= -1

else continue

HL = 2 (I), if

1. (conZeroVol + negVolCnt)=2800 and negVolCnt>5, not programmable
2. negVolCnt > 1440 (50%), negVolCnt.th_2to1=1440
3. negOccCnt: not used, negOccCnt.th_2to1= -1
4. occLockOn > 2304 (80%), occLockOn.th_2to1=2304
5. zVolOnOcc > 2304 (80%), zVolOnOcc.th_2to1=2304
6. overCnt > 2304 (80%), overCnt.th_2to1=2304
7. highOcc > 2592 (90%), highOcc.th_2to1=2592
8. constVol : not used, constVol.th_2to1= -1
9. constOcc : not used, constOcc.th_2to1= -1
10. volOnLowOcc: not used, volOnLowOcc. th_2to1= -1
11. volOccRatio> 2304 (80%), volOccRatio.th_2to1=2304
12. conZeroVol>2870 (99%), conZeroVol.th_2to1 = 2870
13. conZeroOcc: not used, conZeroOcc.th_2to1 = -1
14. COV_th: not used, COV_th.th_2to1= -1

else continue

HL = 1 (T), if

1. negVolCnt > 120 (1hr), negVolCnt.th_1to0=120
2. negOccCnt: not used, negOccCnt.th_1to0= -1
3. occLockOn > 120 (1hr), occLockOn.th_1to0=120
4. zVolOnOcc > 1152 (40%), zVolOnOcc.th_1to0=1152
5. overCnt > 120 (1hr), overCnt.th_1to0=120
6. highOcc: not used, highOcc. th_1to0= -1
7. constVol > 120 (1 hr), constVol.th_1to0=120
8. constOcc > 120 (1 hr), constOcc.th_1to0=120
9. volOnLowOcc > 120 (1 hr), volOnLowOcc.th_1to0=120
10. volOccRatio: not used, volOccRatio.th_1to0= -1
11. conZeroVol: not used, conZeroVol.th_1to0 = -1
12. conZeroOcc: not used, conZeroOcc.th_1to0 = -1
13. COV_th>30%, COV_th.th_1to0= 30 (algorithm includes more conditions)

else

HL = 0 (H), remaining cases.

The final output file is created as a CSV formatted file that exactly matches with the columns defined in Table 2. The file name follows the same timestamp convention with the "health_param" prefix, which is shown below.

health_param.yyyymmdd.csv

This file is save in the default folder, "~/traffic/processed/det_health_param/", or in a user defined folder.

3.3.4 Step 4: Apply COV rule-checks for applicable r_nodes

After computation of all parameters as described in Section 3.3.3, HL is first adjusted based on COV relations within a single r_node. The first character of COV_ap parameter represents the result of this step. There are two cases, when n_type='Station' and more than one detectors per lane exist, and when n_type= 'Entrance'. The rules for using spatial relations are described below.

(1) n_type='Station'

A. If a lane has only a single detector, do nothing

B. If a lane has more than one detector (commonly two):

Let the two detector volumes be denoted x and y.

(i) if x=-1 or y=-1, do nothing

(ii) if x=y=0 and *negVolCnt*<negVolCnt.th_1to0, assign HL="T"

(iii) if x=0 and y<>0, assign HL="I"

Otherwise, compute the difference ratio,

$$\alpha = \frac{|y-x|}{(x+y)/2}$$

(iv) if α<0.2, assign both HL="H"

(v) if 0.2≤ α<0.35, assign HL="T", else HL="I"

(vi) assign the value of COV_ap according to the HL change made (U, D, or S depending on the change by this process)

(2) n_type = 'Entrance'

(i) If det_cat = "B" or "O" and *negVolCnt* < negVolCnt.th_1to0, then HL="H".

(ii) If HL of all detectors consist of only "H" and "O", do not change and exit.

(iii) Spatial relation test. (For volume totals, do not add detVol=-1)

-- Add volumes of all P's and B's, and call *PB_vol*

--Add volumes of all Q's and call *Q_vol*

--Add volumes of all M's and call *M_vol*

Check if *PB_vol*≈ *Q_vol*≈ *M_vol* and *negVolCnt*< negVolCnt.th_1to0, then upgrade the corresponding detectors to HL="H". A similarity requirement is satisfied when the differences are less than 10% (default value).

(3) n_type = 'Exit'

If det_cat = "O" and *negVolCnt* < negVolCnt.th_1to0, then assign HL="H" else no change.

3.3.5 Step 5: Adjust HL according to COV tests for r_nodes with main-lane stations

In Step 4, COV was used within a single r_node when redundant detectors with equivalent traffic flows are available. In Step 5, the COV principle is applied in three equivalent traffic-flow stations in main lanes. The equivalent stations consist of three stations: current station, equivalent upstream station, and equivalent downstream station. How to add or subtract certain detector volumes to maintain the equivalency between the three stations was described in Section 2.4, and the actual detector volume relations among associated detectors are defined in the "COV_def.yyyymmdd.csv" file that matches the date. The computed data according to a "COV_def.yyyymmdd.csv" file is saved in a COV_data.csv file with the same timestamp included in the COV_def filename, i.e.,

COV_data.yyyymmdd.csv

This file is archived in the "~/traffic/processed/COV_data/" folder and later loaded to the database table *cov_data*.

To test if the stations met the requirement of COV rule or not, another intermediate data file is produced. Let three consecutive equivalent station volumes be denoted: *up_vol*, *cur_vol*, and *dn_vol*. For similarity measurements, normalized difference ratios are computed following the steps below.

- Two volumes are considered similar if the *difference ratio* is less than 0.05 when the difference ratio between *v1* and *v2* is computed as:
  $diff\_ratio(v1, v2) = |v1 - v2|/(\frac{v1+v2}{2})$
- Compute *diff_ratio(up_vol, cur_vol)* and *diff_ratio(cur_vol, dn_vol)*

Detectors are considered healthy if the resulting *diff_ratio* is less than 0.05, and they are listed under the column heading *good_dets*. For example, if *diff_ratio(up_vol, cur_vol)* is less than 0.05, all detectors involved in the current and upstream stations are considered to be candidates for HL upgrade. To save *diff_ratio* data, a CSV file is created with its data formatted with the columns defined in Table 7. Its filename starts with "COV_diffRatio" followed by a timestamp of the date, i.e.,

COV_diffRatio.yyyymmdd.csv

This file is stored in the "~/traffic/processed/COV_data/" folder. The detectors listed under the column heading, *good_dets,* satisfy the COV rule and are the detectors to be upgraded to HL=H.

Table 7: Column Headings and Data Types of COV_diffRatio.csv Table

Column Index	Column Heading	Data Type	Null	Notes
0	route	varchar(20), primary key	not null	route name, ex: I-694
1	dir	varchar(10), primary key	not null	direction of the route
2	r_node	varchar(10), primary key	not null	r_node representing current node
3	up_cur_ratio	float4	null	Difference of ratio between upstream and current station volumes. Format ("F5")
4	cur_dn_ratio	float4	null	Difference of ratio between downstream and current station volumes. Format ("F5")
5	good_dets	varchar(120)	null	a list of detectors that are found to be HL="H" according to the COV test.

In order to keep track of which detectors are upgraded following the main lane COV rules, the detectors upgraded are listed in **COV_upgradeDets.yyyymmdd.csv** in which each line is the state before upgrade. An example of this file is shown in Figure 8, which is the content of the file for May 30, 2019. Again, it contains the record of each detector before upgraded to H.

```
det_date,route,dir,staID,r_node,detID,lane,det_cat,abandoned,conZeroVol,negVolCnt,conZeroOcc,negOccCnt,occLockOn,zvolOnOcc,Over
Cnt,highOcc,constVol,constOcc,volOnLowOcc,corrCoef,volOccRatio,detVol,COV_ap,healthLevel
2019-05-30,I-35E,NB,Exit,rnd_87679,3377,0,X,f,2880,0,2880,0,0,0,0,0,0,0,0,0.000000,0,0,N,I
2019-05-30,I-35W,NB,S1702,rnd_168,6911,1,,f,0,1165,0,1165,0,3,0,0,0,0,0,0.972324,1171,16175,N,T
2019-05-30,I-35W,NB,S1702,rnd_168,6912,2,,f,0,1165,0,1165,0,0,0,0,0,0,0,0.965952,1172,15095,N,T
2019-05-30,I-35W,NB,S1702,rnd_168,6913,3,HT,f,0,1165,0,1165,0,0,0,0,0,0,0,0.972900,1171,11335,N,T
2019-05-30,I-35W,NB,S38,rnd_86379,271,1,,f,0,1160,0,1160,0,0,0,0,0,0,0,0.975868,1166,16216,N,T
2019-05-30,I-35W,NB,S38,rnd_86379,272,2,,f,0,1160,0,1160,0,0,0,0,0,0,0,0.964144,1166,15103,N,T
2019-05-30,I-35W,NB,S38,rnd_86379,541,3,HT,f,0,1160,0,1160,0,2,0,0,0,0,0,0.989233,1170,9590,N,T
2019-05-30,I-35W,NB,S40,rnd_86391,275,1,,f,0,0,0,0,0,0,0,39,0,0,0,0.765087,49,23886,D,I
2019-05-30,I-35W,NB,S55,rnd_95787,5963,1,,f,2876,0,2876,0,0,0,0,0,0,0,0,0.827297,1,4,N,I
2019-05-30,I-35W,NB,S58,rnd_86483,322,4,,f,2880,0,2880,0,0,0,0,0,0,0,0,0.000000,0,0,N,I
2019-05-30,I-35W,NB,S58,rnd_86483,6792,5,HT,f,2880,0,2880,0,0,0,0,0,0,0,0,0.000000,0,0,N,I
2019-05-30,I-35W,NB,ST519,rnd_5771,T3521,1,HT,f,0,818,1683,818,0,0,6,0,0,0,1855,0.000000,818,16691,N,T
2019-05-30,I-35W,NB,S62,rnd_86499,T3506,1,,f,0,1572,0,1572,0,0,0,0,0,0,1072,0.000000,1572,16946,S,I
2019-05-30,I-35W,NB,S664,rnd_87489,2734,3,,f,2880,0,2880,0,0,0,0,0,0,0,0,0.000000,0,0,N,I
2019-05-30,I-35W,SB,S678,rnd_87787,2785,1,,f,2880,0,2880,0,0,0,0,0,0,0,0,0.000000,0,0,N,I
2019-05-30,I-35W,SB,S29,rnd_88039,252,1,,f,0,1160,0,1160,0,0,0,2,0,0,0,0.939849,1168,15115,N,T
2019-05-30,I-35W,SB,S29,rnd_88039,253,2,,f,0,1160,0,1160,0,0,0,8,0,0,0,0.927724,1165,18723,N,T
2019-05-30,I-35W,SB,S29,rnd_88039,1001,3,HT,f,0,1160,0,1160,0,0,0,0,0,0,0,0.980668,1168,11488,N,T
2019-05-30,I-35W,SB,S1715,rnd_177,6908,1,,f,0,1167,0,1167,0,0,0,3,0,0,0,0.935885,1172,15291,N,T
2019-05-30,I-35W,SB,S1715,rnd_177,6909,2,,f,0,1167,0,1167,0,1,0,12,0,0,0,0.931156,1169,18875,N,T
2019-05-30,I-35W,SB,S1715,rnd_177,6910,3,HT,f,0,1167,0,1167,0,2,0,0,0,0,0,0,0.978746,1168,12036,N,T
2019-05-30,I-394,EB,S284,rnd_88327,793,1,,f,0,0,0,8,0,0,0,255,0,0,0,0.452633,36,23199,D,T
2019-05-30,I-694,WB,S178,rnd_87149,16,3,,f,2880,0,2880,0,0,0,0,0,0,0,0,0.000000,0,0,N,I
2019-05-30,I-694,WB,S176,rnd_87153,762,3,,f,2880,0,2880,0,0,0,0,0,0,0,0,0.000000,0,0,N,I
2019-05-30,T.H.36,WB,S589,rnd_86737,2304,2,,f,2880,0,2880,0,0,0,0,0,0,0,0,0.000000,0,0,N,I
2019-05-30,T.H.36,WB,S612,rnd_86739,2336,2,,f,2880,0,2880,0,0,0,0,0,0,0,0,0.000000,0,0,N,I
2019-05-30,T.H.52,SB,Exit,rnd_89735,5554,0,X,f,2880,0,2880,0,0,0,0,0,0,0,0,0.000000,0,0,N,I
2019-05-30,T.H.61,NB,Exit,rnd_1586,7497,0,X,f,234,166,234,166,0,11,0,0,0,0,0,0.945813,195,2018,N,T
2019-05-30,T.H.61,NB,S1931,rnd_1585,7453,1,,f,0,166,0,166,0,3,0,0,0,0,0,0.944255,187,14650,N,T
2019-05-30,T.H.61,NB,S1931,rnd_1585,7454,2,,f,0,166,0,166,0,7,0,0,0,0,0,0.981343,170,10987,N,T
2019-05-30,T.H.61,SB,S1896,rnd_1266,7378,1,,f,0,166,0,166,0,6,0,0,0,0,0,0.951461,187,14662,N,T
2019-05-30,T.H.61,SB,S1896,rnd_1266,7379,2,,f,27,166,27,166,0,4,0,0,0,0,0,0.986732,170,11709,N,T
2019-05-30,T.H.61,SB,Entrance,rnd_1573,7487,0,M,f,303,166,303,166,0,11,0,0,0,0,0,0.940157,229,2004,N,T
```

Figure 3.4: COV_upgradeDets.20190530.csv

To illustrate the HL changes, the final detector records in the file health_param.20190530.csv are shown in Figure 9 (only for the first four detector records in Figure 8). Notice that health levels are upgraded to H from I or T. It can be also seen that COV_ap column is set to “NU” in which “N” indicates that HL was not modified from the single r_node COV algorithm but “U” indicates that HL was upgraded after application of the COV rule on the main-lane stations.

```
det_date,route,dir,staID,r_node,detID,lane,det_cat,abandoned,conZeroVol,negVolCnt,conZeroOcc,negOccCnt,occLockOn,zvolOnOcc,Over
Cnt,highOcc,constVol,constOcc,volOnLowOcc,corrCoef,volOccRatio,detVol,COV_ap,healthLevel
2019-05-30,I-35E,NB,Exit,rnd_87679,3377,0,X,f,2880,0,2880,0,0,0,0,0,0,0,0,0.000000,0,0,NU,H
2019-05-30,I-35W,NB,S1702,rnd_168,6911,1,,f,0,1165,0,1165,0,3,0,0,0,0,0,0.972324,1171,16175,NU,H
2019-05-30,I-35W,NB,S1702,rnd_168,6912,2,,f,0,1165,0,1165,0,0,0,0,0,0,0,0.965952,1172,15095,NU,H
2019-05-30,I-35W,NB,S1702,rnd_168,6913,3,HT,f,0,1165,0,1165,0,0,0,0,0,0,0,0.972900,1171,11335,NU,H
```

Figure 3.5: Health level upgrades applied in health_param.20190530.csv for the first four detectors in Figure 3.4.

3.3.6 Step 6: Upload health_param and COV_data to the MySQL detectorhealth database

The final computed records in CSV files (health_param.yyyymmdd.csv and COV_data. yyyymmdd.csv) for the day of computation are one-to-one matches with the corresponding database entries, and they are directly loaded to the detectorhealth database, using two steps: (1) if old data exists for the same day, delete it first, (2) load the latest data computed. These two steps ensure that only the most-recently computed data are loaded to the database.

For loading data to MySQL tables, loading each row at a time is not efficient and time consuming. A more efficient way is used. The solution is use of an import function in MySQL, and it directly loads the CSV file in bulk to the corresponding table. Only restriction of this approach is that it voids if duplicate records are found, determine by primary keys. This problem is resolved, if the old data are removed before importing. This operation is robust and runs much faster than individual loading of records. Below shows an example of MySQL script used for importing one-day data, which was health_param for Nov 15, 2018. A similar script was used for COV_data.

```
use detectorhealth;
load data local infile 'Y:\\traffic\\processed\\det_health_param\\2018\\health_param.20181115.csv'
into table health_param
fields terminated by ','
lines terminated by '\r\n'
ignore 1 lines;
```

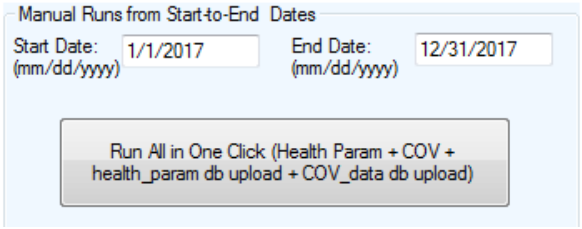
Figure 3.6: MySQL script for importing one day of health_param data file

A total run time for a single day computation and uploading to the database took about 4 minutes of processing time on a PC with i7 CPU that runs on 3.6 GHz clock and 16GB RAM. This processing time is highly dependent on Internet traffic and speed but it took less than 5 minutes in most cases.

3.4 FUNCTIONS OF SERVER MANAGEMENT SOFTWARE

Manual management of the detector-health database would be time consuming and tedious. In order to simplify the sever management operations, a utility program, detHealth_daily.exe, was developed to automatically control all data processing steps and management of the MySQL database in the server, i.e., all steps are automated and it runs once daily through a Windows scheduler. This section briefly describes the features of this software and utilities. The details on how to use this program is available on-line through a user manual.

Figure 11 shows the GUI of detHealth_daily.exe that is used for illustration. This tool can be used for two types of runs, manual and scheduled. For manual runs, user selects a date from the DateTimePicker provided and presses the "One Day Manual Run" button. This will compute all required parameters for the selected date and then load them to the database. The "Auto Run" button processes (computes and upload daily data to database) data for one day at a time from the last ending date set in the Settings to the most recent day (yesterday). This function is called by the Windows Scheduler when daily scheduled-runs are triggered. When it is manually used, this function allows the process to fill in the database to the most recent date. For example, suppose that the RTMC IRIS server or the database server failed for several days. Then, the database must be populated from the date of failure to the most recent day, and a single press of the "Auto Run" button will do the job for populating the missing data. There is also a need for creating or restoring data for a specific period defined by user. Suppose that the database was failed for some reason for a specified period. In such a case, the user should be able to run and restore data for a specific period. Another case would be to create past data for a period where data was never created. For these cases, a manual run function for a period defined by Start and End dates is used, and it can be executed using the interface shown below.



The "**Run All in One Click(...)**" button function goes through five steps for producing and storing health-parameters: (1) compute health-parameters, (2) compute COV_def file, (3) compute COV_data and adjust HL, (4) upload health-parameters to database, and (5) upload COV_data to database. These individual steps can be run for the given period, one-step at a time using the individual buttons provided

in the lower half of the groupbox labeled “Manual Runs from Start-to-End Dates.” It should be cautioned that Steps 1-3 must run by following the numerical order provided, i.e., (1), (2), and (3). One scenario that these partial steps could be useful is when the database failed but detHealth_daily ran, resulting successful production of all health parameters. In this case, steps (4) and (5) could be used to restore the data.

The second tab (named Test Functions) provides several utilities, mostly for manually testing of the database. It includes a test function for downloading the most recent metro_config file and six buttons for database content tests. These tests are all designed to inquire and test a single day data specified in the date textbox. The first four buttons are to get answers or to take an action related to health_param in the database. This should be mainly used by a database administrator to check if the processing was run for a certain date and then to take actions. Here are four tests corresponding to the four buttons.

- “Do health-parameters for the given date exist in the database?” This button is used to check if the data for the Date textbox exists in the database.
- “Upload the health-parameter data (in the form of CSV) available for the given date to database.” This button uploads the health_param.yyyymmdd.csv data in the detector-health parameter folder to the database, corresponding to the Date textbox.
- “Delete the health-parameters from the database for the given date.” This button deletes all detector-health parameters specified in the Date textbox.
- “If data exist in DB for the given date, delete them first then upload.” This button deletes the health-parameters that already exist in the database for the date given in the Date textbox and then loads fresh new data for the same date from the detector-health parameter folder.

Existence test and delete functions exist for the COV database. The two buttons available are:

- “Does COV_data exist in DB for the given date?”
- “Delete the given date of COV_data in the database.” This button checks existence of COV_data for the date in the Date textbox, and then deletes them if they exist.

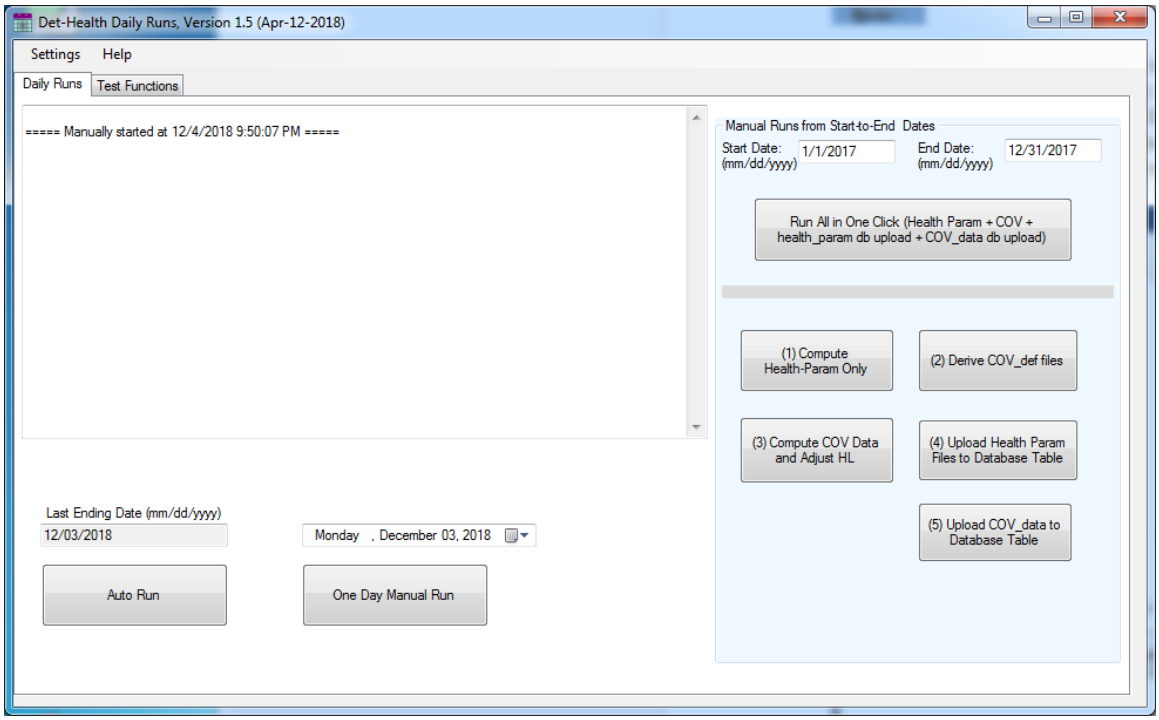


Figure 3.7: Server management software, detHealth_daily

3.5 CLIENT SOFTWARE: DETHEALTH_APP

A client software tool, called “detHealth_app,” was created to provide a data tool that utilizes the detector-health database. This utility was designed as an exploration tool for detector and station level data for up to one year from the ending date entered by user. It also provides utilities with map interfaces to give spatial information of detectors and stations. Since a separate user manual entitled “detHealth_app: User Manual” is available on line, only the key features of the software are described.

detHealth_app currently consists of four tabs and its screen capture is shown in Figure 12. Functions available in each Tab are described based on the Version 2.1 (May 17, 2019). This software continuously evolves as the MnDOT needs change over time, and future versions will likely be different from the one described here.

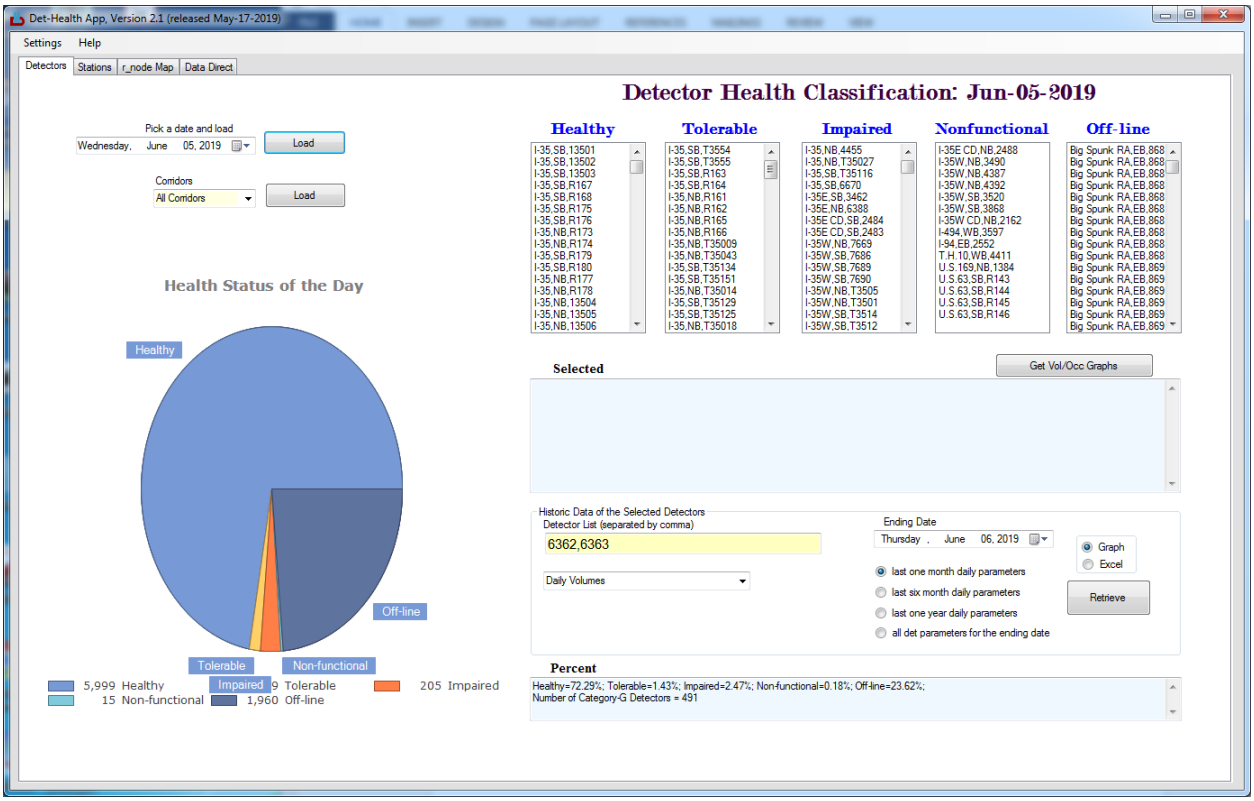


Figure 3.8: First tab of detHealth_app

Tab 1: Detectors. This tab provides a pie chart and listboxes of detector classification for the date selected by the DateTimePicker tool. Five listboxes are provided for five classes: Healthy, Tolerable, Impaired, Nonfunctional, and Off-line. Pressing any of the detectors in the list immediately displays all detector-health parameters of the day in the Selected Detector textbox. The first tab also includes a utility for retrieving historical data. This utility is controlled using the selection tools in the groupbox labeled "Historic Data of the Selected Detectors" and multiple detectors can be listed with comma separation in the Detector List textbox. The ending date should be selected using the provided date-time picker. Historic data is then retrieved with three options: last one month, last six months, or last one year from the user selected ending date. The retrieved data from database can be viewed using a graph or an Excel spreadsheet. If one year past data is selected, AADT computed using the AASHTO method (AASHTO Guidelines for Traffic Data Programs, 2009) is displayed in the graph.

Tab 2: Stations. This tab provides data for a collection of stations that satisfy the COV principle. The data can be loaded for the date specified in the date-time picker tool. Once it is loaded, a station (main-lane r_node) can be selected by a mouse click from the map provided or from the listbox, which would then produce all related information in a callout box as well as in a textbox. The precise location of the station can also be plotted in a Google map. Historic data of the selected station could be retrieved for one month, six months, or one year, and then outputted in a graph or a spreadsheet. One year data retrieval provides an AADT computed using the AASHTO method.

Tab 3: r_node Map. The third tab provides navigation of r_nodes and detectors in the RTMC metro_config file through a map. RTMC defines a location on a road using an r_node for all roads. Types of r_nodes include Station, Exit, Entrance, Intersection, Access, and Interchange, and each of the location is specified using GPS coordinates. If an r_node is a station, it represents a set of detectors on a road covering all main lanes at that specific location. Exit and Entrance r_nodes are similarly defined, and all detectors in the Exit or Entrance ramps become members of the r_node. Intersections and interchanges are transitional r_nodes of roads. Many r_nodes do not have detectors, and it is assigned for future locations of detectors or for identification of a specific location on the road. One of the useful tools in this tab is a search function of an r_node or a detector. After entering a detector or an r_node ID in the respective textbox and then clicking the search button points to the corresponding corridor and r_node, along with all detector information. The information includes corridor, station ID, node type, active or not, address, latitude/longitude, and detectors with lane numbers. It also provides a function to plot the r_node in a Google map. One month worth of volumes for any selected r_node is retrieved and plotted using the "Plot last one month of the r_Node" button.

Tab 4: Data Direct. This tab provides retrieval utilities for volume and detector-health parameters up to one year without using the detector-health database. One of the data types not available from the detector-health database is hourly volumes. This tab provides hourly volumes for one day, 10 days, one month, or six months. It also provides retrieval functions for length-based vehicle classification. Retrieval types can be selected in intervals of hourly or daily. Since the functions implemented in this tab do not use the detector-health database, this tool provides access to detector-health data when the database is not reachable or not available.

CHAPTER 4: DATA ANALYSES

This chapter describes some of data studies completed in "Task 2: Evaluation of Detector-Health Algorithm on a Corridor Study" and few selected examples on the use of the detHealth_app software tool.

4.1 HISTOGRAM ANALYSIS

Histograms provide information on underlying distribution of the given sample data, and it is commonly used as a first step to look into the characteristics of the data. In this project, histogram analyses were used as part of Task 2: Corridor Study, in which I-694 and I-94 data on 2015 and 2016 were used. The analysis results were reported in the Task 2 report.

This section shows histograms of 2018 data on I-694 (EB and WB). Distribution patterns were very similar to that of 2015 and 2016. Histogram data were computed using all detectors in I-694 EB and WB, except for two types of detectors. The first type of detectors excluded were those detectors that are labeled true in the "abandoned" attribute. Another type of detectors excluded were those detectors that had "G" in its category name, because they are not actually detectors but green light counters in highway entrance ramps. The total number of records in 2019 excluding the detectors mentioned above for I-694 was 139,197.

In all histogram data presented here, bins were created based on the number of 30-second time slots allocated by increments of one hour, producing 24 bins. Since one hour contains 120, 30-second time slots, the range was incremented by 120. The label of each bin is expressed using two numbers separated by a two-character symbol "->". For example, "120->239" indicates that the range of this bin is [120,239] or $120 \leq x \leq 239$, and the number in the bin indicates occurrences of detector-health parameters. For example, consider ConZeroVol, which is a count of consecutive zero volumes in 30-second time slots. If ConZeroVol of this detector on a day is 180, it means that consecutive zero volumes were observed for one and half hours and the bin [120, 239] is incremented by one. Because there were a large number of cases that fall at 0, i.e., zero occurrence of the parameter for the whole day, this case was assigned to a separate bin labeled "0-only." Similarly, many cases also fall at 2880, i.e., occurrence of the parameter for the whole day, and it deserves a separate bin. This bin is labeled "2880-only." In summary, all histograms contain twenty-six bins. The complete histogram data for all detector-health parameters of I-694 in 2018 is attached in Appendix A. The histogram data also includes percentage of each bin in a separate column.

In general, three distribution patterns were observed. The first type shows very high frequencies in bins [0-only] and [1, 119] followed by an exponential drop but then frequency rises again in the last bins [2760, 2879] and [2880-only]. This characteristic is shown in Figure 13, and the parameters showing this pattern include ConZeroVol, NegVolCnt, zVolOnOcc and volOccRatio. It should be mentioned that the histogram of ConZeroOcc was nearly identical to that of ConZeroVol and thus omitted.

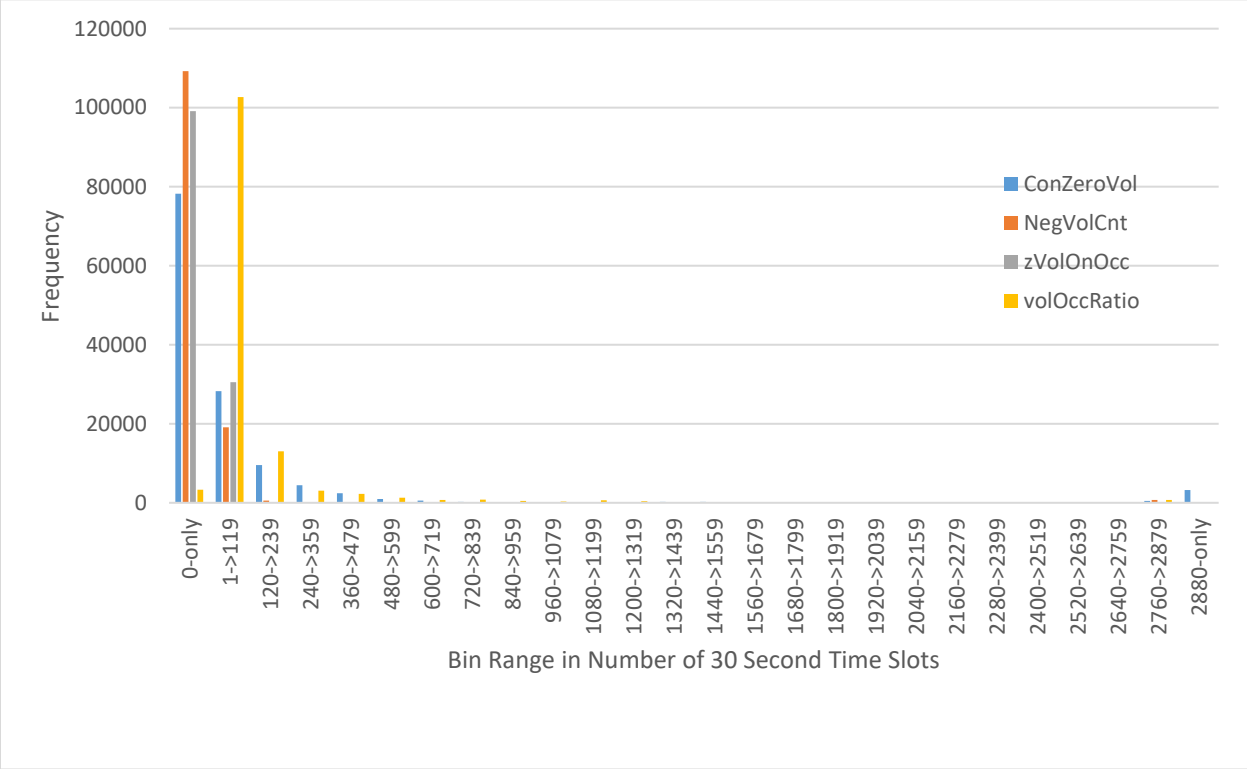


Figure 4.1: Histograms of ConZeroVol, NegVolCnt, zVolOnOcc and volOccRatio parameters on I-694 2018 data

The second distribution pattern observed was concentration of distribution in the [0-only] bin, which indicates that these parameters rarely happen. The parameters in this category include OccLoackOn, ConstVol, ConstOcc, and volOnLOwOcc. Since these parameters rarely happen, two interpretations may be considered: (1) ignore these parameters in determining detector-health level or (2) consider that the quality of the detector data on that day is low when one of these parameters is observed. In this test data, non-zero OccLockOn (10 or more consecutive minutes in which occupancy is in between 99 and 100 percent) occurred only 11 times out of 130,067 detector days (number of detectors * 365), which is very low and shows that this condition rarely occurred.

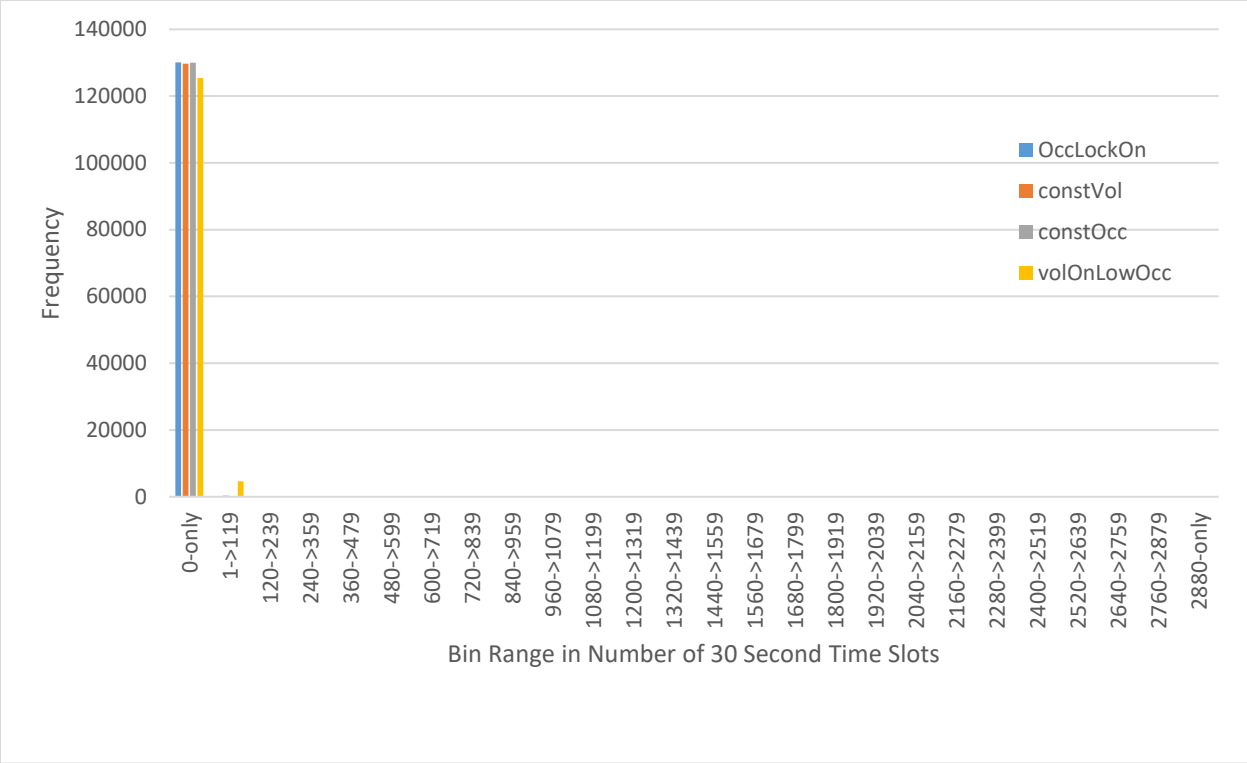


Figure 4.2: Histograms of OccLoackOn, ConstVol, ConstOcc, and volOnLOwOcc parameters on I-694 2018 data

The last pattern observed is an exponential decay of population in low bins and then ending up no population in high bins. This pattern is shown in Figure 15. The parameters belong to this pattern include overCnt and highOcc. OverCnt is the total number of 30-second time slots with volume exceeding 25, and highOcc is the total number of time slots with occupancy exceeding 30%. Both are related to traffic congestion but may not be directly related to detector failure conditions. These two parameters may be used in detection of special events or congestion.

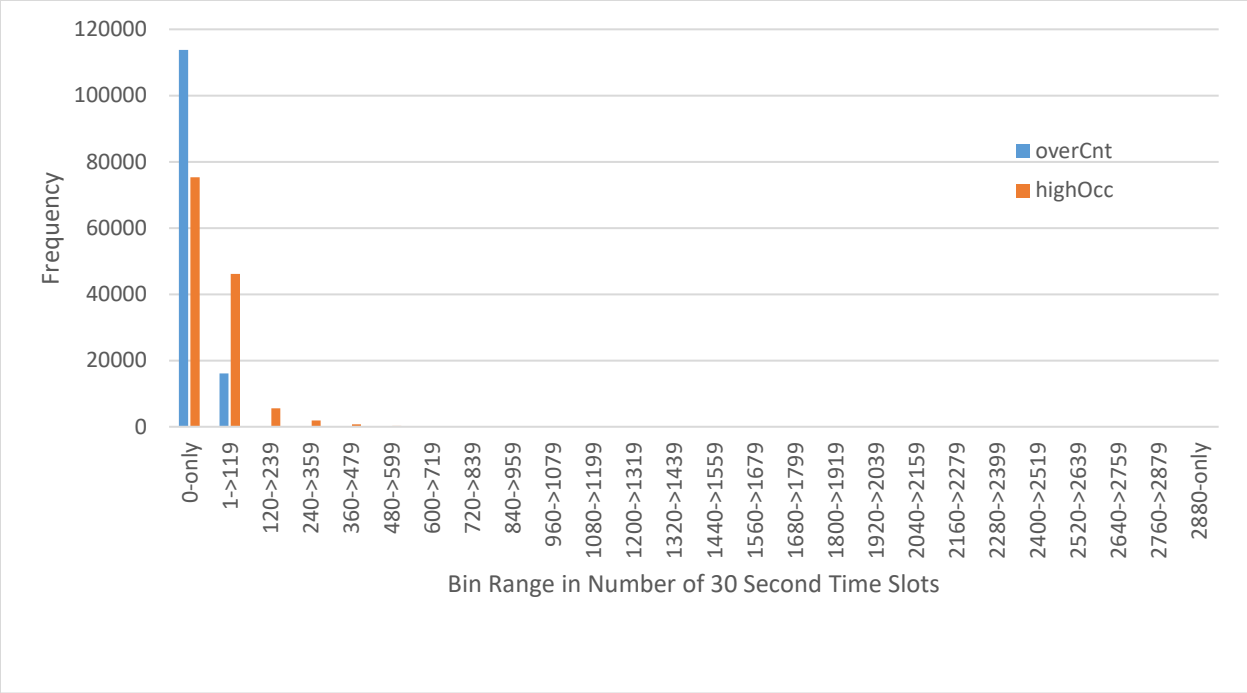


Figure 4.3: Histograms of overCnt and highOcc parameters on I-694 2018 data

Findings from histogram analyses (including the 2015 and 2016 data) are summarized below.

- Histograms of conZeroVol (consecutive zero volume) are nearly identical to that of conZeroOcc (consecutive zero occupancy), which means that using one of them is sufficient for analyzing detector health.
- There are a large number of cases where conZeroVol=2,880 which indicates that zero volumes in every 30 seconds were recorded for all day for that detector. This occurrence was observed from about 2.5% of the test data.
- occLockOn (occupancy lock on) rarely occurred. For I-694 EB and WB in 2015, occLockOn never occurred. In 2018, it occurred only 11 time in I-694.
- Distribution patterns of zVolOnOcc (zero volume on non-zero occupancy) and overCnt (vol>25) exhibit a remarkable similarity, although only similarity between them is that both parameters are not theoretically feasible under realistic traffic conditions.
- constVol (consecutive constant volume) and constOcc (consecutive constant occupancy) parameters remain zero nearly 100% cases, and only few are in the range of 1-120 on all routes.
- highOcc (occ>35%) indicates congestion time. Since congestions may not occur continuously for 24 hours, highOcc=2880 should indicate some malfunction in a detector. This condition only occurred in I-94 EB and 25 cases in 2015 and 6 cases in 2016.
- volOccRatio (total violation time of vol/occ acceptable range) had a similar distribution as that of negVolCnt (negative volume count). Since negVolCnt indicates malfunction of detector, volOccRatio appears a good indicator for detecting negVolCnt or malfunction detectors.

Using histograms, several interesting facts were observed as summarized above. However, they did not lend themselves as a clear indicator for determining detector-health levels, i.e., it is difficult to determine threshold levels of parameters based on histogram analysis. It is also arguable that quality of detector data depends on applications. For example, computing AASHTO AADT does not require perfect data and the threshold for determining good data may be lowered. However, some other applications may require traffic data requiring minimal missing values. Therefore, setting threshold levels should probably be based on application requirements and not by histogram analyses.

4.2 INCIDENT DATA ANALYSIS

Incident data of interstate highway I-694 and I-94 for the period of from 1/1/2015 to 12/31/2016 were provided by RTMC to the research team. The received incident data was stored in a detector-health database table. Incident data provided latitude and longitude of the incident location but did not provide detector ID or station numbers that can correlate to the location of incidents. To identify and analyze the detectors affected by incidents, Google map, MnDOT PDF map, and custom software that can depict the station locations and road lanes were used. Incidents in the RTMC incident data were classified into four types, which are STALL, ROADWORK, HAZARD, and CRASH. The detailed analysis examples are attached in Appendix B. Below summarizes the findings.

- Samples of STALL incidents did not show any abnormal traffic volume patterns or detector-health parameters. It appears that STALL incidents do not affect daily volumes.
- Samples of ROADWORK incidents showed consecutive zero volumes for the entire day or longer. This implies that a lane closure may be associated with ROADWORK.
- Samples of CRASH incidents always led to a short period of high highOcc values on that station. This makes sense since a crash could easily cause congestion. However, it does not appear to affect daily volume totals.
- Samples of HAZARD incidents mostly showed very high conZeroVol (approx. 2880). But in few cases, HAZARD incidents didn’t end up showing high conZeroVol values.

In summary, conZeroVol was able to detect incident types listed as ROADWORK and HAZARD, while highOcc was affected in CRASH incidents. STALL did not show a consistent pattern in any of the detector-health parameters except frequent high conZeroVol values.

4.3 TESLA MAINTENANCE DATA ANALYSIS

The TESLA system is a MnDOT legacy maintenance logging database that recorded loop maintenance tickets. MnDOT transitioned to a new management system called Transportation Asset Management System (TAMS) in Fall 2016. The research team received the legacy TESLA data for analysis of 2015 and 2016.

As the basic methodology, every station's detectors on I-694 and I-94 were investigated. Per every detector, whether it has had a record in the TESLA maintenance log in 2015 or in 2016 was checked. If a maintenance record is found then all parameters for that station were analyzed for 2 years. Example analyses can be found in Appendix –C.

The findings are summarized below.

- A typical pattern of detector repair observed in the data was that all detectors in the station will stop giving data for few days and then they will give a large number of negVolCnt. After that, the detectors start to produce normal patterns of traffic data. The transition from a large number of negative volumes to normal positive traffic volumes imply a successful repair of them.

- Records on temporary detectors were not found from the TESLA database, meaning no maintenance operations were done or not recorded for temporary detectors.

- The following pattern was observed when a detector was repaired. When a detector in a station is faulty and is about to be repaired, the whole station gave a large amount of negVolCnt followed by off-line of the detectors for few days. Once a repair was made, it again gave a large amount of negVolCnt followed by non-negative normal data. However, some exceptions were observed in that some detectors generated a normal pattern of data without giving a large number of negVolCnt.

Temporary detectors were not recorded in the TESLA database, but an interesting pattern was observed. When a temporary detector was placed, the detector initially produced all zero data, i.e., conZeroVol=2880 but with negVolCnt=0. It then began to produce a normal pattern of traffic data. Appendix-C provides detailed information on data patterns of the detectors recorded in the TESLA maintenance tickets.

4.4 DETECTOR REPLACEMENT: A KNOWN CASE

RTMC MNIT provided a special known case to the research team in which problematic loops were replaced with Wavetronix. The location was I-94 WB & 57th Avenue, which corresponds to station ID, S243. According to an email received, the detectors appear turned off on November 13, 2015 and turned back on June 16, 2016.

The interest to this case is that “Can this event be detected from the detector-health database such that we can identify the time period in which the detectors were turned off and then back on?” For this study, all detector-health parameters for station S243 from January 1, 2015 to December 31, 2016 were retrieved from the database. The main parameters affected by off-line were conZeroVol and negVolCnt, which become 2880 and -1, respectively. As an example, conZeroVol of the detector # 472 was plotted for two years and it is shown in Figure 16. ConZeroVol=2880 indicates “detector off-line.” Daily volumes of the same detector for the same period are shown in Figure 17 for verification. Notice that the relation is opposite. The rest of detectors in station S243 had the same off-line pattern. The fully off-line periods detected from data were shown using the orange arrow lines in Figure 16, and the actual off-line periods were

(1) November 14, 2015 – June 15, 2016 (215 days)

(2) September 1, 2016 – November 27, 2016 (88 days)

(3) December 3, 2016 – December 8, 2016 (6 days)

Note that MNIT only provided the off-line period, November 14, 2015 – June 15, which precisely matched with the period identified through detector-health parameters. However, this analysis found that two more periods that were off-lined, and MNIT did not have this record or information. This demonstrates that the detector-health parameters proposed in this research are sufficient to identify off-line detectors and will serve as a useful tool for checking when detectors are offline and then online again.

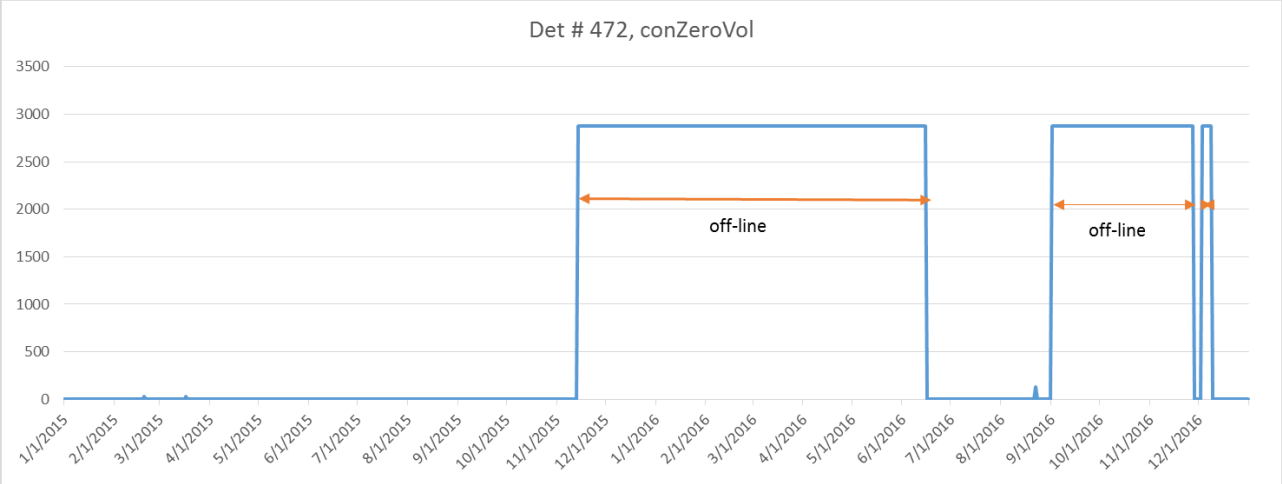


Figure 4.4: Consecutive zero volume plot of detector 472 for the period 1-1-2015 to 31-12-2016

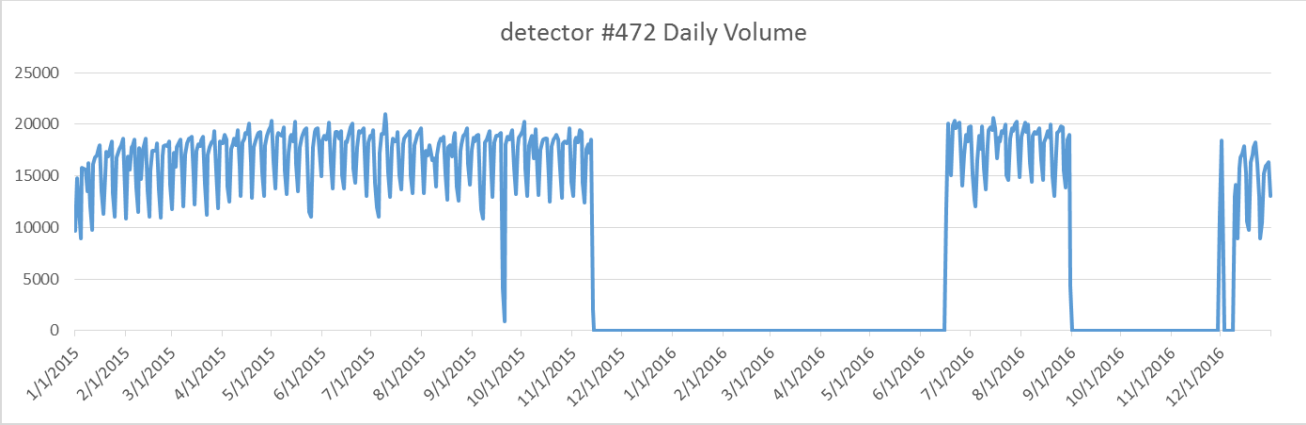


Figure 4.5: Daily detector volume total for the period 1-1-2015 to 31-12-2016

4.5 OTHER EXAMPLES OF DETHEALTH DATABASE USE

MnDOT TFA maintains continuous count (CC) data for the stations allocated in the Twin Cities' freeway network using the RTMC detector data. One of the MnDOT data analysts informed the research team that CC Station# 309 had been giving zero volumes and the final AADT did not make sense in January 2019. This station consists of three detectors and their IDs are 178, 179 and 180. To investigate this station, detHealth_app was run and the data were retrieved for one year with an ending date March 10, 2019. The retrieved result is shown in Figure 18. According to this data, the problem of three detectors started from May 23, 2018 and then continued afterword, producing only zero volumes. This would definitely produce a biased AADT since the volume data are continuously zero for nine months. A preferred missing pattern of AASHTO AADT computation is availability of at least each day-of-week of good data per each month, and it does not meet this condition. Therefore, it is clear that the three detectors in CC #309 were not healthy detectors for the given period, and a different set of detectors for the AADT computation must be chosen or the volume data from these detectors must be thrown away.

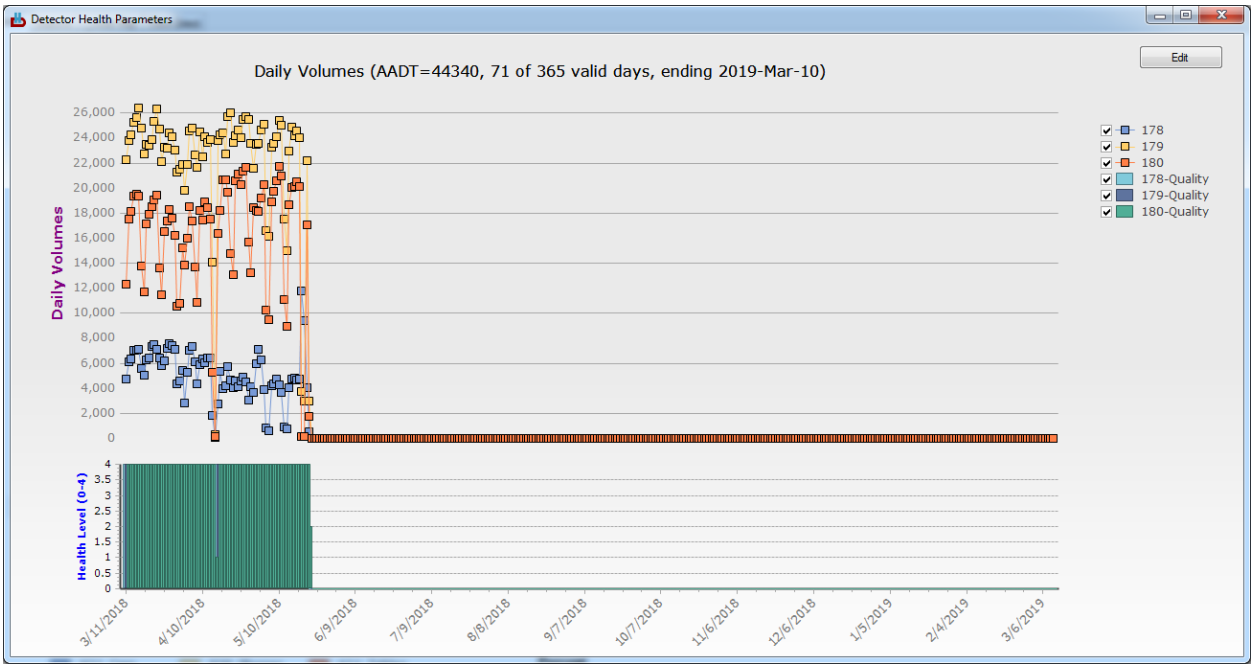


Figure 4.6: Retrieval of a Continuous Count (CC) station #309

The next example is an observation of data patterns of temporary detectors. As constructions start in Spring in Minnesota, MnDOT RTMC creates temporary traffic detectors in relation to a new construction zone to collect traffic data. Information on these temporary detectors, when and where they were placed and began operational, is not readily available to MnDOT TFA. One way of finding information is using the detector-health database. All temporary detector ID starts with a letter "T". As an example, consider a detector ID, T35103, which is located in the interstate highway I-35 SB. Using detHealth_app, six past months of data from the ending date, June 12, 2019, were retrieved for volume and negVolCnt. Figures 19 and 20 show these results. It should be noted that six-month retrieval only returned past 58 days of data instead of 182 days, which indicates that this detector was created and on line 58 days back from the ending date June 12, 2019. Figure 19 shows that this temporary detector was on-line on April 16, 2019. However, the detector produced negative-one volume values until April 25, in which -1 indicates erroneous or missing data.

In summary, the information obtained for T35103 was that this detector was on-line on April 16, 2019 but began producing data starting from April 26, 2019. The first day (April 26) data contained negative volumes on 2,049 30-second time slots and daily volume of 2,565 vehicles on 831 30-second time slots was recorded. The data was further investigated using the "Get Vol/Occ Graphs" function in detHealth_app on April 26, 2019 and the result is shown in Figure 21. It turned out missing data occurred on the first 17 hours of April 26, 2019, i.e., the detector T35103 began operational starting at 5:05PM on April 26. After April 26, the number of time slots on negative volumes dropped below 970 according to Figure 20. After observing Figures 19 and 20, we conclude that the quality of data on this detector is inconsistent at best even after April 26.

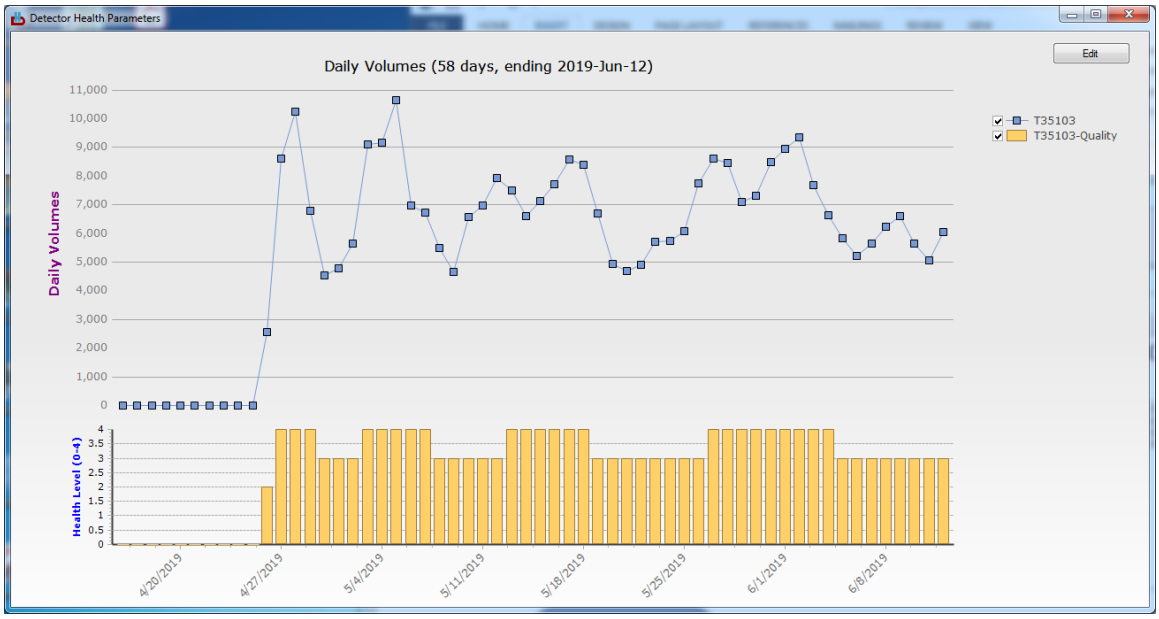


Figure 4.7: Six-month volume data retrieval of temporary detector T35103

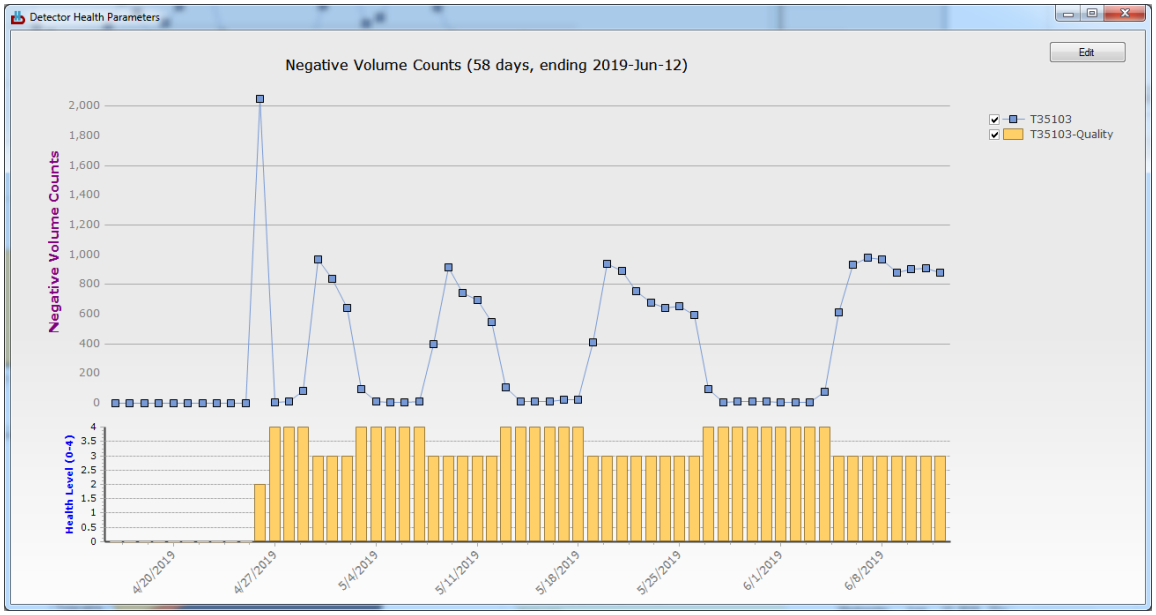


Figure 4.8: Six-month negVolCnt retrieval of temporary detector T35103

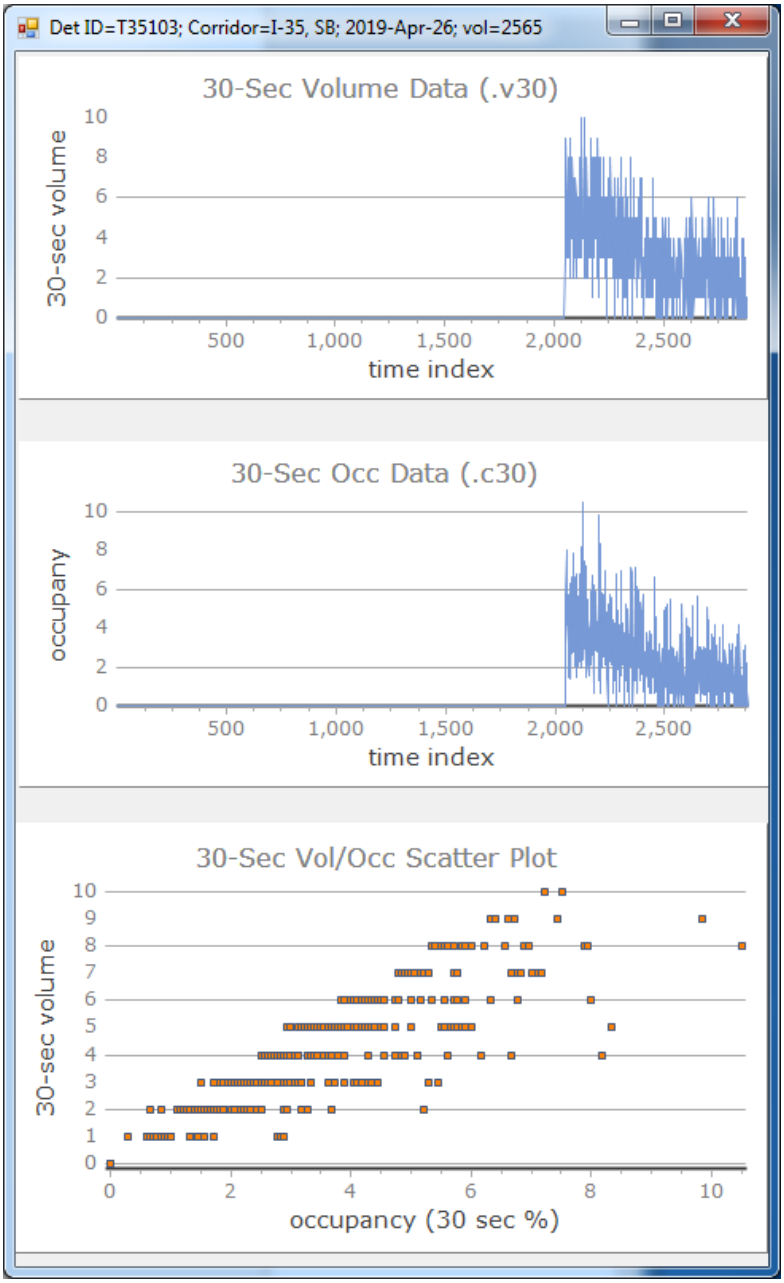


Figure 4.9: 30-Second volume and occupancy plots for detector T35103 on April-26-219

CHAPTER 5: CONLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This project developed a quality-control and data-exploration system targeted for RTMC detector volume data. The key to this system was characterization of daily detector data in 12 detector-health parameters and a simplified classification to four classes: healthy, tolerable, impaired, and nonfunctional. The data from the healthy and tolerable classes were recommended for use in traffic counting programs while the detectors in impaired or nonfunctional classes were recommended for maintenance. The COV principle was exploited and found to be a useful tool for confirming or verifying quality of station data. Violation of COV principle in three consecutive equivalent stations was sufficient to indicate inclusion of one or more bad detectors.

The final detector-health system was implemented as a client-server model in which a relational database became the center of the server. A client software program called detHealth_app.exe was developed, which provided retrieval and visualization of various health parameters along with detector or station volumes. The front page of this program provided a pie chart and a list of each class for the overall view of the detector-health state, from which more details were retrieved.

For data analysis of the detector-health system, maintenance records and incident records were studied and a good correlation to health parameters was observed. The research team was successfully able to identify a known case of detector replacement provided by RTMC using historical data of the detector-health parameters.

In conclusion, the detector-health system developed in this project is a useful tool in exploring quality of detector data and can serve as part of a quality control/assurance program. This tool would help improve quality of the volume data retrieved from the RTMC detectors by choosing healthy detectors.

5.2 RECOMMENDATIONS

Creation of the detector-health database was an attempt to develop parameters for quality control for individual detectors when no hardware malfunction data was available. A better solution recommended would be directly integrating the quality-control parameters in the RTMC raw detector data by recording all observed malfunctions.

The advantage of having a client server-based system is that all heavy computations are done at the server side and then the results are shared among clients. This leads to light computations and less storage requirements at the client end. Another advantage is that client and server software can be evolved independently as long as the interface rule between them does not change. However, one critical issue found is that this approach has a single point failure (server) and is expensive in terms of maintenance, i.e., someone has to manage and take care of the server. More specifically, if the detector-health database in the server fails, someone has to restore the database service. In government

agencies such as MnDOT, adding more IT personal for maintaining the database is not easy under limited budgets and resources. Therefore, the research team recommends conversion of the present system to a serverless, standalone system in which a single program installed on a client's PC provides the same data service without requiring connection to a server.

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APPENDIX A
SAMPLE HISTOGRAM DATA FOR DETECTOR-HEALTH PARAMETERS

Histogram Data of Detector-Health Parameters, I-694 EB/WB, 2018: ConZeroVol, NegVolCnt, ConZeroOcc, NegOccCnt

Range	ConZeroVol	ConZeroVol %	NegVolCnt	NegVolCnt %	ConZeroOcc	ConZeroOcc %	NegOccCnt	NegOccCnt %
0-only	78244	60.2	109240	84	78416	60.3	100421	77.2
1->119	28297	21.8	19104	14.7	28293	21.8	27733	21.3
120->239	9511	7.3	568	0.4	9487	7.3	598	0.5
240->359	4424	3.4	92	0.1	4416	3.4	94	0.1
360->479	2384	1.8	11	0	2375	1.8	30	0
480->599	948	0.7	18	0	944	0.7	30	0
600->719	559	0.4	17	0	557	0.4	22	0
720->839	230	0.2	6	0	227	0.2	7	0
840->959	117	0.1	0	0	118	0.1	3	0
960->1079	106	0.1	11	0	105	0.1	10	0
1080->1199	136	0.1	16	0	134	0.1	18	0
1200->1319	187	0.1	78	0.1	184	0.1	80	0.1
1320->1439	212	0.2	18	0	215	0.2	18	0
1440->1559	231	0.2	21	0	226	0.2	22	0
1560->1679	174	0.1	46	0	180	0.1	45	0
1680->1799	130	0.1	4	0	127	0.1	7	0
1800->1919	82	0.1	0	0	81	0.1	0	0
1920->2039	99	0.1	88	0.1	99	0.1	88	0.1
2040->2159	77	0.1	11	0	77	0.1	10	0
2160->2279	52	0	0	0	51	0	0	0
2280->2399	60	0	0	0	57	0	0	0
2400->2519	37	0	0	0	36	0	2	0
2520->2639	24	0	0	0	24	0	0	0
2640->2759	31	0	0	0	29	0	8	0
2760->2879	483	0.4	718	0.6	439	0.3	815	0.6
2880-only	3232	2.5	0	0	3170	2.4	6	0
Total	**130067**	**100**	**130067**	**100**	**130067**	**99.9**	**130067**	**99.9**

Histogram Data of Detector-Health Parameters, I-694 EB/WB, 2018: OccLockOn, zVolOnOcc, overCnt, highOcc

Range	OccLockOn	OccLockOn %	zVolOnOcc	zVolOnOcc %	overCnt	overCnt %	highOcc	highOcc %
0-only	130055	100	99144	76.2	113763	87.5	75335	57.9
1->119	9	0	30537	23.5	16140	12.4	46132	35.5
120->239	2	0	162	0.1	67	0.1	5551	4.3
240->359	1	0	29	0	39	0	1948	1.5
360->479	0	0	72	0.1	28	0	773	0.6
480->599	0	0	2	0	17	0	258	0.2
600->719	0	0	3	0	9	0	58	0
720->839	0	0	1	0	3	0	11	0
840->959	0	0	0	0	0	0	1	0
960->1079	0	0	0	0	1	0	0	0
1080->1199	0	0	3	0	0	0	0	0
1200->1319	0	0	2	0	0	0	0	0
1320->1439	0	0	0	0	0	0	0	0
1440->1559	0	0	0	0	0	0	0	0
1560->1679	0	0	1	0	0	0	0	0
1680->1799	0	0	0	0	0	0	0	0
1800->1919	0	0	2	0	0	0	0	0
1920->2039	0	0	0	0	0	0	0	0
2040->2159	0	0	0	0	0	0	0	0
2160->2279	0	0	0	0	0	0	0	0
2280->2399	0	0	0	0	0	0	0	0
2400->2519	0	0	1	0	0	0	0	0
2520->2639	0	0	1	0	0	0	0	0
2640->2759	0	0	1	0	0	0	0	0
2760->2879	0	0	46	0	0	0	0	0
2880-only	0	0	60	0	0	0	0	0
Total	**130067**	**100**	**130067**	**100**	**130067**	**100**	**130067**	**100**

Histogram Data of Detector-Health Parameters, I-694 EB/WB, 2018: constVol, constOcc, volOnLowOcc, volOccRatio

Range	constVol	constVol %	constOcc	constOcc %	volOnLowOcc	volOnLowOcc %	volOccRatio	volOccRatio %
0-only	129738	99.7	130033	100	125379	96.4	3293	2.5
1->119	326	0.3	34	0	4687	3.6	102654	78.9
120->239	3	0	0	0	1	0	13005	10
240->359	0	0	0	0	0	0	3073	2.4
360->479	0	0	0	0	0	0	2278	1.8
480->599	0	0	0	0	0	0	1281	1
600->719	0	0	0	0	0	0	728	0.6
720->839	0	0	0	0	0	0	792	0.6
840->959	0	0	0	0	0	0	489	0.4
960->1079	0	0	0	0	0	0	282	0.2
1080->1199	0	0	0	0	0	0	672	0.5
1200->1319	0	0	0	0	0	0	418	0.3
1320->1439	0	0	0	0	0	0	138	0.1
1440->1559	0	0	0	0	0	0	80	0.1
1560->1679	0	0	0	0	0	0	41	0
1680->1799	0	0	0	0	0	0	21	0
1800->1919	0	0	0	0	0	0	4	0
1920->2039	0	0	0	0	0	0	58	0
2040->2159	0	0	0	0	0	0	36	0
2160->2279	0	0	0	0	0	0	6	0
2280->2399	0	0	0	0	0	0	0	0
2400->2519	0	0	0	0	0	0	0	0
2520->2639	0	0	0	0	0	0	0	0
2640->2759	0	0	0	0	0	0	0	0
2760->2879	0	0	0	0	0	0	718	0.6
2880-only	0	0	0	0	0	0	0	0
Total	**130067**	**100**	**130067**	**100**	**130067**	**100**	**130067**	**100**

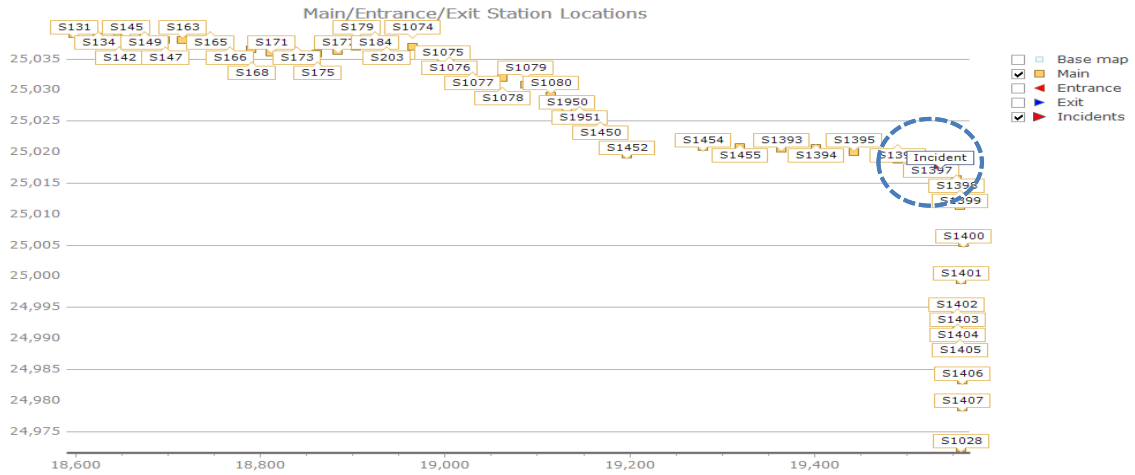
APPENDIX B
EXAMPLES OF INCIDENT DATA ANALYSES

Incident: Crash

Date 02-01-2015, Friday

Incident data

event_id	event_name	event_date	description	road	direction	impact	cleared	confirme
193955087	20150102172749 10	2015-01-02 17:27:49	Incident CRASH	I-694	EB	...!	f	t
193957118	20150102172749 10	2015-01-02 18:10:18	Incident CRASH	I-694	EB	...!	t	t
193957120	20150102181018 05	2015-01-02 18:10:18	Incident CRASH	I-694	EB	...!	f	t
193957821	20150102181018 05	2015-01-02 18:25:44	Incident CRASH	I-694	EB	...!	t	t



As can be seen in the above diagrams, Incident happened near S1397 proved by Google Maps and the location has two lanes. Its detector-health parameters are as follows:

ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDe	COV_upDiff	COV_
2015-01-01	I-694	EB	S1397		6194	0	0	0	0	0	0	0	0	0	0	0	0.926436	53	12200	17667	0	-77.74	-6.18
2015-01-01	I-694	EB	S1397		6195	55	0	55	0	0	0	0	0	0	0	0	0.971785	13	5467	17667	0	-77.74	-6.18
2015-01-02	I-694	EB	S1397		6194	0	0	0	0	0	0	0	26	0	0	0	0.71433	81	18025	30753	0	-78.39	-5.32
2015-01-02	I-694	EB	S1397		6195	180	0	180	0	0	0	0	45	0	0	0	0.613911	24	12728	30753	0	-78.39	-5.32
2015-01-03	I-694	EB	S1397		6194	0	0	0	0	0	0	0	0	0	0	0	0.941423	84	16012	25310	0	-78.95	-7.03
2015-01-03	I-694	EB	S1397		6195	72	0	72	0	0	0	0	0	0	0	0	0.970298	18	9298	25310	0	-78.95	-7.03
2015-01-04	I-694	EB	S1397		6194	0	0	0	0	0	0	0	0	0	0	0	0.936148	50	12744	19334	0	-79.66	-7.35
2015-01-04	I-694	EB	S1397		6195	102	0	102	0	0	0	0	0	0	0	0	0.941777	15	6590	19334	0	-79.66	-7.35
2015-01-05	I-694	EB	S1397		6194	0	0	0	0	0	0	0	0	0	0	0	0.931668	88	17347	30632	0	-78.02	-4.73
2015-01-05	I-694	EB	S1397		6195	219	0	219	0	0	0	0	0	0	0	0	0.962733	36	13285	30632	0	-78.02	-4.73

Observation:

- Incident at the location of S1397 resulted in high conZeroVol on that day at all adjacent stations.
- At S1397, there is highOcc observed for 26 timeslots on detector 6194 and 45 timeslots on detector 6195.
- Even when dates 1-5 of January looked into, we get conZeroVol low or equal to the value on 2nd January which is the incident date. What separates 2nd January data was the highOcc value on that station that day.

Date 05-01-2015, Monday

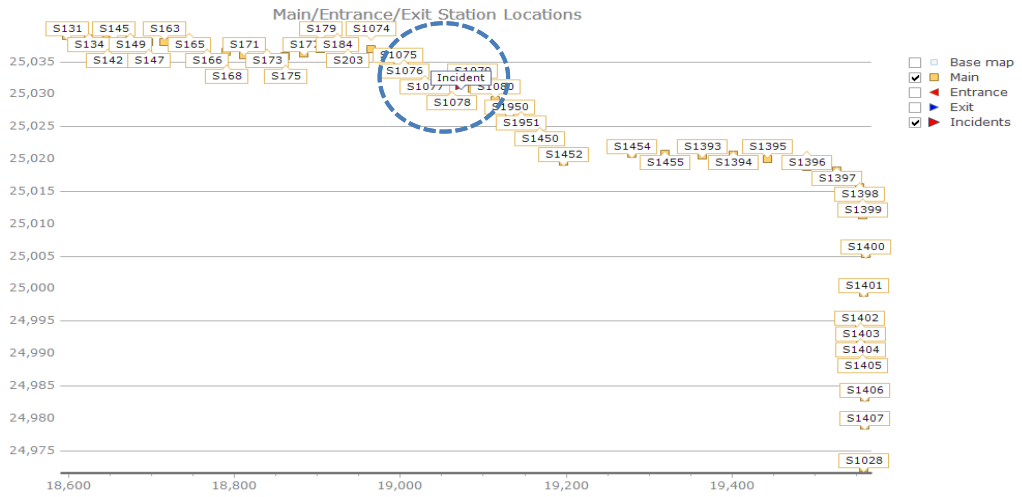
Incident data:

'194168394', '2015010522020079', '2015-01-05 22:02:01', 'Incident CRASH', 'I-694', 'EB', '...!', 'f', 't', 'C709', 'Mainline', 'rollover', NULL, '45.0566215515137', '-93.133674621582'

Station S1077, S1078, S1079 and S1080 are near the location of incident. Thus, we analyze their data trend at adjacent dates 3, 4, 5, 6 of January 2015. The incident occurred on 5th Jan, 2015 at 10pm.

Google Maps of the incident location proves it is S1078.

ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDe	COV_upDiff	COV_
2015-01-03	I-694	EB	S1078		4256	0	0	0	0	0	0	0	0	0	0	0	0.986516	81	21070	37501	4	9.05	-4.89
2015-01-03	I-694	EB	S1078		4257	0	0	0	0	0	0	0	0	0	0	0	0.980222	15	16431	37501	4	9.05	-4.89
2015-01-04	I-694	EB	S1078		4256	0	0	0	0	0	0	0	0	0	0	0	0.98928	42	17610	30058	4	9.4	-5.63
2015-01-04	I-694	EB	S1078		4257	0	0	0	0	0	0	0	0	0	0	0	0.977731	12	12448	30058	4	9.4	-5.63
2015-01-05	I-694	EB	S1078		4256	182	0	182	0	0	0	0	0	0	0	2	0.916931	88	23291	47036	4	11.26	-5.91
2015-01-05	I-694	EB	S1078		4257	24	0	24	2	0	0	4	166	0	0	0	0.482125	51	23745	47036	4	11.26	-5.91
2015-01-06	I-694	EB	S1078		4256	23	2	23	1	0	0	0	0	0	0	0	0.885213	31	23387	47551	4	10.65	-5.21
2015-01-06	I-694	EB	S1078		4257	0	2	0	1	0	0	0	25	0	0	0	0.864463	88	24164	47551	4	10.65	-5.21
2015-01-07	I-694	EB	S1078		4256	0	0	0	0	0	0	0	0	0	0	0	0.909188	62	24109	47409	4	11.38	-6.08
2015-01-07	I-694	EB	S1078		4257	0	0	0	0	0	0	1	8	0	0	0	0.918179	32	23300	47409	4	11.38	-6.08



Observation

- The data proves that incident happened on lane 2 of S1078. Hence, the detector on lane 2, detector ID 4257, shows 166 timeslots of highOcc on 5th January, 2015.

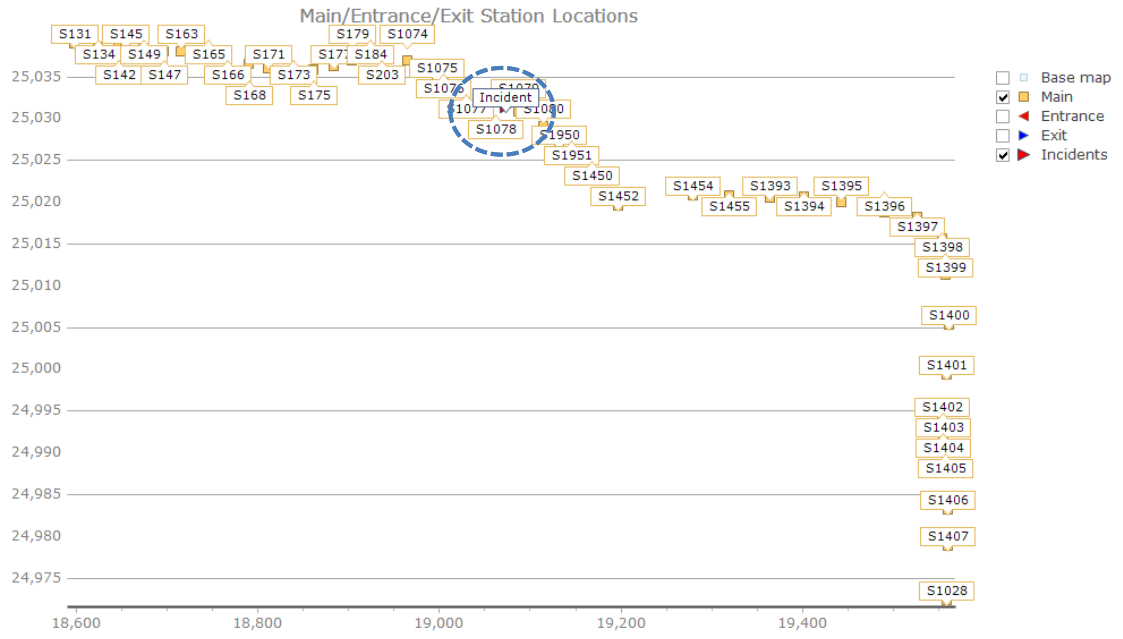
Date 06-01-2015, Tuesday

Incident data:

'194185364', '2015010522020079', '2015-01-06 04:33:21', 'Incident CRASH', 'I-694', 'EB', '...!', 't', 't', 'C709', 'Mainline', 'rollover', NULL, '45.0566215515137', '-93.133674621582'

According to Google Maps, the location is near S1078 and it has two lanes. We analyze its data on 5th, 6th, 7th, and 8th of January, 2015.

ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDe	COV_upDiff	COV_
2015-01-05	I-694	EB	S1078		4256	182	0	182	0	0	0	0	0	0	0	2	0.916931	88	23291	47036	4	11.26	-5.91
2015-01-05	I-694	EB	S1078		4257	24	0	24	2	0	0	4	166	0	0	0	0.482125	51	23745	47036	4	11.26	-5.91
2015-01-06	I-694	EB	S1078		4256	23	2	23	1	0	0	0	0	0	0	0	0.885213	31	23387	47551	4	10.65	-5.21
2015-01-06	I-694	EB	S1078		4257	0	2	0	1	0	0	0	25	0	0	0	0.864463	88	24164	47551	4	10.65	-5.21
2015-01-07	I-694	EB	S1078		4256	0	0	0	0	0	0	0	0	0	0	0	0.909188	62	24109	47409	4	11.38	-6.08
2015-01-07	I-694	EB	S1078		4257	0	0	0	0	0	0	1	8	0	0	0	0.918179	32	23300	47409	4	11.38	-6.08



Observation:

- Incident happened on 4am on 6th Jan. 2015. There is no high conZeroVol on S1078 lane two. However, highOcc value of 25 was observed.

Date 08-01-2015, Thursday

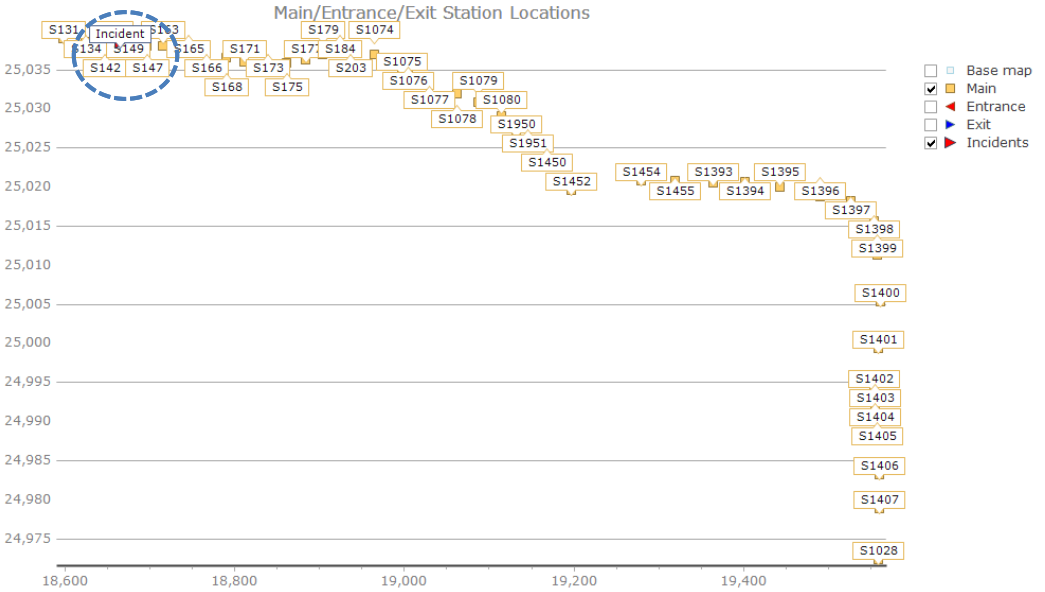
Incidents:

'194380456', '2015010809204808', '2015-01-08 09:20:48', 'Incident CRASH', 'I-694', 'EB', '.....!.', 'f', 't', 'C7011', 'Mainline', '', NULL, '45.0691528320312', '-93.2802963256836'

'194382064', '2015010809204808', '2015-01-08 09:43:02', 'Incident CRASH', 'I-694', 'EB', '.....!.', 't', 't', 'C7011', 'Mainline', '', NULL, '45.0691528320312', '-93.2802963256836'

The data proves that one incident happened at 9:20am and another at 9:43am over S149 which has five lanes and five detectors.

ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDe	COV_upDiff	COV_c
2015-01-06	I-694	EB	S149		526	0	1	0	1	0	0	0	17	0	0	0	0.822087	47	16048	70031	0	10.67	-24.16
2015-01-06	I-694	EB	S149		527	0	1	0	1	0	0	0	15	0	0	0	0.837486	31	18603	70031	0	10.67	-24.16
2015-01-06	I-694	EB	S149		528	0	1	0	1	0	0	0	16	0	0	0	0.832448	112	18380	70031	0	10.67	-24.16
2015-01-06	I-694	EB	S149		529	0	1	0	1	0	0	0	10	0	0	0	0.880721	46	16149	70031	0	10.67	-24.16
2015-01-06	I-694	EB	S149		3070	542	1	542	3	0	3	0	0	0	0	0	0.775421	114	851	70031	0	10.67	-24.16
2015-01-07	I-694	EB	S149		526	0	0	0	0	0	0	0	0	0	0	0	0.962937	34	15616	68322	0	12.01	-25.02
2015-01-07	I-694	EB	S149		527	0	0	0	0	0	0	0	0	0	0	0	0.976124	25	18274	68322	0	12.01	-25.02
2015-01-07	I-694	EB	S149		528	0	0	0	0	0	0	0	0	0	0	0	0.929864	115	17918	68322	0	12.01	-25.02
2015-01-07	I-694	EB	S149		529	0	0	0	0	0	0	0	0	0	0	0	0.974099	51	15105	68322	0	12.01	-25.02
2015-01-07	I-694	EB	S149		3070	431	0	431	0	0	0	0	0	0	0	0	0.823099	120	1409	68322	0	12.01	-25.02
2015-01-08	I-694	EB	S149		526	0	0	0	0	0	0	0	498	0	0	0	0.509203	118	13219	61088	0	10.78	-26.52
2015-01-08	I-694	EB	S149		527	0	0	0	1	0	0	0	577	0	0	0	0.406771	73	15125	61088	0	10.78	-26.52
2015-01-08	I-694	EB	S149		528	0	0	0	1	0	0	0	472	0	0	0	0.385598	265	15196	61088	0	10.78	-26.52
2015-01-08	I-694	EB	S149		529	0	0	0	1	0	0	0	511	0	0	0	0.49846	158	14302	61088	0	10.78	-26.52
2015-01-08	I-694	EB	S149		3070	673	0	673	0	0	0	0	20	0	0	0	0.79093	391	3246	61088	0	10.78	-26.52
2015-01-09	I-694	EB	S149		526	0	0	0	1	0	0	0	97	0	0	0	0.677805	43	16669	72278	0	11.77	-25.03
2015-01-09	I-694	EB	S149		527	0	0	0	0	0	0	0	62	0	0	0	0.751371	36	18861	72278	0	11.77	-25.03
2015-01-09	I-694	EB	S149		528	0	0	0	0	0	0	0	34	0	0	0	0.791882	128	18471	72278	0	11.77	-25.03
2015-01-09	I-694	EB	S149		529	0	0	0	0	0	0	0	41	0	0	0	0.858521	76	16204	72278	0	11.77	-25.03
2015-01-09	I-694	EB	S149		3070	474	0	474	0	0	0	0	0	0	0	0	0.732271	208	2073	72278	0	11.77	-25.03



Observation:

- It can be seen that incidents on 8th Jan 2015 over S149 leads to high highOcc values.

Incidents:

'194381891', '2015010809410057', '2015-01-08 09:41:02', 'Incident CRASH', 'I-694', 'EB', '..!', 'f', 't', 'C861', 'Exit', '', NULL, '44.9519920349121', '-92.9589004516602'

'194382330', '2015010809410057', '2015-01-08 09:47:50', 'Incident CRASH', 'I-694', 'EB', '..!', 't', 't', 'C861', 'Exit', '', NULL, '44.9519920349121', '-92.9589004516602'

Two incidents happened at S1028 on 8-1-2015 and it shows again high occupancies.

ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDa	COV_upDiff	COV_
2015-01-06	I-694	EB	S1028		5090	0	5	0	6	0	0	0	60	0	0	0	0.713071	225	15782	34091	0	4.66	-1000
2015-01-06	I-694	EB	S1028		5091	0	5	0	5	0	0	0	20	0	0	0	0.806654	25	18309	34091	0	4.66	-1000
2015-01-07	I-694	EB	S1028		5090	0	0	0	0	0	0	0	17	0	0	0	0.818848	211	15692	33010	0	4.67	-1000
2015-01-07	I-694	EB	S1028		5091	40	0	40	0	0	0	0	0	0	0	0	0.968926	14	17318	33010	0	4.67	-1000
2015-01-08	I-694	EB	S1028		5090	0	0	0	2	0	0	0	92	0	0	0	0.645436	506	12432	27307	0	4.88	-1000
2015-01-08	I-694	EB	S1028		5091	0	0	0	0	0	0	0	4	0	0	0	0.822556	42	14875	27307	0	4.88	-1000
2015-01-09	I-694	EB	S1028		5090	0	0	0	0	0	0	0	174	0	0	0	0.695768	244	16028	34391	0	6.66	-1000
2015-01-09	I-694	EB	S1028		5091	0	0	0	0	0	0	0	10	0	0	0	0.883156	16	18363	34391	0	6.66	-1000
NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL

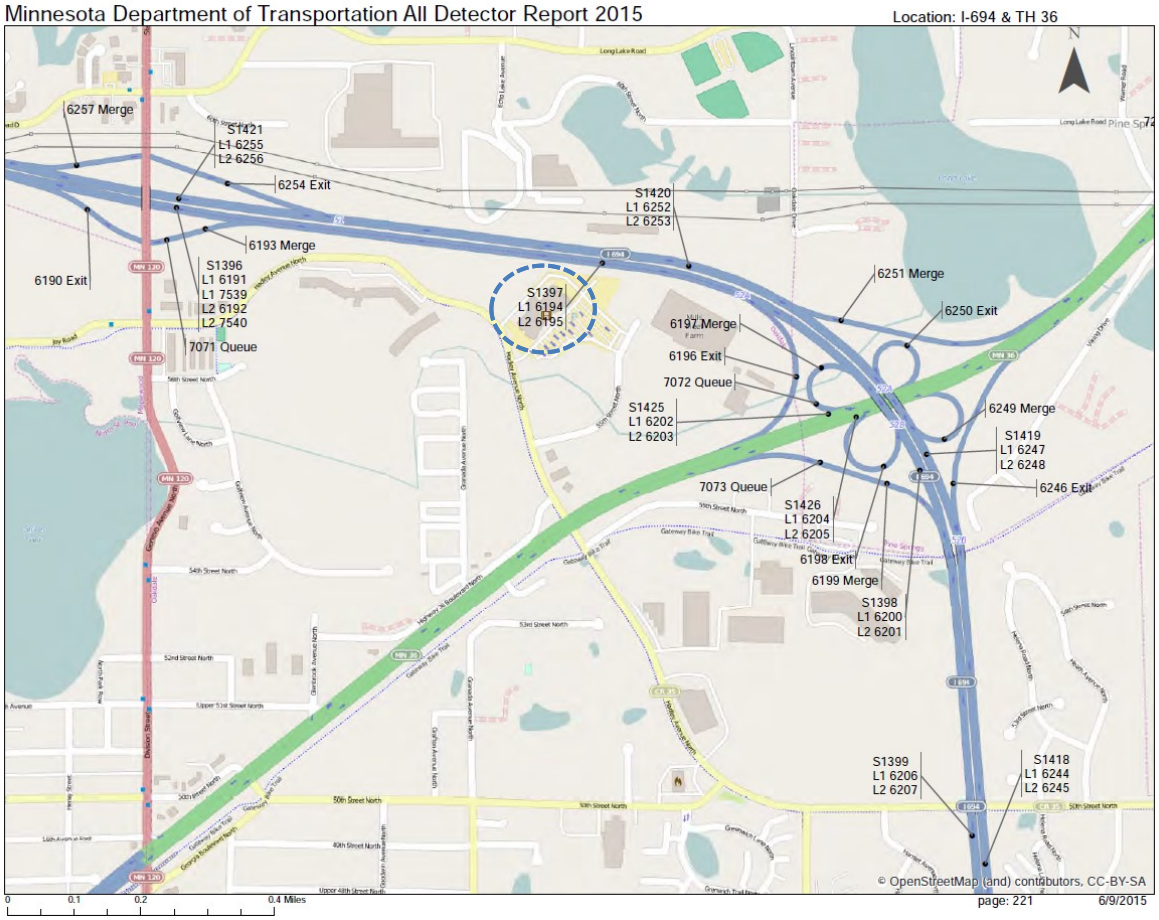
'194387484', '2015010811182594', '2015-01-08 11:18:26', 'Incident CRASH', 'I-694', 'EB', '..!!', 'f', 't', 'C719', 'Mainline', '', NULL, '45.0322380065918', '-92.9670104980469'

'194389316', '2015010811182594', '2015-01-08 11:49:14', 'Incident CRASH', 'I-694', 'EB', '..!!', 't', 't', 'C719', 'Mainline', '', NULL, '45.0322380065918', '-92.9670104980469'

ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDe	COV_upDiff	COV_
2015-01-06	I-694	EB	S1397		6194	0	1	0	1	0	0	0	0	0	0	0	0.918076	119	17403	31643	0	-76.95	-5.47
2015-01-06	I-694	EB	S1397		6195	0	1	0	1	0	0	0	0	0	0	0	0.960598	47	14240	31643	0	-76.95	-5.47
2015-01-07	I-694	EB	S1397		6194	0	0	0	0	0	0	0	0	0	0	0	0.915719	109	17649	30726	0	-77.65	-4.87
2015-01-07	I-694	EB	S1397		6195	55	0	55	0	0	0	1	0	0	0	0	0.962976	41	13077	30726	0	-77.65	-4.87
2015-01-08	I-694	EB	S1397		6194	0	0	0	2	0	0	0	86	0	0	0	0.373119	268	13764	24811	0	-84.66	-1.32
2015-01-08	I-694	EB	S1397		6195	20	0	20	3	0	0	0	123	0	0	0	0.385231	153	11047	24811	0	-84.66	-1.32
2015-01-09	I-694	EB	S1397		6194	0	0	0	0	0	0	0	1	0	0	0	0.872628	105	18193	32300	0	-77.05	-6.5
2015-01-09	I-694	EB	S1397		6195	44	0	44	0	0	0	0	0	0	0	0	0.924819	47	14107	32300	0	-77.05	-6.5
NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL

It can be seen that on 8th Jan, 2015 that two incidents of CRASH occurred, which resulted in high occupancy values at S1397.

It should also be noted that this incident resulted in a closure of two lanes instead of one in previous incidents.



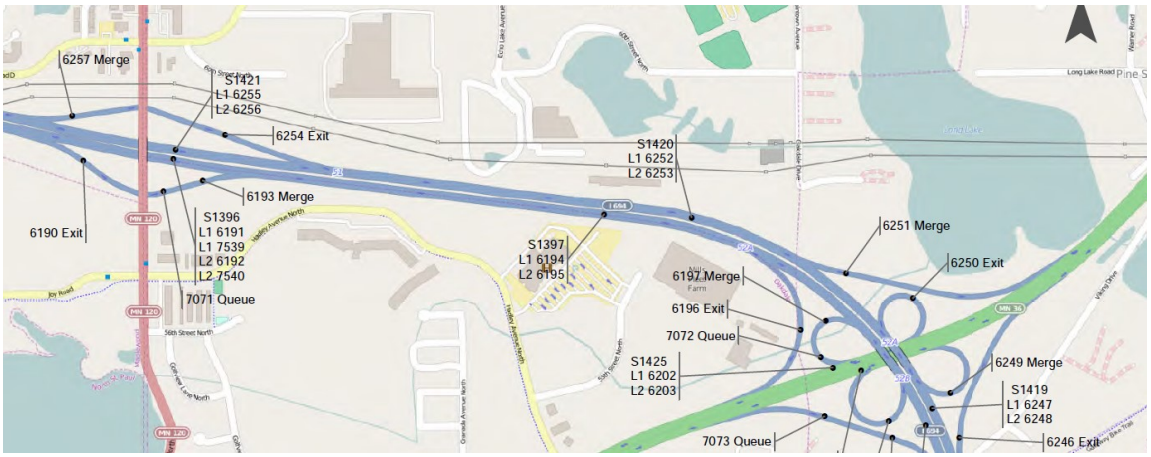
'194390265', '2015010812034773', '2015-01-08 12:03:48', 'Incident CRASH', 'I-694', 'EB', '..!!', 'f', 't', 'C718', 'Mainline', '', NULL, '45.0336532592773', '-92.9810638427734'

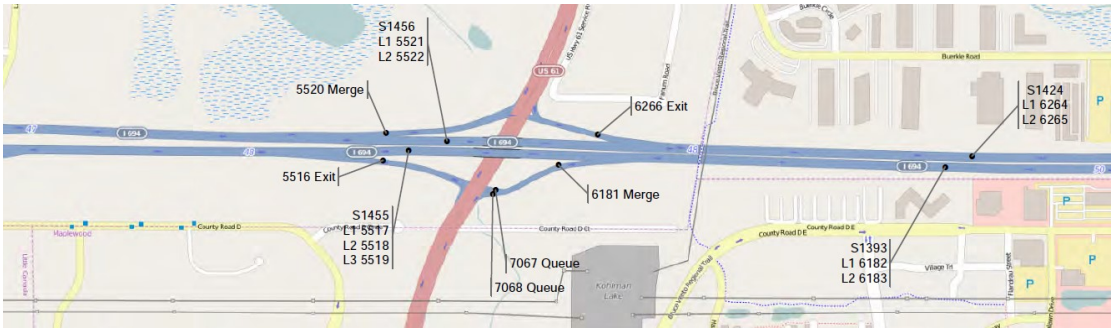
'194391100', '2015010812034773', '2015-01-08 12:16:35', 'Incident CRASH', 'I-694', 'EB', '...!', 'f', 't', 'C718', 'Mainline', '', NULL, '45.0336532592773', '-92.9810638427734'

'194397012', '2015010812034773', '2015-01-08 13:47:05', 'Incident CRASH', 'I-694', 'EB', '...!', 't', 't', 'C718', 'Mainline', '', NULL, '45.0336532592773', '-92.9810638427734'

2015-01-08	I-694	EB	S1394	6185	0	0	0	0	0	0	0	100	0	0	0	0.45186	356	11735	23145	0	100	18.
2015-01-08	I-694	EB	S1394	6186	24	0	24	0	0	0	0	59	0	0	0	0.675826	131	11410	23145	0	100	18.
2015-01-08	I-694	EB	S1395	6188	0	0	0	0	0	0	0	74	0	0	0	0.598209	218	15630	27392	0	15.5	67.
2015-01-08	I-694	EB	S1395	6189	48	0	48	0	0	0	0	32	0	0	0	0.685482	153	11762	27392	0	15.5	67.
2015-01-08	I-694	EB	S1396	6191	0	0	0	16	0	0	0	103	0	0	0	0.252153	346	11115	45816	0	40.21	-45
2015-01-08	I-694	EB	S1396	6192	40	0	40	8	0	0	0	102	0	0	0	0.36473	186	10431	45816	0	40.21	-45
2015-01-08	I-694	EB	S1396	7539	124	0	124	0	0	0	0	0	0	0	0	0.87181	224	12303	45816	0	40.21	-45
2015-01-08	I-694	EB	S1396	7540	186	0	186	0	0	0	0	0	0	0	0	0.895236	104	11967	45816	0	40.21	-45
2015-01-08	I-694	EB	S1397	6194	0	0	0	2	0	0	0	86	0	0	0	0.373119	268	13764	24811	0	-84.66	-1.
2015-01-08	I-694	EB	S1397	6195	20	0	20	3	0	0	0	123	0	0	0	0.385231	153	11047	24811	0	-84.66	-1.
2015-01-08	I-694	EB	S1455	5517	1986	0	1986	0	0	0	0	0	0	0	0	0.699051	41	281	25149	0	-0.78	-10
2015-01-08	I-694	EB	S1455	5518	0	0	0	0	0	0	0	204	0	0	0	0.34498	267	15283	25149	0	-0.78	-10
2015-01-08	I-694	EB	S1455	5519	57	0	57	1	0	0	0	204	0	0	0	0.603279	140	9585	25149	0	-0.78	-10

Since S1455, S1393, S1394, S1395, S1396 and S1397 are adjacent, incident at S1396 has effect on all of them, resulting in high highOcc values at all stations on the date of incident. S1393 was not working at that time.





'194390304', '2015010812043678', '2015-01-08 12:04:37', 'Incident CRASH', 'I-694', 'EB', '!..!', 'f', 't', 'C715', 'Mainline', '', NULL, '45.0374145507812', '-93.0440902709961'

'194391513', '2015010812043678', '2015-01-08 12:23:36', 'Incident CRASH', 'I-694', 'EB', '!..!', 't', 't', 'C715', 'Mainline', '', NULL, '45.0374145507812', '-93.0440902709961'

'194391789', '2015010812043678', '2015-01-08 12:27:36', 'Incident CRASH', 'I-694', 'EB', '!..!', 'f', 't', 'C715', 'Mainline', '', NULL, '45.0374145507812', '-93.0440902709961'

'194393899', '2015010812043678', '2015-01-08 13:02:07', 'Incident CRASH', 'I-694', 'EB', '!..!', 't', 't', 'C715', 'Mainline', '', NULL, '45.0374145507812', '-93.0440902709961'

All these incidents happened at S1455. Same patterns as previous are shown. All downstream stations are affected resulting high occupancies.

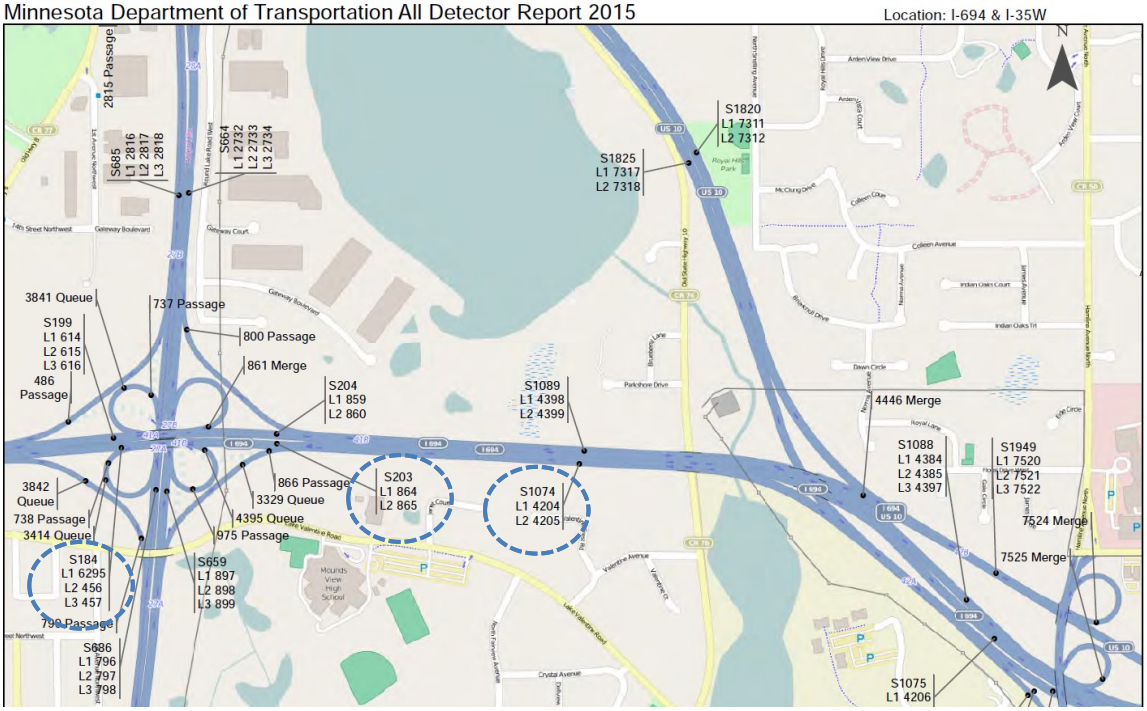
2015-01-08	I-694	EB	S1394	6185	0	0	0	0	0	0	0	100	0	0	0	0.45186	356	11735	23145	0	100	18.
2015-01-08	I-694	EB	S1394	6186	24	0	24	0	0	0	0	59	0	0	0	0.675826	131	11410	23145	0	100	18.
2015-01-08	I-694	EB	S1395	6188	0	0	0	0	0	0	0	74	0	0	0	0.598209	218	15630	27392	0	15.5	67.
2015-01-08	I-694	EB	S1395	6189	48	0	48	0	0	0	0	32	0	0	0	0.685482	153	11762	27392	0	15.5	67.
2015-01-08	I-694	EB	S1396	6191	0	0	0	16	0	0	0	103	0	0	0	0.252153	346	11115	45816	0	40.21	-45
2015-01-08	I-694	EB	S1396	6192	40	0	40	8	0	0	0	102	0	0	0	0.36473	186	10431	45816	0	40.21	-45
2015-01-08	I-694	EB	S1396	7539	124	0	124	0	0	0	0	0	0	0	0	0.87181	224	12303	45816	0	40.21	-45
2015-01-08	I-694	EB	S1396	7540	186	0	186	0	0	0	0	0	0	0	0	0.895236	104	11967	45816	0	40.21	-45
2015-01-08	I-694	EB	S1397	6194	0	0	0	2	0	0	0	86	0	0	0	0.373119	268	13764	24811	0	-84.66	-1.
2015-01-08	I-694	EB	S1397	6195	20	0	20	3	0	0	0	123	0	0	0	0.385231	153	11047	24811	0	-84.66	-1.
2015-01-08	I-694	EB	S1455	5517	1986	0	1986	0	0	0	0	0	0	0	0	0.699051	41	281	25149	0	-0.78	-10
2015-01-08	I-694	EB	S1455	5518	0	0	0	0	0	0	0	204	0	0	0	0.34498	267	15283	25149	0	-0.78	-10
2015-01-08	I-694	EB	S1455	5519	57	0	57	1	0	0	0	204	0	0	0	0.603279	140	9585	25149	0	-0.78	-10

'194390567', '2015010812085843', '2015-01-08 12:08:58', 'Incident CRASH', 'I-694', 'EB', '...!', 'f', 't', 'C706', 'Mainline', '', NULL, '45.0670928955078', '-93.182731628418'

'194390577', '2015010812085843', '2015-01-08 12:09:14', 'Incident CRASH', 'I-694', 'EB', '...!', 't', 't', 'C706', 'Mainline', '', NULL, '45.0670928955078', '-93.182731628418'

The incidents affected occupancies of S203, S184 and S1074.

ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDe	COV_upDiff	COV_
2015-01-06	I-694	EB	S1074		4204	0	1	0	1	0	0	0	34	0	0	0	0.730805	84	19040	36193	0	6.96	-13.06
2015-01-06	I-694	EB	S1074		4205	44	1	44	2	0	0	0	120	0	0	0	0.586941	41	17153	36193	0	6.96	-13.06
2015-01-06	I-694	EB	S184		456	0	1	0	2	0	0	0	89	0	0	0	0.503197	94	14967	40988	0	-31.12	-17.85
2015-01-06	I-694	EB	S184		457	26	1	26	2	0	0	0	90	0	0	0	0.644341	53	15072	40988	0	-31.12	-17.85
2015-01-06	I-694	EB	S184		6295	0	1	0	2	0	0	0	38	0	0	0	0.691201	89	10949	40988	0	-31.12	-17.85
2015-01-06	I-694	EB	S203		864	0	1	0	3	0	0	0	135	0	0	0	0.661015	74	16368	33673	0	-21.72	7.48
2015-01-06	I-694	EB	S203		865	0	1	0	2	0	0	0	144	0	0	0	0.530043	111	17305	33673	0	-21.72	7.48
2015-01-07	I-694	EB	S1074		4204	0	0	0	0	0	0	0	16	0	0	0	0.778081	86	19301	35695	0	7.64	-14.29
2015-01-07	I-694	EB	S1074		4205	0	0	0	0	0	0	0	30	0	0	0	0.717717	35	16394	35695	0	7.64	-14.29
2015-01-07	I-694	EB	S184		456	0	0	0	0	0	0	0	0	0	0	0	0.919029	93	15081	40085	0	-31.83	-17.76
2015-01-07	I-694	EB	S184		457	0	0	0	0	0	0	0	0	0	0	0	0.972465	47	14194	40085	0	-31.83	-17.76
2015-01-07	I-694	EB	S184		6295	0	0	0	0	0	0	0	0	0	0	0	0.95801	53	10810	40085	0	-31.83	-17.76
2015-01-07	I-694	EB	S203		864	0	0	0	0	0	0	0	3	0	0	0	0.917957	53	15438	32967	0	-21.59	8.27
2015-01-07	I-694	EB	S203		865	0	0	0	0	0	0	0	4	0	0	0	0.850625	123	17529	32967	0	-21.59	8.27
2015-01-08	I-694	EB	S1074		4204	0	0	0	0	0	0	0	147	0	0	0	0.403825	321	15569	29400	0	6.56	-13.32
2015-01-08	I-694	EB	S1074		4205	0	0	0	0	0	0	0	281	0	0	0	0.390011	205	13831	29400	0	6.56	-13.32
2015-01-08	I-694	EB	S184		456	0	0	0	16	0	0	0	371	0	0	0	0.19908	309	11987	32748	0	-33.06	-16.12
2015-01-08	I-694	EB	S184		457	0	0	0	0	0	0	0	371	0	0	0	0.370179	168	12489	32748	0	-33.06	-16.12
2015-01-08	I-694	EB	S184		6295	0	0	0	1	0	0	0	16	0	0	0	0.776896	266	8272	32748	0	-33.06	-16.12
2015-01-08	I-694	EB	S203		864	0	0	0	2	0	0	0	442	0	0	0	0.379842	190	13572	27470	0	-19.21	7.03
2015-01-08	I-694	EB	S203		865	0	0	0	12	0	0	0	413	0	0	0	0.268324	310	13898	27470	0	-19.21	7.03
2015-01-09	I-694	EB	S1074		4204	0	0	0	1	0	0	0	86	0	0	0	0.682981	122	19054	35799	0	7.87	-14.41
2015-01-09	I-694	EB	S1074		4205	0	0	0	0	0	0	0	225	0	0	0	0.576672	71	16745	35799	0	7.87	-14.41
2015-01-09	I-694	EB	S184		456	0	0	0	1	0	0	0	406	0	0	0	0.4153	160	14734	40641	0	-33.11	-18.85
2015-01-09	I-694	EB	S184		457	0	0	0	6	0	0	0	390	0	0	0	0.637662	82	14504	40641	0	-33.11	-18.85
2015-01-09	I-694	EB	S184		6295	0	0	0	0	0	0	0	39	0	0	0	0.798258	95	11403	40641	0	-33.11	-18.85
2015-01-09	I-694	EB	S203		864	0	0	0	4	0	0	0	421	0	0	0	0.661563	83	15822	32981	0	-23.23	8.54
2015-01-09	I-694	EB	S203		865	0	0	0	3	0	0	0	511	0	0	0	0.471117	154	17159	32981	0	-23.23	8.54

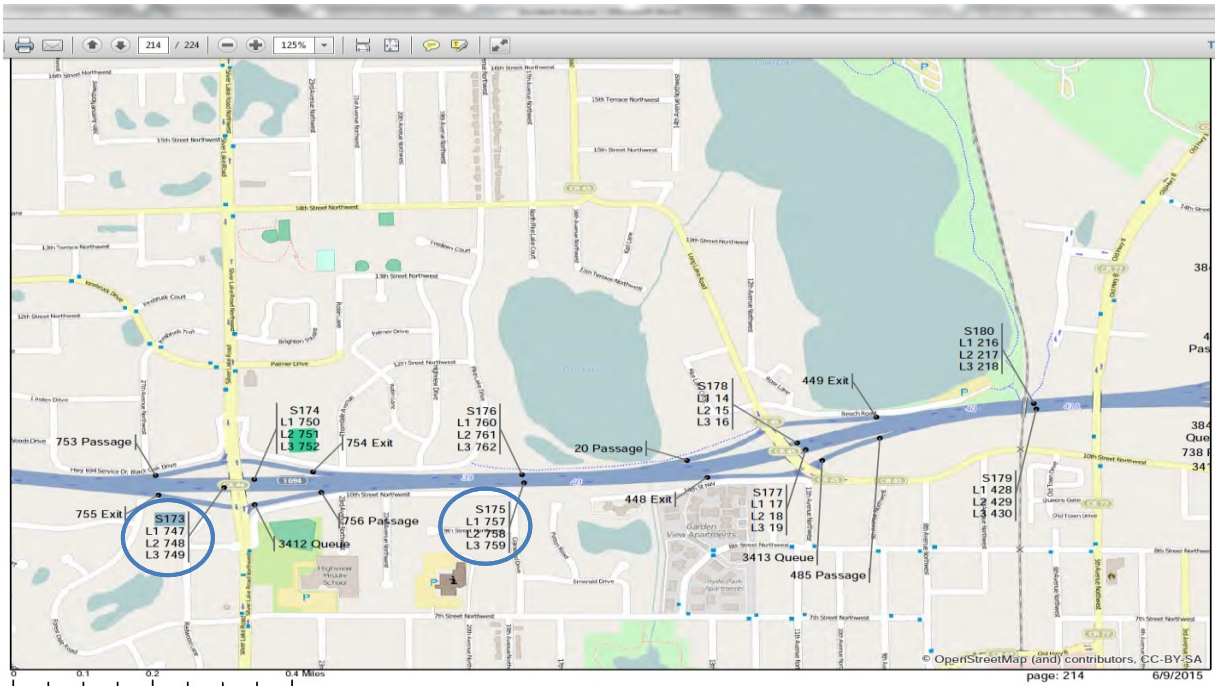


'194392694', '20150108124248 91', '2015-01-08 12:42:49', 'Incident CRASH', 'I-694', 'EB', '...!!', 'f', 't', 'C704', 'Mainline', '', NULL, '45.0645713806152', '-93.223518371582'

'194404372', '20150108124248 91', '2015-01-08 14:45:34', 'Incident CRASH', 'I-694', 'EB', '...!!', 't', 't', 'C704', 'Mainline', '', NULL, '45.0645713806152', '-93.223518371582'

The incidents affected highOcc on S173 and S175.

ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDe	COV_upDi
2015-01-07	I-694	EB	S173		747	0	0	0	0	0	0	0	0	0	0	0	0.931924	36	15591	48403	0	-13.98
2015-01-07	I-694	EB	S173		748	0	0	0	0	0	0	0	0	0	0	0	0.929928	84	18061	48403	0	-13.98
2015-01-07	I-694	EB	S173		749	79	0	79	0	0	0	0	0	0	0	0	0.974389	44	14751	48403	0	-13.98
2015-01-07	I-694	EB	S175		757	0	0	0	0	0	0	0	7	0	0	0	0.929455	93	21572	54811	0	11.69
2015-01-07	I-694	EB	S175		758	0	0	0	0	0	0	0	2	0	0	0	0.930445	116	19019	54811	0	11.69
2015-01-07	I-694	EB	S175		759	51	0	51	0	0	0	0	0	0	0	0	0.972337	35	14220	54811	0	11.69
2015-01-08	I-694	EB	S173		747	46	0	46	0	0	0	0	10	0	0	0	0.677747	100	12659	40825	0	-13.83
2015-01-08	I-694	EB	S173		748	0	0	0	0	0	0	0	19	0	0	0	0.65339	242	14827	40825	0	-13.83
2015-01-08	I-694	EB	S173		749	0	0	0	0	0	0	0	19	0	0	0	0.701244	144	13339	40825	0	-13.83
2015-01-08	I-694	EB	S175		757	0	0	0	0	0	0	1	90	0	0	0	0.717011	180	19438	47725	0	14.46
2015-01-08	I-694	EB	S175		758	0	0	0	0	0	0	0	33	0	0	0	0.706137	272	15484	47725	0	14.46
2015-01-08	I-694	EB	S175		759	0	0	0	0	0	0	0	68	0	0	0	0.554405	157	12803	47725	0	14.46
2015-01-09	I-694	EB	S173		747	0	0	0	0	0	0	0	1	0	0	0	0.842282	43	15945	50553	0	-14.26
2015-01-09	I-694	EB	S173		748	0	0	0	0	0	0	0	7	0	0	0	0.82797	83	18607	50553	0	-14.26
2015-01-09	I-694	EB	S173		749	0	0	0	0	0	0	0	2	0	0	0	0.890229	60	16001	50553	0	-14.26
2015-01-09	I-694	EB	S175		757	0	0	0	0	0	0	0	59	0	0	0	0.868777	96	21957	57115	0	11.49
2015-01-09	I-694	EB	S175		758	0	0	0	0	0	0	0	18	0	0	0	0.859563	107	19615	57115	0	11.49
2015-01-09	I-694	EB	S175		759	0	0	0	0	0	0	0	10	0	0	0	0.873268	58	15543	57115	0	11.49

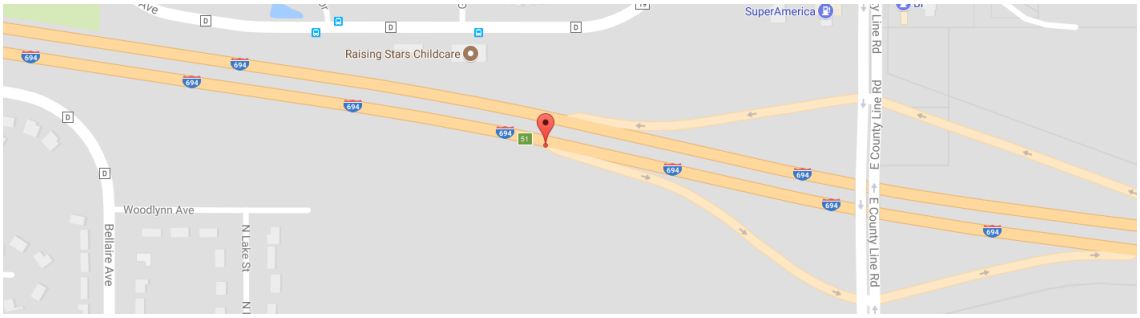


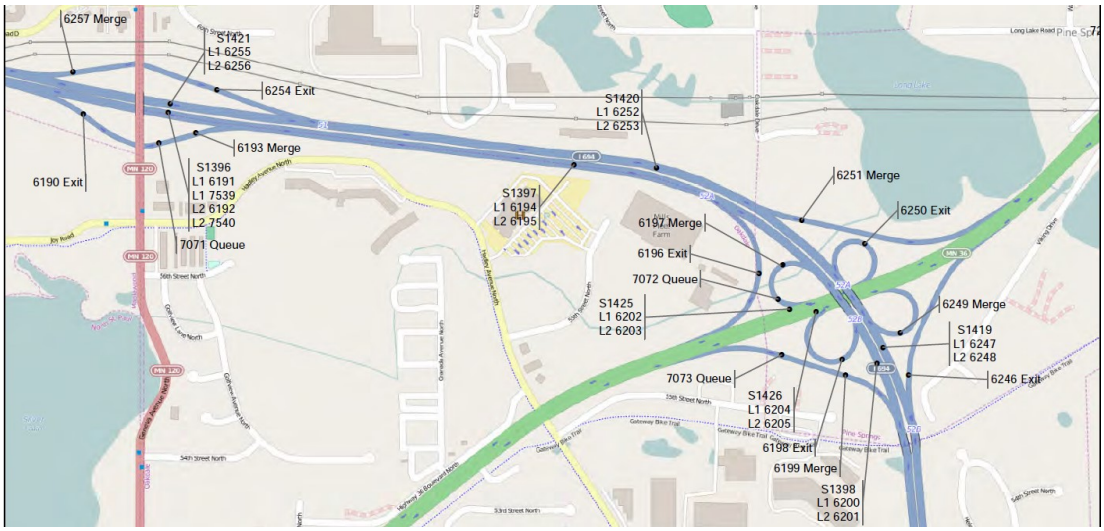
Incident: Roadwork

Incidents:

'194787531', '2015011312165690', '2015-01-13 12:16:57', 'Incident ROADWORK', 'I-694', 'EB', '!!!', 'f', 't', 'C718', 'Exit', '', NULL, '45.0346717834473', '-92.9891204833984'

'194791241', '2015011312165690', '2015-01-13 13:45:11', 'Incident ROADWORK', 'I-694', 'EB', '!!!', 't', 't', 'C718', 'Exit', '', NULL, '45.0346717834473', '-92.9891204833984'





ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDe	COV_u
2015-01-12	I-694	EB	S1395		6188	0	3	0	3	0	0	0	1	0	0	0	0.925267	90	21203	37131	0	17.03
2015-01-12	I-694	EB	S1395		6189	162	3	162	3	0	0	0	0	0	0	0	0.95836	38	15928	37131	0	17.03
2015-01-12	I-694	EB	S1396		6191	0	4	0	4	0	0	0	0	0	0	0	0.891772	108	14297	56926	0	34.77
2015-01-12	I-694	EB	S1396		6192	222	4	222	4	0	0	0	0	0	0	0	0.966979	32	14123	56926	0	34.77
2015-01-12	I-694	EB	S1396		7539	0	4	0	4	0	0	0	0	0	0	0	0.906355	150	14382	56926	0	34.77
2015-01-12	I-694	EB	S1396		7540	221	4	221	4	0	0	0	0	0	0	0	0.972428	33	14124	56926	0	34.77
2015-01-12	I-694	EB	S1397		6194	0	3	0	3	0	0	0	0	0	0	0	0.931936	83	18599	33036	0	-72.32
2015-01-12	I-694	EB	S1397		6195	166	3	166	3	0	0	0	0	0	0	0	0.967487	33	14437	33036	0	-72.32
2015-01-13	I-694	EB	S1395		6188	0	0	0	0	0	0	0	1	0	0	0	0.916993	109	21442	38071	0	17.28
2015-01-13	I-694	EB	S1395		6189	52	0	52	0	0	0	0	3	0	0	0	0.934606	53	16629	38071	0	17.28
2015-01-13	I-694	EB	S1396		6191	0	0	0	0	0	0	0	0	0	0	0	0.900215	138	14881	59669	0	36.2
2015-01-13	I-694	EB	S1396		6192	132	0	132	0	0	0	0	0	0	0	0	0.962855	47	14931	59669	0	36.2
2015-01-13	I-694	EB	S1396		7539	0	0	0	0	0	0	0	0	0	0	0	0.916228	176	14947	59669	0	36.2
2015-01-13	I-694	EB	S1396		7540	132	0	132	0	0	0	0	0	0	0	0	0.969772	51	14910	59669	0	36.2
2015-01-13	I-694	EB	S1397		6194	0	0	0	0	0	0	0	0	0	0	0	0.931633	132	19338	34549	0	-72.71
2015-01-13	I-694	EB	S1397		6195	114	0	114	0	0	0	0	0	0	0	0	0.968255	35	15211	34549	0	-72.71
2015-01-14	I-694	EB	S1395		6188	0	0	0	0	0	0	0	4	0	0	0	0.893419	117	21699	38636	0	16.85
2015-01-14	I-694	EB	S1395		6189	219	0	219	0	0	0	0	1	0	0	0	0.946491	41	16937	38636	0	16.85
2015-01-14	I-694	EB	S1396		6191	0	0	0	0	0	0	0	0	0	0	0	0.878127	131	14663	59142	0	34.67
2015-01-14	I-694	EB	S1396		6192	176	0	176	0	0	0	0	0	0	0	0	0.962072	55	14840	59142	0	34.67
2015-01-14	I-694	EB	S1396		7539	0	0	0	0	0	0	0	0	0	0	1	0.896801	181	14804	59142	0	34.67
2015-01-14	I-694	EB	S1396		7540	176	0	176	0	0	0	0	0	0	0	0	0.970464	62	14835	59142	0	34.67
2015-01-14	I-694	EB	S1397		6194	0	0	0	0	0	0	0	0	0	0	0	0.915784	108	19184	34383	0	-72.01
2015-01-14	I-694	EB	S1397		6195	167	0	167	0	0	0	0	0	0	0	0	0.964871	46	15199	34383	0	-72.01

As can be seen, highOcc was not affected by 'Incident Roadwork' because all lanes were closed "!!!" in this case. The conZeroVol values seem to be high but it is interesting to note that they are also high before as well as after the date of incident. Thus, it appears "Incident Roadwork" cause lane closures and zero volumes.

Incidents:

'195117558', '2015011716115872', '2015-01-17 16:11:59', 'Incident CRASH', 'I-694', 'EB', '!!.....', 'f', 't', 'C701', 'Mainline', '', NULL, '45.0691680908203', '-93.2806396484375'

'195118387', '2015011716115872', '2015-01-17 16:29:43', 'Incident CRASH', 'I-694', 'EB', '!!!....', 'f', 't', 'C701', 'Mainline', '', NULL, '45.0691680908203', '-93.2806396484375'

'195124950', '2015011716115872', '2015-01-17 18:43:38', 'Incident CRASH', 'I-694', 'EB', '!!!....', 't', 't', 'C701', 'Mainline', '', NULL, '45.0691680908203', '-93.2806396484375'

ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDe	COV_upD
2015-01-15	I-694	EB	S145		439	0	0	0	0	0	0	0	73	0	0	0	0.63854	27	13127	67782	0	-1.79
2015-01-15	I-694	EB	S145		440	0	0	0	0	0	0	0	68	0	0	0	0.655264	24	17484	67782	0	-1.79
2015-01-15	I-694	EB	S145		441	0	0	0	0	0	0	0	57	0	0	0	0.749982	47	17933	67782	0	-1.79
2015-01-15	I-694	EB	S145		442	0	0	0	0	0	0	0	63	0	0	0	0.708185	93	19238	67782	0	-1.79
2015-01-15	I-694	EB	S149		526	0	0	0	1	0	0	0	87	0	0	0	0.643677	42	17471	77030	0	12.01
2015-01-15	I-694	EB	S149		527	0	0	0	0	0	0	0	77	0	0	0	0.713798	18	19876	77030	0	12.01
2015-01-15	I-694	EB	S149		528	0	0	0	0	0	0	0	36	0	0	0	0.773604	94	19614	77030	0	12.01
2015-01-15	I-694	EB	S149		529	0	0	0	0	0	0	0	43	0	0	0	0.800195	49	18107	77030	0	12.01
2015-01-15	I-694	EB	S149		3070	384	0	384	0	0	0	0	0	0	0	1	0.649644	174	1962	77030	0	12.01
2015-01-16	I-694	EB	S145		439	0	0	0	0	0	0	0	73	0	0	0	0.724783	23	14084	70941	0	-1.68
2015-01-16	I-694	EB	S145		440	0	0	0	0	0	0	0	76	0	0	0	0.689592	17	18505	70941	0	-1.68
2015-01-16	I-694	EB	S145		441	0	0	0	0	0	0	0	67	0	0	0	0.750776	31	18381	70941	0	-1.68
2015-01-16	I-694	EB	S145		442	0	0	0	0	0	0	0	87	0	0	0	0.720839	86	19971	70941	0	-1.68
2015-01-16	I-694	EB	S149		526	0	0	0	0	0	0	0	72	0	0	0	0.688027	33	18620	81131	0	12.56
2015-01-16	I-694	EB	S149		527	0	0	0	0	0	0	0	62	0	0	0	0.743913	18	20912	81131	0	12.56
2015-01-16	I-694	EB	S149		528	0	0	0	0	0	0	0	44	0	0	0	0.79073	90	20577	81131	0	12.56
2015-01-16	I-694	EB	S149		529	0	0	0	0	0	0	0	41	0	0	0	0.829179	34	18657	81131	0	12.56
2015-01-16	I-694	EB	S149		3070	241	0	241	0	0	0	0	0	0	0	0	0.732871	171	2365	81131	0	12.56
2015-01-17	I-694	EB	S145		439	21	0	21	1	0	0	0	219	0	0	0	0.627494	10	10288	45287	0	-0.53
2015-01-17	I-694	EB	S145		440	0	0	0	1	0	0	0	201	0	0	0	0.444584	28	13448	45287	0	-0.53
2015-01-17	I-694	EB	S145		441	304	0	304	0	0	0	0	0	0	0	0	0.960468	28	8711	45287	0	-0.53
2015-01-17	I-694	EB	S145		442	241	0	241	0	0	0	0	31	0	0	0	0.571877	72	12840	45287	0	-0.53
2015-01-17	I-694	EB	S149		526	30	0	30	0	0	0	0	0	0	0	0	0.978048	13	14189	53344	0	15.1
2015-01-17	I-694	EB	S149		527	30	0	30	0	0	0	0	0	0	0	0	0.972323	18	15212	53344	0	15.1
2015-01-17	I-694	EB	S149		528	31	0	31	0	0	0	0	0	0	0	0	0.938205	60	13959	53344	0	15.1
2015-01-17	I-694	EB	S149		529	59	0	59	0	0	0	0	0	0	0	0	0.974225	33	8717	53344	0	15.1
2015-01-17	I-694	EB	S149		3070	430	0	430	1	0	0	0	0	0	0	0	0.532049	103	1267	53344	0	15.1

This CRASH incident happened right after S145 and before S149. High values of highOcc are mostly visible at the time of the crash incident.

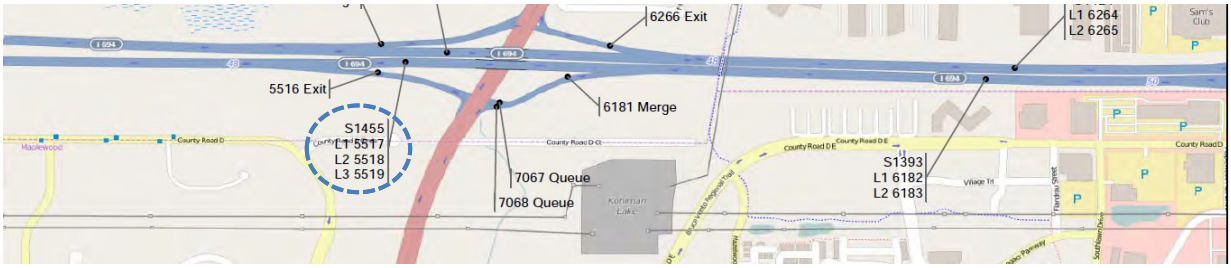
Incident: STALL

'194931151', '2015011507040689', '2015-01-15 07:04:07', 'Incident STALL', 'I-694', 'EB', '.?!', 'f', 't', 'C715', 'Exit', '', NULL, '45.0374145507812', '-93.0481567382812'

'194931279', '2015011507040689', '2015-01-15 07:05:22', 'Incident STALL', 'I-694', 'EB', '.?!', 't', 't', 'C715', 'Exit', '', NULL, '45.0374145507812', '-93.0481567382812'

ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDe	COV_u
2015-01-14	I-694	EB	S1393		6182	0	1370	0	1372	0	2	0	16	0	0	0	0.922057	1388	14358	25235	0	-40.25
2015-01-14	I-694	EB	S1393		6183	0	1370	0	1370	0	0	0	1	0	0	0	0.946015	1385	10877	25235	0	-40.25
2015-01-14	I-694	EB	S1455		5517	910	0	910	0	0	0	0	0	0	0	0	0.865926	31	571	35393	0	6.74
2015-01-14	I-694	EB	S1455		5518	0	0	0	0	0	0	0	6	0	0	0	0.858071	133	21079	35393	0	6.74
2015-01-14	I-694	EB	S1455		5519	250	0	250	0	0	0	0	2	0	0	0	0.922412	38	13743	35393	0	6.74
2015-01-15	I-694	EB	S1393		6182	0	0	0	0	0	0	0	1	0	0	0	0.941245	86	23412	40640	0	11.13
2015-01-15	I-694	EB	S1393		6183	45	0	45	0	0	1	0	2	0	0	0	0.964955	38	17228	40640	0	11.13
2015-01-15	I-694	EB	S1455		5517	935	0	935	0	0	0	0	0	0	0	0	0.915678	9	590	36117	0	6.76
2015-01-15	I-694	EB	S1455		5518	0	0	0	0	0	0	0	0	0	0	0	0.924412	84	21295	36117	0	6.76
2015-01-15	I-694	EB	S1455		5519	92	0	92	0	0	0	0	0	0	0	0	0.969427	41	14232	36117	0	6.76
2015-01-16	I-694	EB	S1393		6182	0	0	0	0	0	0	0	8	0	0	0	0.910323	68	23793	41264	0	11.2
2015-01-16	I-694	EB	S1393		6183	44	0	44	0	0	0	0	6	0	0	0	0.936536	27	17471	41264	0	11.2
2015-01-16	I-694	EB	S1455		5517	806	0	806	0	0	0	0	0	0	0	0	0.920885	15	678	36644	0	6.9
2015-01-16	I-694	EB	S1455		5518	0	0	0	0	0	0	0	2	0	0	0	0.901611	97	21746	36644	0	6.9
2015-01-16	I-694	EB	S1455		5519	46	0	46	0	0	0	0	0	0	0	0	0.948525	26	14220	36644	0	6.9

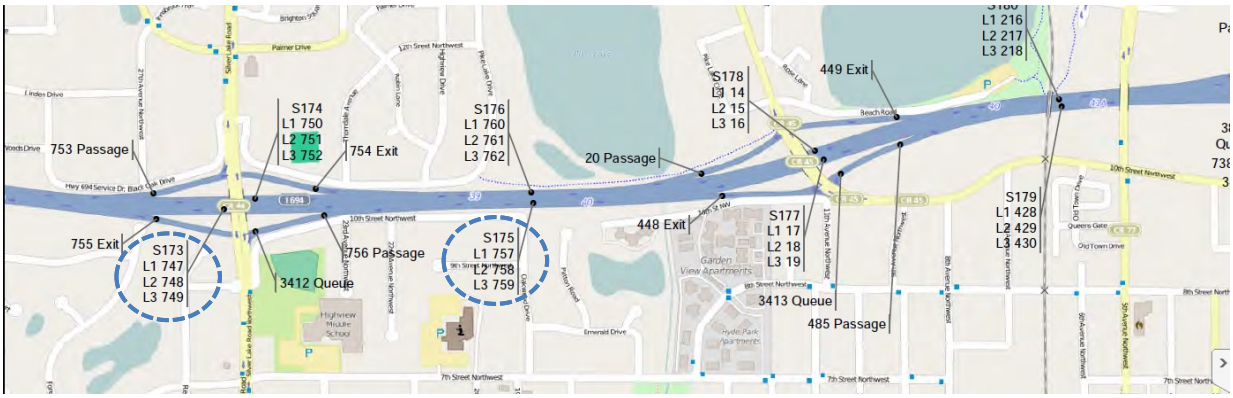
The above data on 15-01-2015 shows a pattern that somewhat matches with the lane closing pattern ".?!". The above incident happened at directly above S1455.



'194949148', '2015011510480883', '2015-01-15 10:48:10', 'Incident STALL', 'I-694', 'EB', '..!', 'f', 't', 'C704', 'Exit', '', NULL, '45.0644226074219', '-93.2216796875'

'194952921', '2015011510480883', '2015-01-15 12:17:12', 'Incident STALL', 'I-694', 'EB', '..!', 't', 't', 'C704', 'Exit', '', NULL, '45.0644226074219', '-93.2216796875'

ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDe	COV_upD
2015-01-14	I-694	EB	S173		747	0	0	0	0	0	0	0	0	0	0	0	0.935103	32	16738	52908	0	-14.53
2015-01-14	I-694	EB	S173		748	0	0	0	0	0	0	0	0	0	0	0	0.930843	86	19399	52908	0	-14.53
2015-01-14	I-694	EB	S173		749	26	0	26	0	0	0	0	0	0	0	0	0.971225	64	16771	52908	0	-14.53
2015-01-14	I-694	EB	S175		757	0	0	0	0	0	0	1	28	0	0	0	0.912754	67	23336	60192	0	12.1
2015-01-14	I-694	EB	S175		758	0	0	0	0	0	0	0	1	0	0	0	0.931259	97	20711	60192	0	12.1
2015-01-14	I-694	EB	S175		759	20	0	20	0	0	0	1	4	0	0	0	0.917519	51	16145	60192	0	12.1
2015-01-15	I-694	EB	S173		747	0	0	0	0	0	0	0	3	0	0	0	0.877133	44	17389	54396	0	-13.81
2015-01-15	I-694	EB	S173		748	0	0	0	0	0	0	0	2	0	0	0	0.907485	61	19679	54396	0	-13.81
2015-01-15	I-694	EB	S173		749	0	0	0	0	0	0	0	0	0	0	0	0.953637	34	17328	54396	0	-13.81
2015-01-15	I-694	EB	S175		757	0	0	0	0	0	0	0	7	0	0	0	0.959021	69	24251	62020	0	12.29
2015-01-15	I-694	EB	S175		758	0	0	0	0	0	0	0	5	0	0	0	0.920585	93	20974	62020	0	12.29
2015-01-15	I-694	EB	S175		759	0	0	0	0	0	0	1	5	0	0	0	0.929848	31	16795	62020	0	12.29
2015-01-16	I-694	EB	S173		747	0	0	0	0	0	0	0	0	0	0	0	0.941816	45	18399	56694	0	-13.52
2015-01-16	I-694	EB	S173		748	0	0	0	0	0	0	0	0	0	0	0	0.940192	61	20570	56694	0	-13.52
2015-01-16	I-694	EB	S173		749	0	0	0	0	0	0	0	0	0	0	0	0.977745	29	17725	56694	0	-13.52
2015-01-16	I-694	EB	S175		757	0	0	0	0	0	0	1	0	0	0	0	0.969553	55	25570	64277	0	11.8
2015-01-16	I-694	EB	S175		758	0	0	0	0	0	0	0	0	0	0	0	0.953526	94	21682	64277	0	11.8
2015-01-16	I-694	EB	S175		759	0	0	0	0	0	0	0	0	0	0	0	0.973753	27	17025	64277	0	11.8



This incident STALL was on S173. Checking both S173 and S175, it does not show any noticeable increase in health parameters and change in traffic volume.

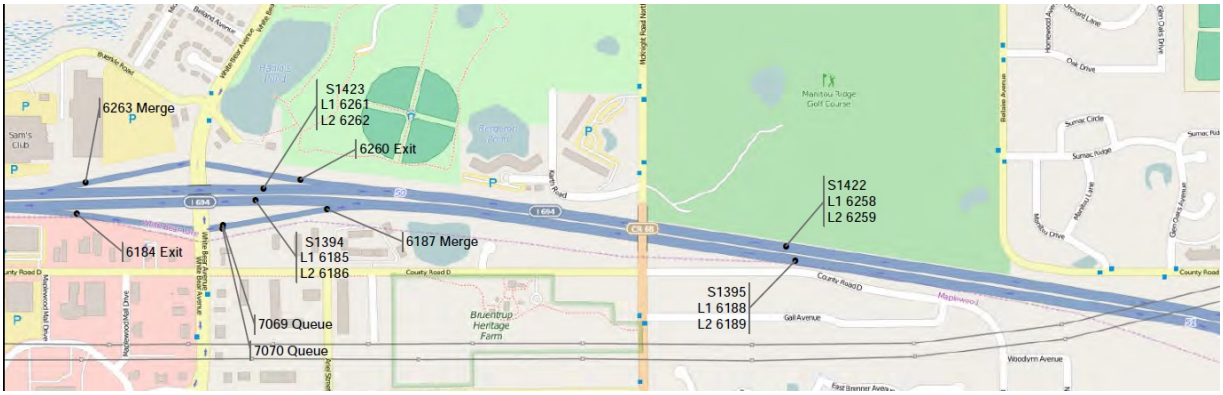
Incident: HAZARD

'195061627', '2015011618101286', '2015-01-16 18:10:13', 'Incident HAZARD', 'I-694', 'EB', '.?.', 'f', 't', 'C716', 'Exit', '', NULL, '45.0370445251465', '-93.0217514038086'

'195061729', '2015011618101286', '2015-01-16 18:10:52', 'Incident HAZARD', 'I-694', 'EB', '.?.', 't', 't', 'C716', 'Exit', '', NULL, '45.0370445251465', '-93.0217514038086'

ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDe	COV_up
2015-01-15	I-694	EB	S1393		6182	0	0	0	0	0	0	0	1	0	0	0	0.941245	86	23412	40640	0	11.13
2015-01-15	I-694	EB	S1393		6183	45	0	45	0	0	1	0	2	0	0	0	0.964955	38	17228	40640	0	11.13
2015-01-15	I-694	EB	S1394		6185	0	0	0	0	0	0	0	0	0	0	0	0.893199	136	15831	32627	0	-24.56
2015-01-15	I-694	EB	S1394		6186	0	0	0	0	0	0	0	0	0	0	0	0.97197	37	16796	32627	0	-24.56
2015-01-16	I-694	EB	S1393		6182	0	0	0	0	0	0	0	8	0	0	0	0.910323	68	23793	41264	0	11.2
2015-01-16	I-694	EB	S1393		6183	44	0	44	0	0	0	0	6	0	0	0	0.936536	27	17471	41264	0	11.2
2015-01-16	I-694	EB	S1394		6185	0	0	0	0	0	0	0	0	0	0	0	0.885631	122	15835	32666	0	-26.32
2015-01-16	I-694	EB	S1394		6186	43	0	43	0	0	0	0	5	0	0	0	0.929302	23	16831	32666	0	-26.32
2015-01-17	I-694	EB	S1393		6182	0	0	0	0	0	1	0	0	0	0	0	0.968624	48	21061	32398	0	12.07
2015-01-17	I-694	EB	S1393		6183	97	0	97	0	0	0	0	0	0	0	0	0.981263	23	11337	32398	0	12.07
2015-01-17	I-694	EB	S1394		6185	0	0	0	0	0	0	0	0	0	0	0	0.921001	75	13386	24132	0	-34.25
2015-01-17	I-694	EB	S1394		6186	32	0	32	0	0	0	0	0	0	0	0	0.977885	30	10746	24132	0	-34.25

This HAZARD incident happened between S1393 and S1394. It does not show any noticeable impact on traffic patterns or health parameters.



Incident: Hazard

'218882207', '2015092011220178', '2015-09-20 11:22:02', 'Incident HAZARD', 'I-694', 'EB', '!!..', 'f', 't', 'C819', 'Mainline', '', NULL, '45.0694808959961', '-93.2978897094727'

'218882209', '2015092011220178', '2015-09-20 11:22:06', 'Incident HAZARD', 'I-694', 'EB', '!!..', 't', 't', 'C819', 'Mainline', '', NULL, '45.0694808959961', '-93.2978897094727'

'218882211', '2015092011220586', '2015-09-20 11:22:06', 'Incident HAZARD', 'I-694', 'EB', '!!..', 'f', 't', 'C819', 'Mainline', 'debris', '2015092011220178', '45.0694808959961', '-93.2978897094727'

'218882297', '2015092011220586', '2015-09-20 11:24:16', 'Incident HAZARD', 'I-694', 'EB', '!!..', 't', 't', 'C819', 'Mainline', 'debris', '2015092011220178', '45.0694808959961', '-93.2978897094727'

ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDe	COV_upl
2015-09-20	I-694	EB	S134		681	2880	0	2880	0	0	0	0	0	0	0	0	0	0	0	11899	0	-121.51
2015-09-20	I-694	EB	S134		682	0	0	0	0	0	0	0	0	0	0	0	0.978677	5	11899	11899	0	-121.51
NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL

This “Incident Hazard” caused lane closures at S134 which has two lanes with detector IDs 681 and 682. Detector 681 was continuously giving 2880 conZeroVol and 0 negVolCnt throughout two years. It is suspected that there must be construction on that lane, but it needs to be proved through construction data.

'220088561', '2015100815394822', '2015-10-08 15:39:53', 'Incident HAZARD', 'I-694', 'EB', '....!', 't', 't', 'C704', 'Mainline', '', NULL, '45.0656967163086', '-93.2338333129883'

'220088563', '2015100815395316', '2015-10-08 15:39:53', 'Incident HAZARD', 'I-694', 'EB', '....!', 'f', 't', 'C704', 'Mainline', 'emrg_veh', '2015100815394822', '45.0656967163086', '-93.2338333129883'

The HAZARD incident was located between S168 and S171. We suspect that detector 551 was in a construction zone or broken since that detector has conZeroVol=2880.

ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDe	COV_upD
2015-10-07	I-694	EB	S168		549	0	0	0	0	0	0	0	2	0	0	0	0.929858	44	23421	46277	0	-35.11
2015-10-07	I-694	EB	S168		550	0	0	0	0	0	0	0	0	0	0	0	0.914491	88	22856	46277	0	-35.11
2015-10-07	I-694	EB	S168		551	2880	0	2880	0	0	0	0	0	0	0	0	0	0	0	46277	0	-35.11
2015-10-07	I-694	EB	S171		741	0	0	0	0	0	0	0	0	0	0	0	0.956573	27	24521	66403	0	30.31
2015-10-07	I-694	EB	S171		742	0	0	0	0	0	0	0	0	0	0	0	0.922721	62	22044	66403	0	30.31
2015-10-07	I-694	EB	S171		743	0	0	0	0	0	0	0	0	0	0	0	0.964509	29	19838	66403	0	30.31
2015-10-08	I-694	EB	S168		549	0	1	0	1	0	0	0	4	0	0	0	0.936912	47	23497	46971	0	-36.72
2015-10-08	I-694	EB	S168		550	0	2	0	1	0	0	0	3	0	0	0	0.915184	80	23474	46971	0	-36.72
2015-10-08	I-694	EB	S168		551	2879	1	2879	1	0	0	0	0	0	0	0	0	1	0	46971	0	-36.72
2015-10-08	I-694	EB	S171		741	0	1	0	1	0	0	0	0	0	0	0	0.954017	43	24603	67804	0	30.73
2015-10-08	I-694	EB	S171		742	0	2	0	1	0	0	0	0	0	0	0	0.933679	62	22678	67804	0	30.73
2015-10-08	I-694	EB	S171		743	26	1	26	1	0	0	1	0	0	0	0	0.971587	18	20523	67804	0	30.73
2015-10-09	I-694	EB	S168		549	0	7	0	0	0	0	0	2	0	0	0	0.931773	52	24577	49078	0	-35.33
2015-10-09	I-694	EB	S168		550	0	7	0	0	0	0	0	0	0	0	0	0.922536	78	24501	49078	0	-35.33
2015-10-09	I-694	EB	S168		551	2880	0	2880	0	0	0	0	0	0	0	0	0	0	0	49078	0	-35.33
2015-10-09	I-694	EB	S171		741	0	7	0	0	0	0	1	0	0	0	0	0.945345	48	25556	70632	0	30.52
2015-10-09	I-694	EB	S171		742	0	7	0	0	0	0	0	0	0	0	0	0.928342	58	23831	70632	0	30.52
2015-10-09	I-694	EB	S171		743	0	10	0	0	0	0	2	1	0	0	0	0.961572	29	21245	70632	0	30.52

'220365473', '2015101308513143', '2015-10-13 08:51:33', 'Incident HAZARD', 'I-694', 'EB', '.?....', 'f', 't', 'C702', 'Mainline', '', NULL, '45.0683441162109', '-93.2563629150391'

This HAZARD incident was located between S165 and S163, but the data does not show any sign of abnormal patterns.

ddate	corridor	dir	staID	detPrefix	detID	conZeroVol	negVolCnt	conZeroOcc	negOccCnt	occLockOn	zvolOnOcc	overCnt	highOcc	constVol	constOcc	volOnLowOcc	corrCoef	volOccRatio	detVol	staVol	missingDe	COV_upDif
2015-10-12	I-694	EB	S163		530	0	9	0	0	0	0	0	0	0	0	0	0.921463	45	27617	86808	0	9.51
2015-10-12	I-694	EB	S163		531	0	0	0	0	0	0	0	0	0	0	0	0.913379	105	20587	86808	0	9.51
2015-10-12	I-694	EB	S163		532	67	0	67	0	0	0	1	0	0	0	0	0.956413	15	18583	86808	0	9.51
2015-10-12	I-694	EB	S163		6569	0	0	0	0	0	0	0	0	0	0	0	0.905456	99	20021	86808	0	9.51
2015-10-12	I-694	EB	S165		538	0	0	0	0	0	0	0	0	0	0	0	0.936218	47	15075	54234	0	-60.06
2015-10-12	I-694	EB	S165		539	0	0	0	0	0	0	0	0	0	0	0	0.92882	113	20380	54234	0	-60.06
2015-10-12	I-694	EB	S165		540	23	0	23	0	0	0	0	1	0	0	0	0.966686	21	18779	54234	0	-60.06
2015-10-13	I-694	EB	S163		530	0	1	0	0	0	0	2	6	0	0	0	0.927682	32	29413	92281	0	9.95
2015-10-13	I-694	EB	S163		531	0	0	0	0	0	0	0	0	0	0	0	0.929719	81	21898	92281	0	9.95
2015-10-13	I-694	EB	S163		532	0	0	0	0	0	0	2	0	0	0	0	0.973035	38	19670	92281	0	9.95
2015-10-13	I-694	EB	S163		6569	0	0	0	0	0	0	0	0	0	0	0	0.908982	136	21300	92281	0	9.95
2015-10-13	I-694	EB	S165		538	0	0	0	0	0	0	0	0	0	0	0	0.936082	48	15946	57581	0	-60.26
2015-10-13	I-694	EB	S165		539	0	0	0	0	0	0	0	0	0	0	0	0.935908	94	21578	57581	0	-60.26
2015-10-13	I-694	EB	S165		540	0	0	0	0	0	0	0	0	0	0	0	0.978798	33	20057	57581	0	-60.26
2015-10-14	I-694	EB	S163		530	0	0	0	0	0	0	4	1	0	0	0	0.946953	43	30269	95597	0	10.21
2015-10-14	I-694	EB	S163		531	0	0	0	0	0	0	0	0	0	0	0	0.91039	103	22690	95597	0	10.21
2015-10-14	I-694	EB	S163		532	23	0	23	0	0	0	2	1	0	0	0	0.967588	30	20716	95597	0	10.21
2015-10-14	I-694	EB	S163		6569	0	0	0	0	0	0	0	0	0	0	0	0.923794	141	21922	95597	0	10.21
2015-10-14	I-694	EB	S165		538	0	0	0	0	0	0	0	1	0	0	0	0.921509	56	16570	59988	0	-59.36
2015-10-14	I-694	EB	S165		539	0	0	0	0	0	0	0	1	0	0	0	0.918471	91	22332	59988	0	-59.36
2015-10-14	I-694	EB	S165		540	0	0	0	0	0	0	6	2	0	0	0	0.963162	33	21086	59988	0	-59.36

APPENDIX C
TESLA MAINTENANCE LOG DATA ANALYSES

694-EB, 2015

The following stations in 694-EB had no records in the TESLA Maintenance 2015 and 2016 log, and thus they are excluded from analyses.

S131, S142, S149, S163, S165, S166, S171, S173, S175, S177, S179, S184, S203, S1074, S1075, S1076, S1077, S1950, S1951, S1394, S1395, S1396, S1397, S1398, S1399, S1400, S1401, S1402, S1403, S1404, S1405, S1406, S1407, S1028

The stations that include detectors with one or more maintenance tickets is reviewed one by one.

Station: S134

Detector: 681

It has a TESLA maintenance record in 2015 as follows:

ticketnumber	eventdescription	device	remark	ticketstatus	ticketdate	ponumber	parts	labor	overhead
245204	No Hits	681		Replace Loop	2015-06-17 08:50:52	ROST090616	0.22	0.21	0.19
NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL

Observations from data:

Detector 681 belongs to station S134 and has a TESLA record on 6/17/2015 as shown above. Data is reviewed for the date of maintenance, followed by analysis of health parameters for two years. Observations are summarized below.

- S134 has two detectors 681 and 682. 681 had been giving consecutive 0s throughout the year 2015 and 2016. In contrast, 682 had been working fine during the same time, producing normal patterns of traffic data.
- On 6/17/2015, 'REPLACE LOOP' in Ticketstatus can be found from the TESLA log.
- In 2015, detector 681 had conZeroVol=2,880 throughout the year except for a few days. negVolCnt was 1,800 on 12/16/2015 and 1,650 on 12/212015.
- It kept the same behavior in 2016. It would either give conZeroVol=2,880 most of the time or else it gave conZeroVol + negVolCnt =2,880. For example, conZeroVol=1,509 and negVolCnt=1371 on 12/23/2016. The total of conZerovol and negVolCnt was always near 2,880.

Comments:

Detector 681 gave conZeroVol=2,880 for the most of two years (2015 and 2016) and some negVolCnt in thousands. The loop was supposed to be replaced on 6/17/2015 but apparently it was still not replaced or the fix was not successful, because volume counts were either zeros or negative ones.

Station: S145

Detectors: 439, 440, 441 and 442

TESLA records were only found in 2016 as follows:

ticketnumber	eventdescription	device	remark	ticketstatus	ticketdate	ponumber	parts	labor	overhead
264830	No Hits	439		Maintenance Analyze	2016-03-09 14:51:45	NULL	0.22	0.21	0.19
264831	No Hits	440		Maintenance Analyze	2016-03-09 14:51:57	NULL	0.22	0.21	0.19
264832	No Hits	441		Maintenance Analyze	2016-03-09 14:52:07	NULL	0.22	0.21	0.19
264833	No Hits	442		Maintenance Analyze	2016-03-09 14:52:16	NULL	0.22	0.21	0.19
269348	No Hits	442		Maintenance Analyze	2016-05-03 15:02:18	NULL	0.22	0.21	0.19
NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL

Observations

Maintenance tickets were issued for all four detectors on 3/9/2015 and only detector 442 on 5/3/2015. Data observations are summarized below.

2015

- Station S145 has four detectors 439, 440, 441 and 442, in which all of them had been showing a normal pattern of traffic data in 2015 from 1/1/2015 to 11/29/2015.
- After 11/29/2015, volumes become mostly 0's and conZeroVol=2,880.
- negVolCnt was 120 for all detectors on 3/8/2015; 1023 on 8/7/205; 1,023 on 8/7/2015; and 693 on 12/16/2015.
- On 3/9/2015, a ticket was issued for 'Maintenance Analyze' for all detectors in S145. That means that negVolCnt=120 on 3/8/2015 was noticed by MnDOT, from which they may have placed it in the TESLA maintenance log. On 2nd or 3rd May 2015, data is back to normal, so the maintenance ticket of detector 442 on 3rd May might have been placed for confirmation.

2016

- conZeroVol becomes large or near 2,880 zeroes starting from 11/30/2015 and it continues until 1/16/2016.
- All detectors or S145 were offline from 1/17/2016 to 7/6/2016.
- negVolCnt was 1671 on 7/7/2016, then after which detectors 439 and 440 returned to normal, whereas detectors 441 and 442 started giving conZeroVol=2,880. This indicates that detectors 439 and 440 were repaired but not 441 and 442.
- On 8/31/2016, the detectors 441 and 442 stop giving conZeroVol=2,880 and returned to normal. It can be concluded that they finally repaired 441 and 442 in S145.

Comments:

‘Maintenance Analyze’ tickets were issued on 3/9/2015 and 5/3/2015. Detectors 439 and 440 returned to normal on 7/7/2016, and detectors 441 and 442 on 8/31/2016. This case shows that it a long delay may be possible between the repair ticket issue and the actual repair.

Station: S147

Detectors: 3071, 393, 394, 395

Maintenance record was found on 9/16/2015 that detector 394 passed the 'Operations Test'.

Observations:

2015

- Detector 394 gave high conZeroVol (> 2860) until 10/7/2015 and the volume was very low.
- negVolCnt was 120 on 3/8/2015, 1,423 on 5/5/2015, 1,500 on 7-5-2015, 434 on 7/15/2015, then 1,380 on 7/20/2015.
- Detector 394 was offline on 5/6/2015 and between 7/16/2015 and 7/20/2015.

2016

- conZeroVol seems fine the whole year except on 20 and 21st August, where we get "conZeroVol > 2600". Then on 10th and 11th September we get "conZeroVol > 2,600".
- negVolCnt is 120 on 13-3-2016. It is greater than 2,000 on 19th and 20th of June.

Comments

Even though the TESLA data says detector 394 passed 'Operations Test' on 9/16/2015, it gave high conZeroVol (near 2,800) until 10/7/2015. Detector 394 began producing normal data started staring from 10/8/2015.

Station: S168

Detectors: 549, 550, 551

It has one maintenance record for detector 551 saying 'In Repair' on 9/16/2015.

Observations

2015

- Detector 551 kept giving very high conZeroVol (> 2,870) throughout 2015.
- Detector 549 and 550 were working fine, and no data was missing throughout 2015.
- negVolCnt on detector 551 was 120 on 8th March, 493 on 5th May, and 254 on 15th July.
- Volumes of detector 551 were zero throughout 2015.

2016

- Detector 551 kept giving very high conZeroVol (> 2870) throughout 2016.
- Detector 549 and 550 were working fine. No data was missing throughout 2016.
- For detector 551, negVolCnt was 120 on 13th March, 2,028 on 19th June, and 340 on 20th June.
- Volumes of detector 551 were zero the whole year.

Comment

The detector 551 that was recorded 'In Repair' on 16th September 2015 keeps giving conZeroVol near 2,880 throughout 2015 and 2016. Volumes were zero throughout 2015 and 2016. This detector is clearly not working in 2015 and 2016, and thus it may never have been repaired, i.e., "In Repair" status is probably equivalent to "not repaired yet."

Station: S1450

Detectors: 5504, 5505, 5506, 5507, 5508, T6008, T6009, T6010, T6011, T6012

Only one maintenance record was found from detector 5504 for "In Construction" on 4/3/2015.

ticketnumber	eventdescription	device	remark	ticketstatus	ticketdate	ponumber	parts	labor	overhead
239542	Low Counts	5504		In Construction	2015-04-03 09:22:57	NULL	0.22	0.21	0.19
NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL

Observations:

2015

- Detector 5504 worked normal from Jan 1 to March 4. Starting March 5, it showed high conZeroVol and low daily volume (less than 400). Detector 5504 started working normal after August 23. All other detectors appear to work fine.
- negVolCnt was 120 on 8th March for all detectors, 125 on 12th July, 722 on 13th Sept, on, 1,630 on 15th September, 1,416 on 29th September, and 2,190 negVolCnt on 5th October.
- Detector 5504 was offline on 14th September and five days between 30th September and 4th October.
- Followed by offline, a large negVolCnt value was found in the first online day, i.e., 1,630 on 15th September and 2,190 on 5th October.
- Temporary detectors gave no data in 2015. They started giving data from 10th May, 2016.

2016

- All detectors work fine until 29th April, 2016 after which only Temporary 'T' detectors work and normal detectors become offline.
- negVolCnt was 1,950 on 28th April for all detectors.
- Temporary detectors gave 2,072 negVolCnt on 10th May and then started giving normal data from 11th.

Comments

S1450 has 10 detectors, five of them were temporary and the rest five were regular. Regular detectors worked fine in 2015 except detector 5504 which had few problems (offline and negVolCnt). Regular detectors were completely offline starting from April 30, 2016, and then detectors were switched to temporary detectors and they were online staring from May 10, 2016. Therefore, there were no detectors activated for 10 days between April 29 – May 9, 2016.

It was observed that negVolCnt was very high just before offline or right after online.

Station: S1393

Detectors: 6182, 6183

One maintenance record was found for detector 6182 on 10/15/2015:

ticketnumber	eventdescription	device	remark	ticketstatus	ticketdate	ponumber	parts	labor	overhead
253645	Lock On	6182		Passed Operations Test	2015-10-15 13:27:50	NULL	0.22	0.21	0.19
NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL

Observations:

2015

- Both detectors were online on January 1, offline until January 13th, and then online again starting from January 14th and then worked fine for the rest of 2015.
- On 1st Jan, 2015 both detectors gave 1396 negVolCnt=1,396. At the first day of online (January 14), negVolCnt was 1,370 for both detectors.

2016

- Detector 6182 started giving conZeroVol=2,880 from January 6th and then until June 26th.
- It is strange that it does not give large negVolCnt before and after it starts giving conZeroVol=2,880.
- Starting 27th June, all detectors worked fine and normal.

Comments

The strange thing here is that detector 6182 starts giving 2,880 consecutive zeroes in 2016 and stops them without the usual pattern of giving large negVolCnt values. It might be due to that the detectors were placed online near midnight and worked from start.

The TESLA record indicates that a ticket was issued for Lock-On on detector 6182 on October 15, 2015. There were no significant change of data near this log date. However, the data showed that detector 6182 began working fine starting June 27, 2016, which appears the date of final repair or recovery from zero volumes.