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Investigation of the Impact of the I-94 ATM System on the Safety of the I-94 Commons High Crash Area

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May 2014

Research Project
Final Report 2014-19

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16. Abstract (Limit: 250 words)

Active Traffic Management (ATM) strategies are being deployed in major cities worldwide to deal with pervasive system congestion and safety concerns. While such strategies include a diverse array of components, in the Twin Cities metropolitan area the deployment of the Intelligent Lane Control Signs (ILCS) allowed for the implementation of Variable Speed Limits (VSL). The VSL system in the Twin Cities aims to detect congestion and preemptively warn upstream drivers to reduce speed. By reducing the severe change in speed between upstream and downstream traffic, safety and operational benefits are sought. This report presents an investigation of the effect the I-94 VSL system has on the safety of the high frequency crash area located on the westbound lanes of the freeway through downtown Minneapolis (I-94/I-35W commons).

This report describes several methodologies that were used to examine the impact of the VSL system within the I-94/I-35W commons high crash area. Numerous data sources were utilized, including video records of crash and near crash events, loop detector traffic measurements, machine vision sensor data, and actuations from the VSL system. A before-after approach was taken to examine the incident rates for crashes and near crashes using visually identified events within video data.

Utilizing the unique capabilities of the Minnesota Traffic Observatory's I-94 Freeway Lab, high resolution traffic measurements, collected by machine vision sensors at the bottleneck location, were used within a new cross-correlation based analysis methodology to measure and visualize shockwave activity before and after the implementation of the VSL system.

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Final Report

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Active Traffic Management (ATM) strategies are being deployed in major cities worldwide to deal with pervasive system congestion and safety concerns. While such strategies include a diverse array of components, in the Twin Cities metropolitan area the deployment of the Intelligent Lane Control Signs (ILCS) allowed for the implementation of two cutting-edge components, Active Incident Management and Variable Speed Limits (VSL). Two corridors have been equipped, so far, with the necessary infrastructure required by these systems, I-35W and I-94. The VSL system in the Twin Cities aims to detect congestion and preemptively warn upstream drivers to reduce speed. By reducing the severe change in speed between upstream and downstream traffic, safety and operational benefits are sought. In an earlier project, the VSL system on I-35W was the subject of an evaluation of operational effectiveness, while the incident management component of the system is currently being evaluated in a separate, ongoing project. This report presents an investigation of the effect the I-94 VSL system has on the safety of the high frequency crash area located on the westbound lanes of the freeway through downtown Minneapolis (I-94/I-35W commons).

In contrast to the earlier project, this investigation did not cover the entire I-94 VSL system but focused on the effect it has on driver behavior in the aforementioned challenging section. The project capitalized on a unique field laboratory, established in 2002 by the Minnesota Traffic Observatory, in this location. The I-94 Field Lab instrumentation provided a uniquely detailed picture of the high crash area both in terms of observations, with its seamless surveillance coverage, and traffic measurements.

This report describes several methodologies that were used to examine the impact of the VSL system within the I-94/I-35W commons high crash area. Numerous data sources were utilized, including video records of crash and near crash events, loop detector traffic measurements, machine vision sensor data, and actuations from the VSL system. A before-after approach was taken to examine the incident rates for crashes and near crashes using visually identified events within video data (corroborated with State Patrol crash records).

Shockwaves propagating through the corridor were similarly identified and analyzed both before and after VSL installation. Counts were developed for each hour and the first three shockwaves of each day were examined to identify changes in the onset pattern of congestion during the afternoon peak period.

Using traffic measurements collected from loop detectors, speed patterns following the onset of congestion were identified. Using five-minute intervals, the first hour during congestion for the region upstream of the Commons area was analyzed. Also, for each crash and near crash event identified, an estimated trajectory was constructed and intersected with the actuations from the VSL system to determine if and where drivers received information from the system.

Finally, utilizing the unique capabilities of the Minnesota Traffic Observatory's I-94 Freeway Lab, high resolution traffic measurements, collected by machine vision sensors at

the bottleneck location, were used within a new cross-correlation based analysis methodology to measure and visualize shockwave activity before and after the implementation of the VSL system.

Each of these methodologies showed there was no significant change in safety along the corridor due to the VSL system. Crash and near crash rates before and after remained similar, shockwave generation patterns were consistent, and speeds upstream of the bottleneck show no statistically significant change. Additionally, based on the estimated trajectories, roughly 40% of vehicles involved in incidents observed active VSL signs before reaching the location of the event.

1. INTRODUCTION

Active Traffic Management (ATM) strategies are being deployed in major cities worldwide to deal with pervasive system congestion and safety concerns. While such strategies include a diverse array of components, in the Twin Cities, MN the implementation of the Intelligent Lane Control Signs (ILCS) allowed for the implementation of two cutting-edge components, Active Incident Management and Variable Speed Limits (VSL). Variable Speed Limit systems have been deployed in several major cities across the world aiming to proactively reduce vehicle speeds upstream of congestion to ease the transition from free flow to slow or stop-and-go conditions. This function aims towards safety and operational benefits. Two corridors have been equipped, so far, with the necessary infrastructure required by these systems, I-35W and I-94.

The VSL system on I-35W was the subject of an evaluation of its operational effectiveness in an earlier project (Hourdos et al. 2013) while the incident management component is currently been evaluated in an ongoing project. This report presents an investigation of the effect the I-94 VSL system has on the safety of the High Crash Area (HCA) located on the westbound direction as the freeway go through the Minneapolis Downtown area (I-94/I-35W commons). The HCA, a nearly two-mile segment of westbound I-94 along the south edge of downtown Minneapolis, experiences more crashes than any other freeway location in the state of Minnesota. This region includes a significant shockwave-generating bottleneck located at the merge point of I-94 and traffic entering from I-35W northbound. Crash events are observed on average once every two to three days, making the corridor ideal for collecting significant safety data within a short period of time. The project capitalized on a unique field laboratory, established in 2002 by the Minnesota Traffic Observatory, in this location. The I-94 Field Lab instrumentation provided a uniquely detailed picture of the high crash area both in terms of observations, with its seamless surveillance coverage, and traffic measurements.

To observe safety impacts directly, crash and near crash events were isolated from video data and examined before and after implementation of the VSL system. These were also tabulated with records obtained from the Minnesota State Patrol. A preliminary examination of the accuracy of the State Patrol database is included in Appendix I.

The other methodologies within this project focus on speed and shockwave activity as surrogate measures for safety. Speeds upstream of congested conditions were isolated using loop detector data both before and after VSL implementation. Reduced upstream speeds were used as an indicator of improved safety.

Shockwave activity within the HCA was examined through direct observation and through a new cross-correlation based analysis methodology that measured and visualized shockwave activity before and after the VSL system implementation. The new analysis methodology utilized individual vehicle measurements taken on more than one location with the help of machine vision sensors located immediately upstream of the shockwave-generating bottleneck.

Estimated trajectories for vehicles involved in crash and near crash events were also generated based on speed data along the corridor and related to the VSL messages displayed along their trajectory. A 'success rate' was described and estimated describing how often drivers involved in events received VSL information prior to their crash or near crash incident.

The report begins with a short background on other studies devoted to the evaluation of VSL systems. This section also contains a summary description of the logic the MnDOT VSL system follows. The report follows with a description of the site under investigation and a description of the data collected for the purposes of this research. The methodologies utilized in this research are presented next followed by the presentation of the project results and conclusions.

2. Related Studies of Variable Speed Limit Systems

Variable Speed Limit systems are a recent addition to the traffic management toolbox. Initially, the concept was associated with safety relating speed limits with weather and roadways conditions. In this work we will not discuss any such systems since the scope is to focus on VSL systems for the purpose of managing congestion or indirectly improve safety by influencing traffic flow conditions. The rest of this chapter offers a summary of the most relevant works on the subject.

Lee, Hellinga, and Saccomanno (2004) studied the effect of variable speed limit systems on safety using a microscopic simulation model (PARAMICS) assuming random compliance of drivers with VSL system. They used a crash prediction model (Lee, Saccomanno, and Hellinga 2000 and Lee, Hellinga, and Saccomanno 2003) to determine the crash potential of traffic conditions as they evolved within the simulation. When crash potential met a certain threshold, VSL speed was adjusted according to the average speed of the current traffic. Using a low threshold showed greater reductions in crash potential but at the cost of increased travel time. However, since these results were based on simulation, no actual compliance rate was measured and safety improvements from the VSL were not considered.

Minnesota VSL System

The Minnesota Department of Transportation has implemented VSLS along portions of Interstates I-35 and I-94. The selections of advisory variable speed limits to be posted are computed by an algorithm developed by the RTMC and the University of Minnesota – Duluth (Kwon 2007 and Kwon et al, 2011). RTMC operators have the option to override the calculated advisory speeds or to accept the recommendation and verify the posting of the message.

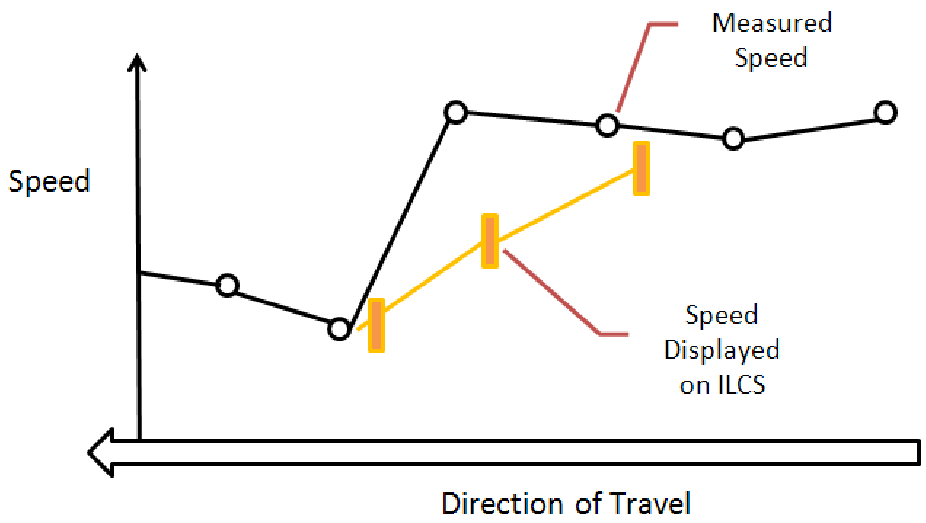

Figure 1. Display of advisory speed limits on DMS as it relates to freeway speeds.

The goal of the advisory VSL system is to mitigate shockwave propagation from downstream bottleneck by gradually reducing speed levels of incoming traffic flow. Figure 1 illustrates how speed data is collected through traffic sensors on the roadway at point locations shown as black circles on the chart. Without advisory VSL, vehicles approaching congested traffic are forced to change speeds within a very short distance leading to sudden stopping and possible rear end collisions. The advisory speed limits are posted to allow for a more gradual deceleration between upstream free-flowing traffic and congested traffic. The speeds displayed on the signs gradually reduce traffic speeds as shown by the yellow boxes in the figure.

As congestion levels develop, two or three sets of signs prior to the congestion display an advisory speed limit based on the algorithm depending on what the speed differential is between upstream and downstream traffic. Speeds are currently posted up to 1 ½ miles upstream of the congestion.

Advisory speeds posted on the overhead signs change by no more than 5 MPH with each change in speed, and can be updated every 30 seconds if traffic conditions warrant. The minimum advisory speed displayed is 30 MPH and the maximum advisory speed displayed is 50 MPH. If the current speeds on the roadway are below 30 MPH the signs go blank. It is important to note a characteristic of the current implementation which may be the reason for not realizing its full potential. The MnDOT freeway detection infrastructure is mainly comprised by single loop detectors measuring volume and occupancy. Speed is estimated from the two primary measurements and a locally calibrated effective vehicle length constant. The latter is calibrated offline. This speed estimation procedure introduces noise in the 30sec speed time series. To alleviate this problem and create a stable algorithm speed is updated every 30sec but averaged over a 90sec window. This helps to reduce outliers but also increases the systems response time. MnDOT has been replacing detection at key locations with radar units and is in the process of updating the system to work on a 10sec update cycle.

As noted earlier, the algorithm was designed by Kwon et al. (2011) who also performed a simulation study with the I-35W corridor where VSLS was first installed. The system reduced sudden deceleration rates of the traffic flow and increased in percentage travel time ranging 2.2% to 14.9% with a mean of about 8.6 minutes. No crash analysis was performed.

A recently concluded research project by University of Minnesota – Twin Cities researchers Hourdos, Abou, and Zitzow (2013) examined the effects of the advisory Variable Speed Limit system. The work was funded by the Intelligent Transportation Systems Institute of the University of Minnesota a USDOT UTC. Vehicle behavior before and after VSL implementation was examined to (1) determine if and how the congestion throughout the corridor is impacted by the system and (2) determine if the driver behavior is changed and, if it is, how this affects the traffic flow characteristics of the instrumented freeway segments. This study did not evaluate the compliance and behavior of individual drivers but focused on the aggregate effect such behaviors have on traffic flow.

The study utilized loop detector measurements combined with speed sign activation records available from the MnDOT. Through this information, the impact of the variable speed limits was explored through (1) examination of the actuations of each station as

compared to the estimated speeds throughout the corridor based on 30-second loop detector data, (2) generation of fundamental diagram curves for specific detectors, and (3) tabulation of speed-based congestion for each region of the I-35W corridor. The first two analysis techniques focused on well-correlated days based on 15-minute aggregated volumes along the boundary of each corridor (upstream station and entrance ramps)
In general, from the available data, a very small compliance to the advisory speed limits is observed. Additionally, for the days were data were collected it seems that the speed of the congestion wave is too fast for the VSL signs to give timely warning to oncoming traffic. As noted earlier this is an inherent issue related with the detection infrastructure and MnDOT is improving this part of the system.

Regardless, looking at the general congestion patterns, the VSL system did appear to positively impact the most severe congestion (speeds below 10-15 mph). Specifically, the instances and spread of extreme congestion waves (speeds bellow 10 mph) have been reduced after the VSL system activation. Severe shockwaves propagating upstream are a serious danger of rear-end collisions therefore their reduction is a valuable effect of the VSL. Although it is not possible to make definitive observations of this effect through loop detector data, the analysis of the fundamental diagram curves for specific detectors shows that although drivers do not comply with the advisory speed limit, they do take it into consideration. One can hypothesize that the drivers use the advisory speed limit as a gage of downstream congestion and prepare themselves for encountering the upcoming shockwaves. As seen in Figure 2 this behavior may reduce the rate of the speed reduction, i.e. slower moving shockwaves. The effect is observable albeit weak.

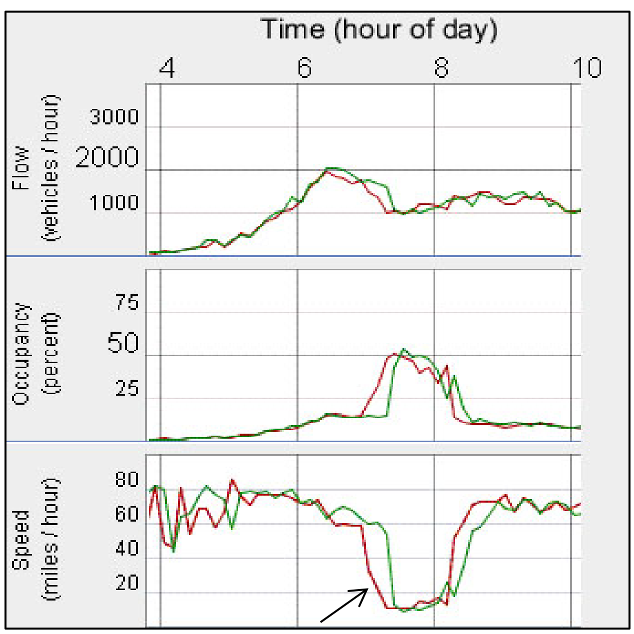

Figure 2. Flow, Occupancy, and Speed for Detector 259 between two of the most highly correlated dates; green is before VSL, red is after VSL.

Finally, in order to evaluate the system-wide effect the VSL system has on speeds and in extend congestion, a statistical analysis of all before and after speeds was conducted. Because the corridor experienced rapid changes in demand after the UPA project was concluded, to conduct a more fair assessment a set of well correlated days between before and after was generated based on volumes entering the corridor. In addition, analysis focused on the two major bottlenecks, the interchanges of I-35W with Cliff Road and I-494. Although perforce conditions vary greatly between the two bottlenecks, on average, the morning peak experienced approximately 17% less congestion with the VSL system in place, even though for those same days the lower speeds were largely unchanged (25 mph or less). This translates into having 7.6 minutes less congestion during the average AM peak period on the set of well correlated days.

The second deployment site of the VSLS system was in the I-94 freeway between Minneapolis and St. Paul. This segment includes the highest crash frequency site in the state of Minnesota. The High Crash Corridor is along the westbound side of the freeway in Minneapolis between 3rd Avenue and Park Avenue. Within the I-94 HCA, which is the focus of the current work, past research has been conducted. Hourdos (2005) investigated the crash prone traffic conditions prevailing in the I-94 westbound section around Portland Avenue as well as the causal factors involved in their development. The work showed that three elements coalesce to increase the probability of a crash: shockwaves generated at the merge section with the entrance ramp from I-35W northbound, the volume of an upstream entrance ramp, and the large speed differential between the right and middle lanes which makes lane changes more difficult and contributes to driver distraction. The work by Hourdos concluded with the development of an algorithm for crash prone condition detection.

In the course of that work as well as on two projects by the Minnesota Traffic Observatory (Hourdos, Garg, and Michalopoulos 2008; Hourdos, Xin, and Michalopoulos 2008) this location has been under investigation since 2002. In fact, the MTO established a permanent field laboratory in this site dedicated in the study of freeway safety and traffic flow. The facilities of the MTO were utilized for the work described in this report and are discussed further in later sections.

GERMAN AUTOBAHN

Variable speed limit and driver information systems (DIS) were installed along both directions of a 16.3 km German highway (Autobahn A99). A VSL algorithm estimated the most appropriate speed limit based on incident detection, traffic harmonization, and weather conditions. The VSL displayed a recommended speed, warning sign, or both. Speed limits were enforced through automated cameras in a system that generated citations to a random vehicle among those who did not comply with the speed limit. This resulted in a very high compliance rate. There was also a ban on trucks (not enforced) for passing when the driver information system was active. According to Weikl, Bogenberger, and Bertini (2013), the VSLS decreased stop-and-go (speed varied strongly between 0 and 80 km/h) queues from 50 % to 36% but increased wide jam (uniform speed between 0 and 40 km/h) queues from 44% to 54% most of the time. The study used only a limited dataset for VSL-off scenarios. The researchers also found lower shock velocities when the VSL was on. The researchers attributed these findings as surrogate to increase in traffic safety but did not perform a crash analysis. Also, the researchers considered speed limit along with the warning signs which might have influenced the change of speed by the drivers.

HANGYONG FREEWAY

A VSLS was developed and deployed along Hangyong Freeway in Hangzhou, China. The impact of the system on traffic operations and safety was evaluated through a before and after study by Duan, Liu, Wan, and Li (2012). After the implementation of VSL, the average speed increased from 3 km/h to 4 km/h and the speed differences between subsequent locations along the corridor were reduced.

3. I- 94 High Crash Area and VSL System description

Interstate 94 is the major freeway that connects the Twin Cities (Minneapolis and St. Paul) and carries an average daily traffic of more than 80,000 vehicles in each direction. The corridor has three general purpose lanes in each direction with auxiliary lanes at several locations for entering and exiting traffic. Figure 3 shows the portion of I-94 from Huron Avenue on the east to the I-394 interchange downstream of the Lowry Hill tunnel. There is a 1.7 mile portion of this corridor along westbound I-94 starting from 11^{th} Avenue to the beginning of Lowry Hill tunnel which is identified by MnDOT as the highest crash area in the state. The crash rate is 4.81 crashes/MVM (million vehicle miles) which is roughly equivalent to one crash every two days.

Figure 3. I-94/I-35W commons in Minneapolis

At this location, traffic congestion occurs for roughly five hours daily during the afternoon peak hours. There are two locations which act as bottlenecks (Figure 4). In most cases, breakdown occurs at bottleneck 1 and is therefore of primary importance to this study. This is the location where the ramp from I-35W northbound merges with I-94 westbound as shown in a magnified view in Figure 5.

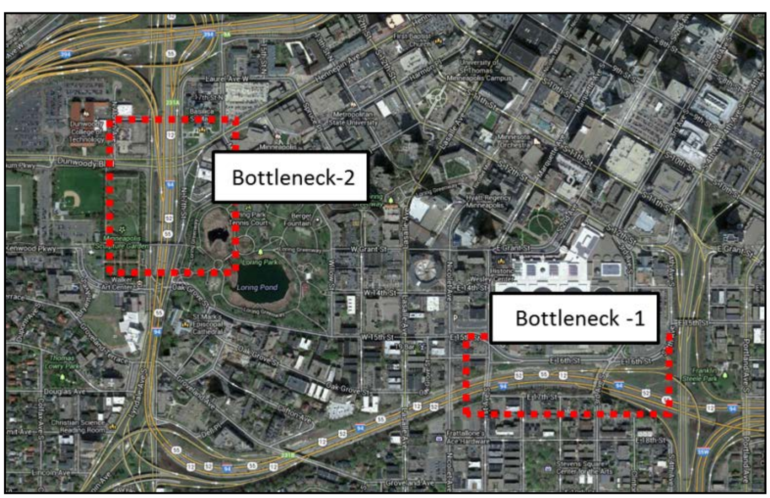

Figure 4. Traffic bottleneck locations along study corridor

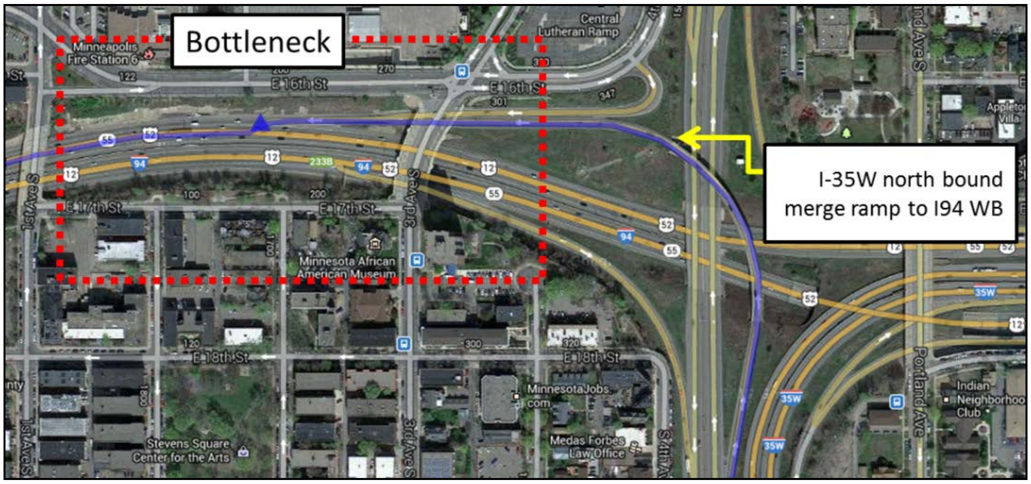

Figure 5. Location of first bottleneck where I-35W northbound merge ramp joins I-94 westbound

To address the problems caused by these bottlenecks, as well as to improve traffic flow and safety in the entire corridor, MnDOT implemented a Variable Speed Limit system as a part of its traffic management plan. The VSL system is operated through the Intelligent Lane Control Signs (ILCS) system. The ILCS is comprised of lane by lane variable message signs placed roughly every half mile on overhead gantries. The locations of each gantry within the study area are shown as vertical red bars in Figure 3. The VSL system uses speed measurements at the bottlenecks from radar sensors and translates them into advisory speeds displayed at various upstream VSL gantries. This provides warnings to upstream drivers to reduce their speeds gradually as they travel downstream, generating a forward moving shockwave intended to weaken or absorb backward moving congestion shockwaves. The aim of this project is to evaluate how effective the VSL system is in reducing crashes by (1) decreasing the intensity (speed, distance of propagation) of shockwaves, or (2) decreasing the frequency of crash-causing shockwaves. The VSLs were activated starting September 27, 2012.

In order to compare the situation before and after VSL implementation, all significant changes made to the corridor in terms of either geometry (addition of lanes, change of lane width, and so forth). A systematic data collection protocol was developed and implemented to collect data. For aggregate traffic volume, the AADT were about 166500, 163000 and 162000 for 2008, 2010 and 2012 respectively on the high crash section. From this, we assumed that the overall traffic pattern did not change significantly during this period.

DATA COLLECTION

A variety of sensors and data collection devices were used throughout the study area to collect key traffic data. This, MTO owned, infrastructure was deployed in 2002 and formed the I-94 Freeway Field Lab (Hourdos et al. 2004). The lab is comprised by permanently deployed equipment at three key locations along the corridor as shown in Figure 6. These locations, referred to as the Third Avenue, Augustana, and Cedar sites, were equipped with cameras and Autoscope® machine vision sensors (MVS). As indicated in the figure, the Third Avenue site includes four cameras and three machine vision sensors (named Merge, Middle, and Portland), Augustana includes two cameras and two MVSs, and Cedar includes two cameras and a single MVS.

Figure 6. Map of video and machine vision sensors along I-94

In the figure, the coverage area for each camera is indicated by the boxed regions and the approximate locations of the machine vision detectors are indicated by bars across the roadway. The Middle and Portland MVSs and Third Avenue cameras are the primary data sources used throughout this investigation.

Video data was collected between 10 AM and 8 PM for every weekday within the study period. The Third Avenue site was active during the entire study period (with the exception of Cam4 covering the merge point of the I-35W northbound to I-94 westbound ramp, which was offline in 2008). Both the Augustana and Cedar sites were inactive during 2008 and 2012, coming online at the start of 2013 after VSL implementation.

In addition to these data collected by the MTO, MnDOT infrastructure provided several data streams. Along the corridor, loop detector stations are situated at roughly quarter-mile to half-mile intervals and collect 30-second aggregated volume and occupancy data for each lane. Using calibrated (and corrected, see later methodologies) effective lengths for each detector, speed estimations are also possible from these sensors. These data will be described further in the relevant methodology sections.

The Variable Speed Limit system itself provided a record of actuations for all gantries along the corridor in the form of time stamped advisory speed postings. These were complemented by a copy of the VSL algorithm, available from the MnDOT code repository.

As part of a related analysis, crash records were also accessed from the State Patrol Computer Aided Dispatch (CAD) system. These records include location, type, severity, and other descriptive parameters for each crash logged by the State Patrol.

4. ANALYSIS METHODOLOGIES

Three main methodologies were used to identify safety impacts of the VSL system along the I-94 high crash area. To directly examine safety, crash and near crash events were identified in the video footage taken from the corridor and catalogued. These records were also compared with CAD records to form a preliminary analysis of the effectiveness of state patrol record keeping. Although not directly related to this project, the results of that analysis are presented in Appendix I.

Using shockwave activity and behavior as a surrogate for safety, two additional methodologies were employed. Based on loop detector data and the VSL actuation records obtained from MnDOT, aggregated statistics were generated describing the shockwave characteristics. Speed contour figures were also created for each day and overlaid with VSL actuations and hypothetical trajectories for vehicles involved in crashes or near crashes. The generation and use of these figures will be described in greater detail in following sections.

Shockwave activity was also examined using high resolution data from the MTO machine vision sensors. Data from the sensors bracketing the most predominant crash locations were correlated to identify traffic patterns. These data were visualized as Correlograms showing similarity and dissimilarity patterns between the two sensors and highlight both normal traffic conditions and shockwave activity. Again, these were overlaid with VSL actuations and the time instances of crashes and near crashes for examination. Further explanation follows.

CRASH AND NEAR CRASH ANALYSIS

Video footage from the high crash area was recorded between 10 AM and 8 PM during all weekdays for significant portions of 2008, 2012, and 2013. The 2008 data were recorded immediately after the I-35W Bridge was opened to traffic. These records represent a 'Long Before' data set with the same infrastructural characteristics as the 2012 data. Similarly, events were isolated for the 'Before' and 'After' time windows, with Before representing April through **September 27th, 2012** (when the VSL was activated) and After following from the tail of September 2012 through fall of 2013.

The incidents collected from the video stream were organized and analyzed with their corresponding average lane speed and average adjacent lane speed. These average speeds were retrieved from the RTMC data repository using the DataExtract tool and taking the 5-minute average speed for the appropriate lane at Station 76 or Station 560 (the two sets of loop detectors nearest to the related cameras in which crashes/near-crashes were observed). For certain dates, loop detector data was unavailable, so vehicle speed measurements from the machine vision sensors at the relevant locations were used to determine prevailing speed. Using these tabulated data, figures were generated showing the speed for the incident and adjacent lanes for each event.

Additionally, while observing the video for crash and near crash events, shockwave activity was tabulated by hour. These data were aggregated to determine the average hourly shockwave rates for the various analysis windows (Long Before, Before, and After).

In order to quantify any changes in safety from the non-VSL to VSL conditions, the incidents were normalized by the total vehicle volume observed for each day video was collected and converted to incident rates per million vehicles traveled (MVT). These rates were then compared between the Before and After conditions as well as a special After condition which excluded winter months to match with the data available from the Before months.

Finally, the crash and near crash events taking place in lane 1 (the rightmost lane) were analyzed in terms of the speed differential to the adjacent lane 2. Speed differences were calculated and binned into 5-mph intervals. (Incidents in lane 2 were sparse and not included; incidents in lane 3 did not have a left-hand adjacent lane to compare with and were similarly not included.)

Video-Based Shockwave Analysis

From previous studies of the I-94 high crash area, one major feature contributing to crashes and near crashes are shockwaves generated by vehicles merging from the I-35W northbound ramp onto I-94 westbound. By quantifying the characteristics of these shockwaves, changes caused by the VSL system can be identified. While collecting the crash and near crash events used in the previous analysis methodology, shockwave activity was recorded for each hour and averaged across all study days.

In addition, the first three shockwaves from each recorded day were isolated for particular examination. As the afternoon peak period begins, traffic builds toward capacity and, eventually, cross from uncongested into congested conditions. As this transition occurs, shockwaves begin propagating through the traffic stream from the merge point and eventually build sufficient strength to propagate through the worst crash areas. By identifying the first three shockwaves for each day, possible differences in the onset conditions could be isolated. The exact start time for each of these first three shockwaves was determined and binned into 15-minute intervals, and the time gaps between successive shockwaves (first-to-second and second-to-third) were similarly calculated and binned into 5-minute intervals.

Loop Detector-Based Shockwave Analysis

Using MnDOT loop detector data from the high crash location, the spread of congestion and shockwave activity was isolated. In this region, the merge point is a fixed-location bottleneck and, as congested conditions build, the tail of congestion travels upstream toward and past the high crash area. By observing the speed for each detector in the region over time, the progression of the tail of congestion was tracked. Figure 7 shows the stations of interest along the region with detectors at each location listed in order from right to left.

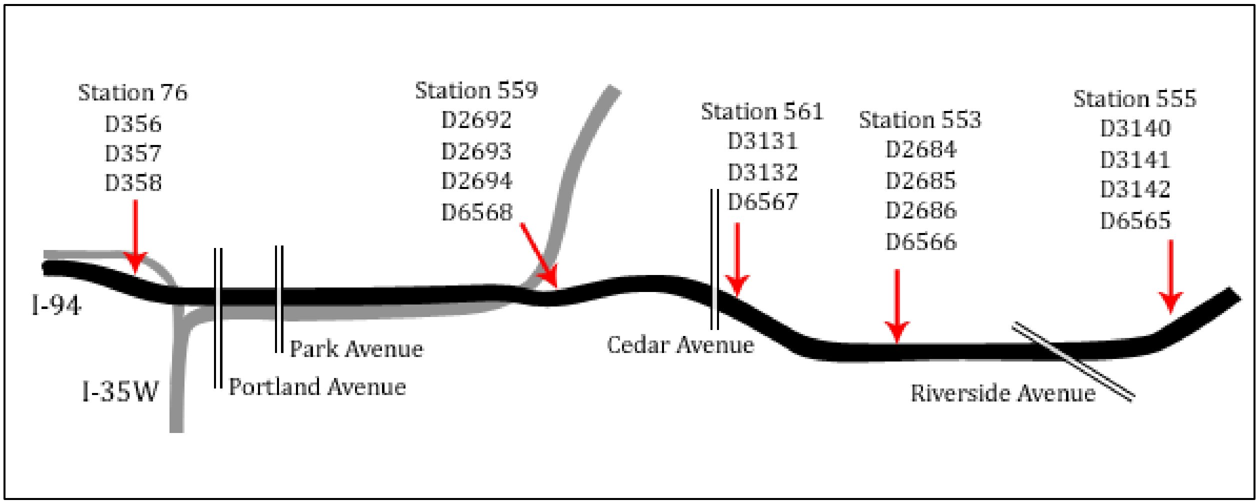

Figure 7. Map of detectors upstream of the bottleneck station (Station 76)

In order to synchronize these measurements for analysis, the onset of congestion at the most downstream detector (D356) was identified for every 'typical' day between January 1, 2011 and August 8, 2013. Holidays and days with unusual weather were excluded from this set. A simple algorithm was developed to locate the first breakdown in traffic for each afternoon. Using data from 10 AM to 7 PM aggregated to 5-minute intervals, the two hour window with the largest difference in average speed between the first and second hours was located. The center point of this two hour window was identified as the time of breakdown. Figure 8 shows a sample plot showing the identified breakdown for July 29, 2013.

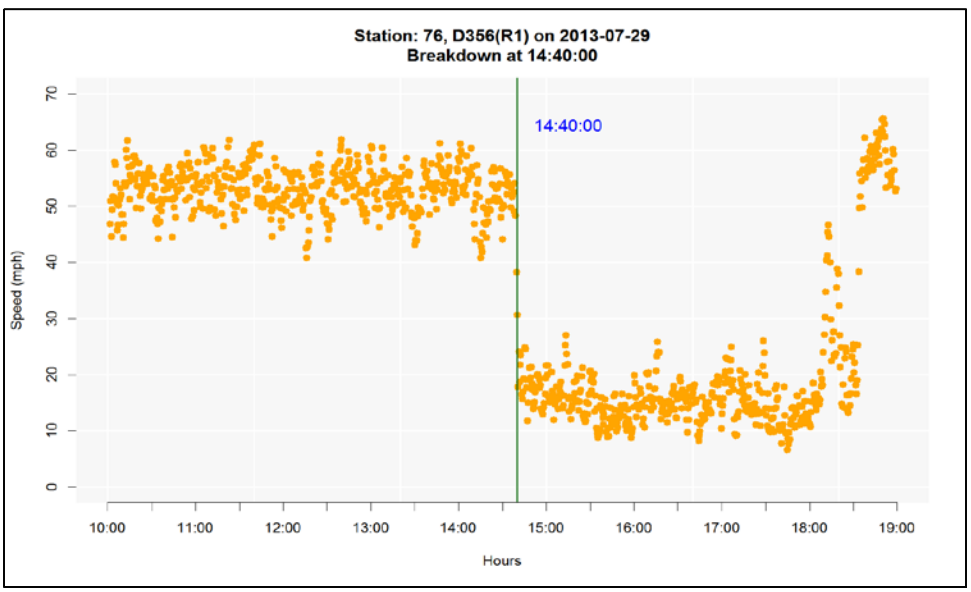

Figure 8. Identified time of breakdown for July 29, 2013

Each day was plotted and examined manually to eliminate days with multiple breakdowns, such as those similar to Figure 9.

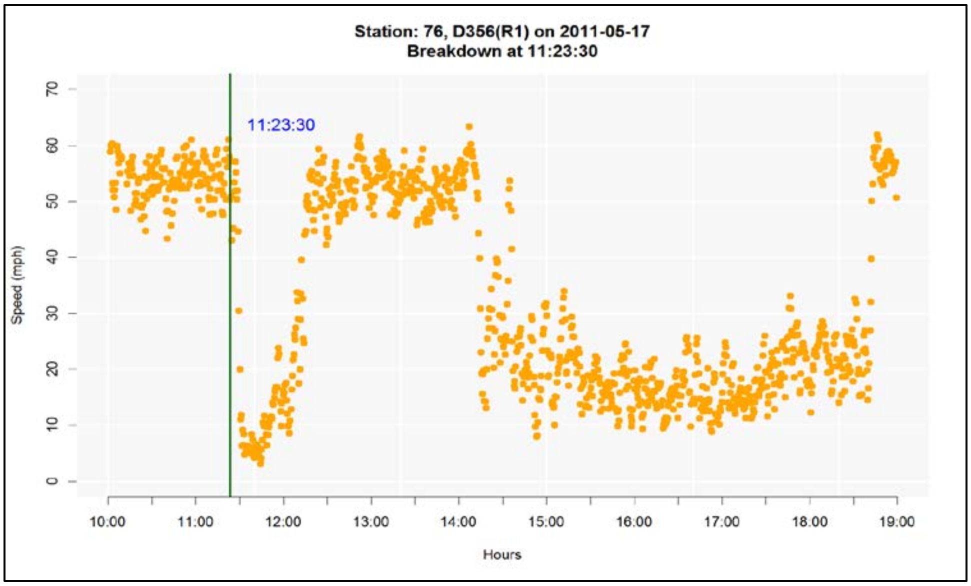

Figure 9. Bad identification of breakdown point for a day with multiple congestion regions

Because the data from the loop detectors spans several years, the traffic environment and loop detectors themselves changed, leading to erroneous speed readings. Although it had no effect on identifying the breakdown point, the data were corrected prior to being analyzed for differences between the Before and After conditions.

Between 9 and 11 AM on nearly all days free flow conditions were experienced along the corridor. As such, the speeds were assumed to stay relatively stable over time, allowing the effective field length of each detector in the corridor to be calibrated. Figure 10 shows the average speed during this time for a sample detector. Note the significant and sudden shift.

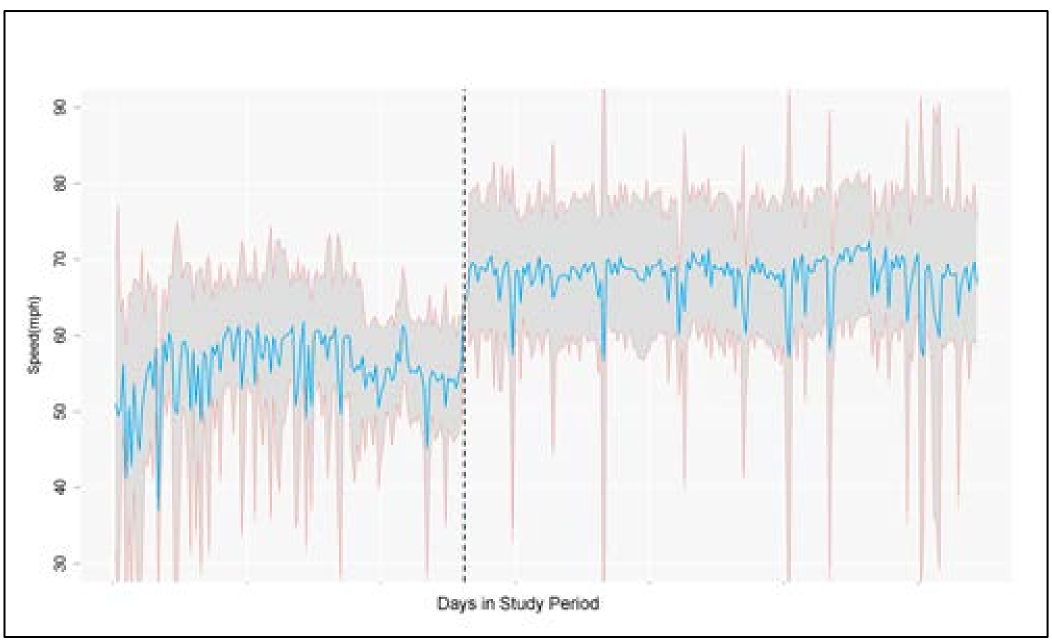

Figure 10. Mean speed ± 1 standard deviation for detector D2685 showing a sudden change in measured speed

For each detector, the regions exhibiting abnormal shifts in speed were manually identified. Each such region was then adjusted to have a mean speed equivalent to regions showing normal speed patterns. Field lengths for each adjusted region were computed and used to estimate speeds for the 10 AM to 7 PM period.

With this change in effective length corrected, the data from detectors upstream of the bottleneck were examined using data starting at the point of breakdown identified from the algorithm described above. The first hour after breakdown for each day was broken into 5-minute intervals. For each 5-minute interval (i.e. 0-5 minutes after breakdown, 5-10 minutes, etc.), the average speed was calculated. Figure 11 shows, from top to bottom, each of these 5-minute intervals with each day across the horizontal axis. Within each subplot, speed is marked along the left vertical axis, with a reference line running through each at 40 MPH. The vertical red line indicates the date of VSL activation.

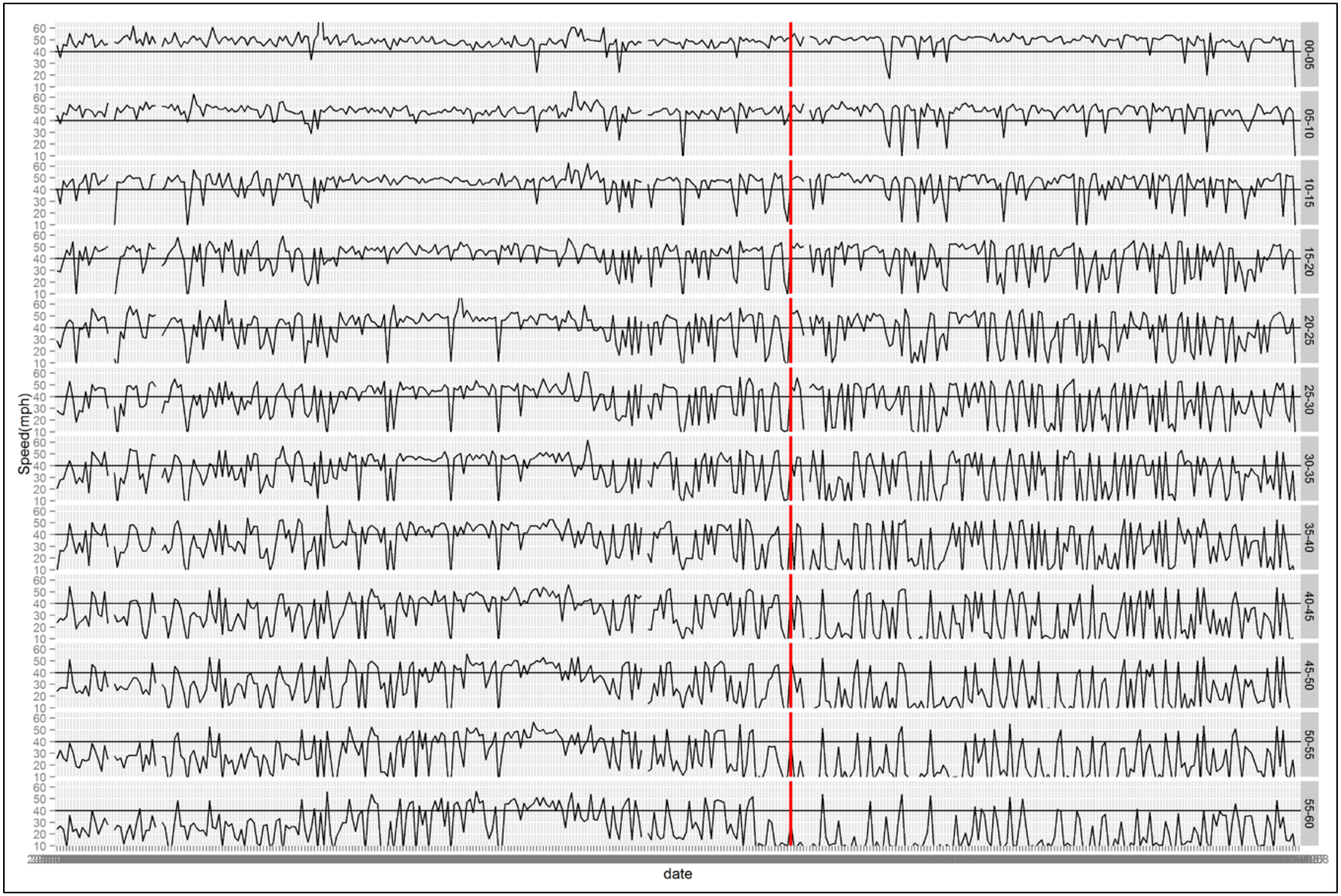

Figure 11. 5-minute average speeds after breakdown for detector D2692

To extract useful statistical data from these speed measurements, the data from the summer months of 2011, 2012, and 2013 were analyzing using the student t-test. For each 5-minute interval after breakdown, the p-value was determined for 2011 v. 2013 and 2012 v. 2013. The p-value indicates how likely the two data sets are from the same underlying pattern. If the p-value is high, the two samples are likely based in the same distribution, while p-values below 0.05 indicate a strong confidence (95%) that the two data are significantly different. Figure 12 below shows a sample figure showing these results for the first upstream detector in the right lane (D2692) for 2011 v. 2013.

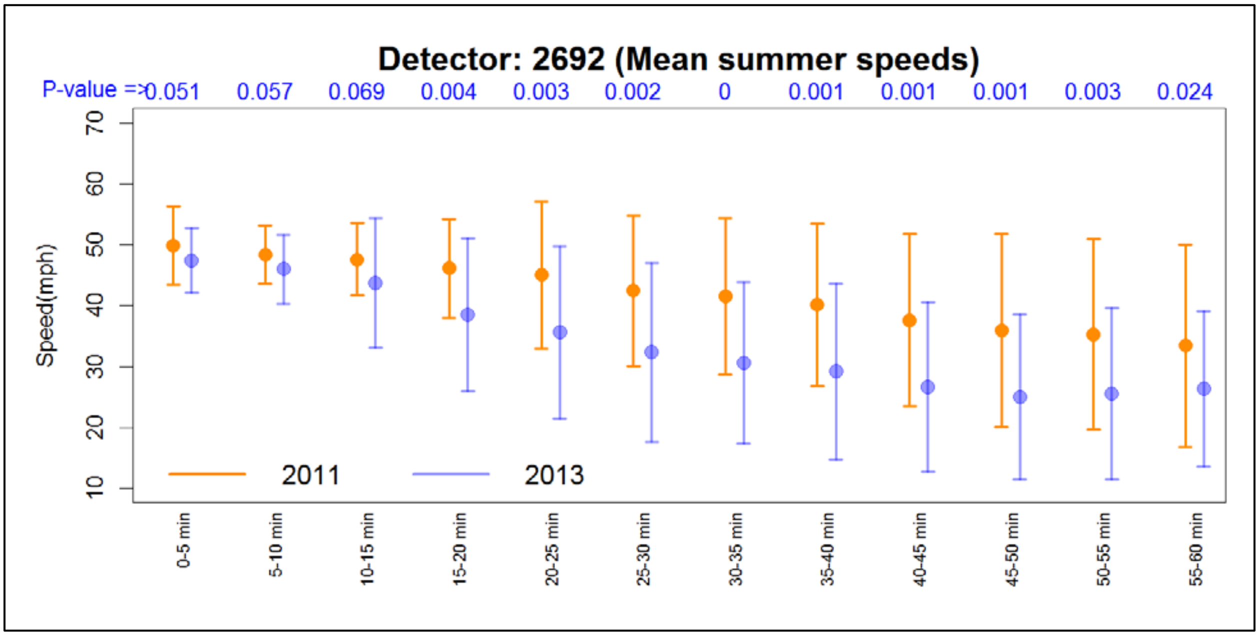

Figure 12. Mean and 1 standard deviation for speeds at detector D2692 for 2011 v. 2013

Several of the 5-minute intervals were also isolated for the stations (with each detector individually plotted), such as 0-5 minutes after breakdown, for closer inspection. Figure 13 shows a sample plot of just the first five minutes of activity after breakdown for station S559. Note that the detectors are labeled as L1 through L4 in the figure, corresponding to detectors from right to left across the roadway.

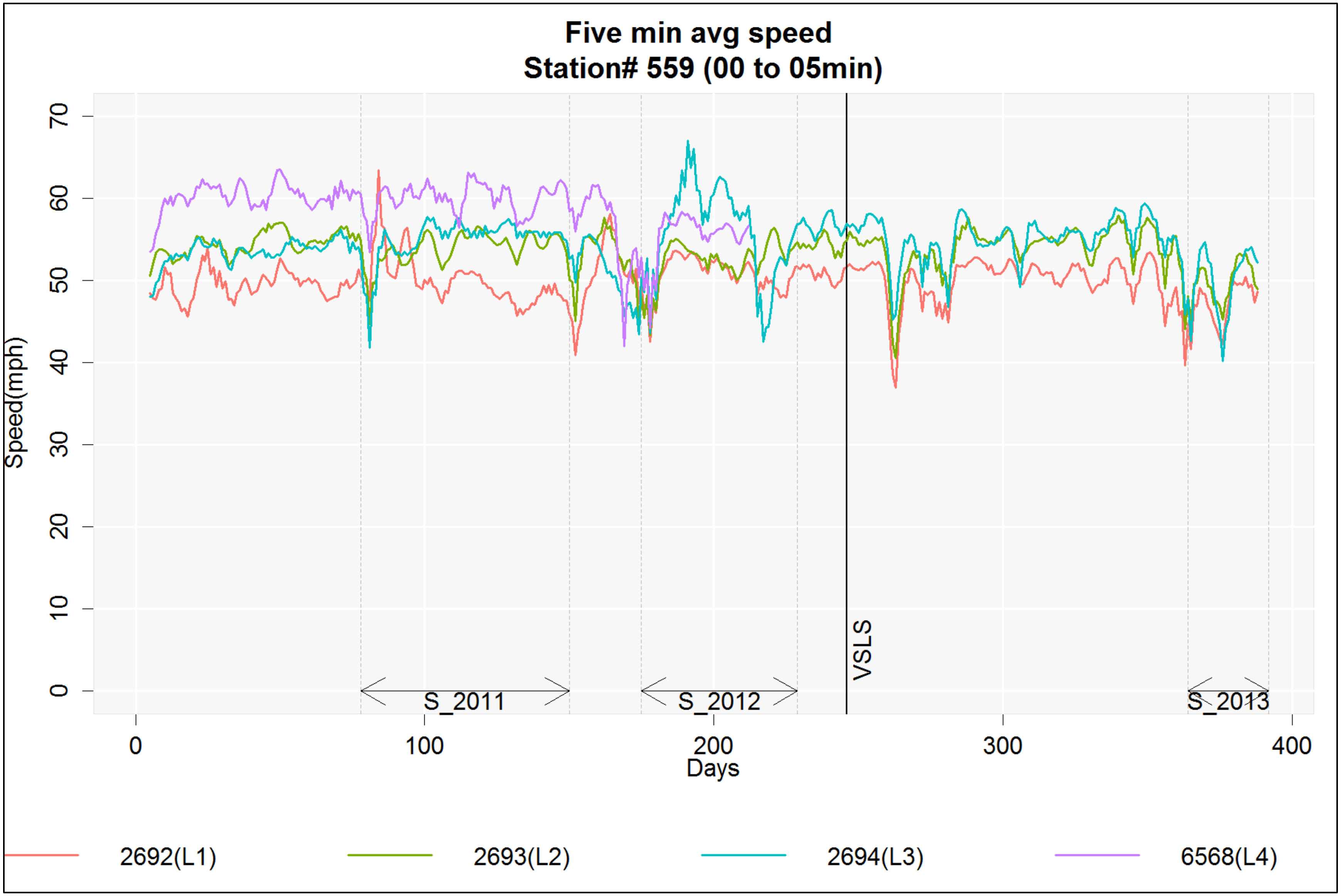

Figure 13. Average speed for station S559 0-5 minutes after breakdown

Crash and Near Crash Trajectories

By combining the crash/near crash incidents, loop detector data, and VSLS actuations, speed contour figures were generated to examine whether vehicles involved in crashes passed through the corridor at a time when the VSLS was active.

Using the loop detector data, speeds were estimated for every 30-second interval between 10 AM and 7 PM for every station along the corridor. On top of these speeds, the VSLS actuations and crash events were added. In order to properly locate all events along the corridor, a GIS application was used to map the locations of each station, gantry, or crash/near crash.

To determine whether a vehicle involved in an incident passed by active VSL gantries, a trajectory was reconstructed using the loop detector speed data. At the time and location of the crash, the speed was linearly interpolated using surrounding values. Moving backward in time, the speed was used to determine the distance the vehicle traversed since the previous 30-second interval. A line was then added between the point of the crash and the determined location and time.

At this new time, the speed was again linearly interpolated and used to step back to the previous 30-second interval. The process was continued until the trajectory of the vehicle reached the edge of the corridor of interest. Figure 14 shows a sample produced by this method.

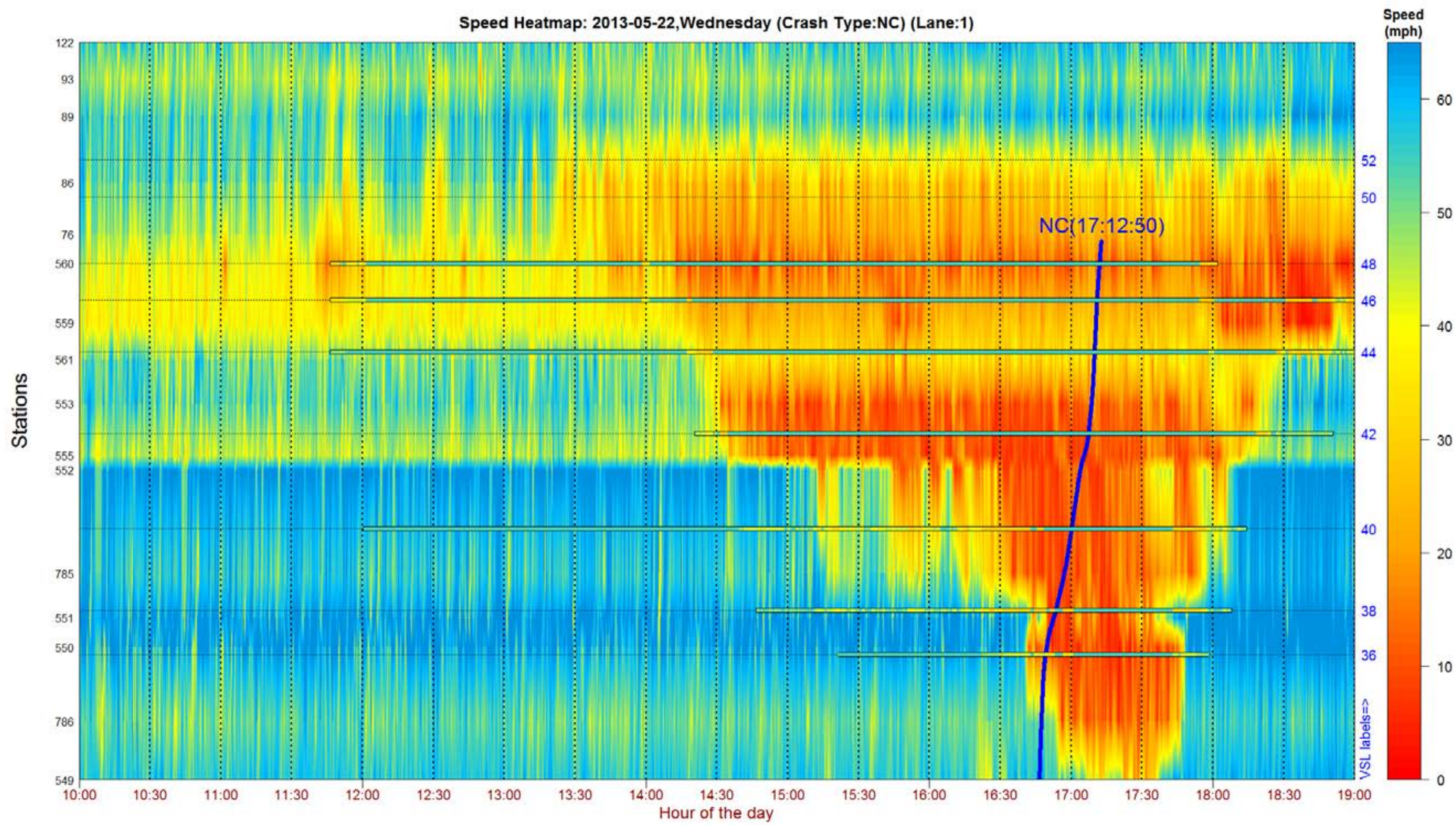

Figure 14. Speed plot with estimated vehicle trajectory for a near crash event on April 4, 2013

The solid blue line indicates the 'trajectory' of the vehicle involved in the near crash event. As the vehicle depicted in the figure traversed the corridor, it passed, early on, by two gantries showing low speed advisories. Blue color in the VSL lines indicates inactive state (normal speed limit). This methodology assumes that the vehicles involved in the crash or near crash approach the high crash location along I-94 and not from one of the ramps along the corridor.

CORRELATION ANALYSIS

To study the shockwaves more directly, the data available from the machine vision detectors was analyzed. In particular, data from the rightmost lane at locations referred to as Middle (Camera 1 in Figure 6) and Portland (Camera 2 in Figure 6) were correlated to visualize the evolution of traffic conditions. The Middle and Portland MVS's are separated by roughly 450 feet.

Cross-correlation is a standard method of estimating the degree to which two series are correlated. Consider two series *x(i)* and *y(i)* where *i=0,1,2...N-1*. The cross-correlation *r* at delay t_D is defined as:

$$r(t_D) = \frac{\sum_i [(x(i) - \bar{x})(y(i - t_D) - \bar{y})]}{\sqrt{\sum_i [(x(i) - \bar{x})^2]}\sqrt{\sum_i [(y(i - t_D) - \bar{y})^2]}}$$

where $\bar{x}$ and $\bar{y}$ are the means of the corresponding series. If the above is computed for all delays t_D=0, 1, 2,...N-1 then it results in a cross-correlation series of twice the length as the original series. There is the issue of what to do when the index into the series is less than 0 or greater than or equal to the number of points ($i - t_D < 0$ or $i - t_D >= N$). The most common approaches are to either ignore these points or assume the series x and y are zero for $i < 0$ and $i >= N$. In many signal processing applications the series is assumed to be circular in which case the out-of-range indexes are "wrapped" back within range, i.e., *x(-1) = x(N-1), x(N+5) = x(5)*, etc.

GENERATING CORRELOGRAMS

For this analysis, a different approach was used. Instead of selecting two equally sized pieces of data for comparison, a smaller portion from one sensor was used to compare with a longer portion from the other.

Correlation analysis methodology requires equally spaced time series while the MVSs generate uneven event sets as vehicles pass by each location. A simple interpolation was applied to the uneven MVS data to generate evenly-spaced 1-second time series between 10 AM and 8 PM.

To perform the correlation, a sample of 700 seconds of data from the Portland MVS and 350 seconds from the Middle MVS were isolated. The time series from the Middle MVS was offset from the Portland time series by 175 seconds so that, according to the time stamps associated with each set, the two time series are aligned (lag of zero seconds).

The time series from the Middle MVS was then aligned to the beginning of the Portland MVS time series (a negative lag of 175 seconds). The overlapping 350-second data sets were compared using the equation above, and a correlation value was determined. The Middle data set was then incremented by one second and the new overlapping data sets were compared. By repeating this process, the Middle MVS data set was compared against the entire Portland MVS data set. Figure 15 shows this framework graphically.

This methodology produces a correlation curve describing the relationship between the Middle and Portland data sets. By stepping across the day at 5-second intervals, the two-dimensional correlation curves are aggregated to form a three-dimensional Correlogram where intensity is represented by color.

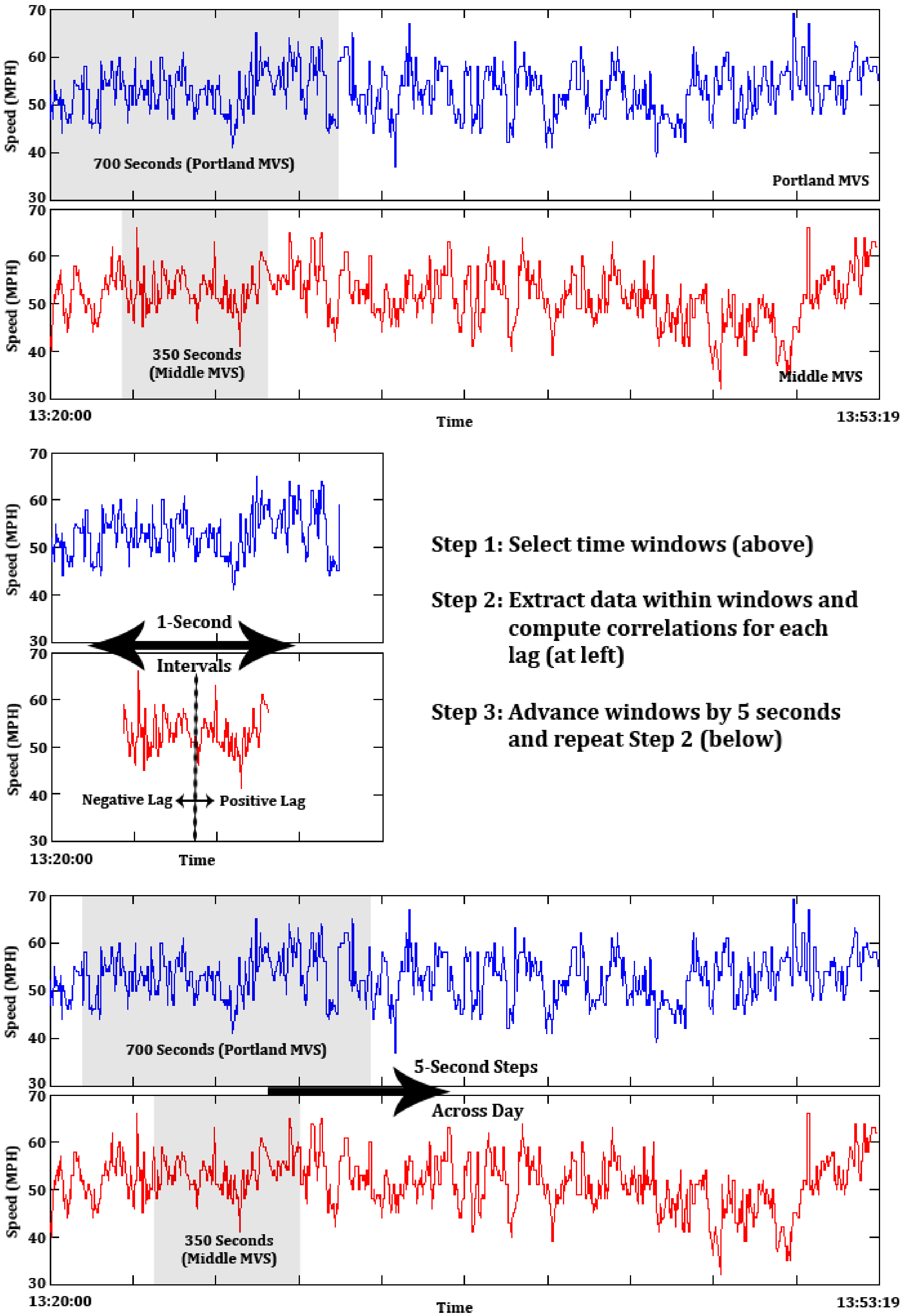

Figure 15. Generating the Correlogram

DECIPHERING THE CORRELOGRAM

The correlation values from this methodology identify traffic patterns as they evolve over time within the examined location. Major traffic events can be isolated based on their specific characteristics. Chassiakos (1992) categorized four types of inhomogeneities in traffic: bottlenecks, traffic pulses, compression waves, and recurrent congestion. Although the I-94 corridor is governed by a significant bottleneck, the MVSs of interest are not targeting that behavior. The other three are observed at the Middle and Portland locations.

Traffic pulses are patterns in traffic that move downstream along with the flow of vehicles during uncongested periods. These pulses appear as high correlation regions in the negative lag portion of the Correlogram. The lag value will correspond to the travel time between the two locations of interest. A simple example of such a pattern can be the platoon of vehicles behind a truck all moving at the speed limit. The platoon will register as a high density peak first on the upstream detector and later on the downstream detector. Since the two detectors are not far enough for traffic to change significantly in the intermediary space due to lane changes, there will be a clear high correlation between the two time series at a lag equal to the travel time between the two stations. Depending on the time reference point the two time series are aligned the lag sign can change. For the purposes, of this work the time reference point is on the downstream detector therefore patterns like traffic pulses which appeared in the upstream in the past are reported at negative lags. The sign is relevant to the selection of a reference point.

Compression waves mirror traffic pulses and represent patterns in the flow of vehicles that move upstream during congested periods. As such, they appear in the Correlogram as highly correlated regions in the positive lag domain of the figure. Again, the lag value corresponds to the travel time, from downstream to upstream, of the compression wave. As noted above, the compression waves always have the opposite sign as compared to traffic pulses.

The strength of the similarities between the data are indicated by the power shown in the plot. Strongly correlated data will appear in reds (values near 1) while data showing similar but opposite trends will appear in blues (values near -1). If no significant correlation can be found, the power is small and values near 0 are reported.

Figure 16 shows a sample Correlogram for July 25, 2012 which highlights key features of the Correlogram.

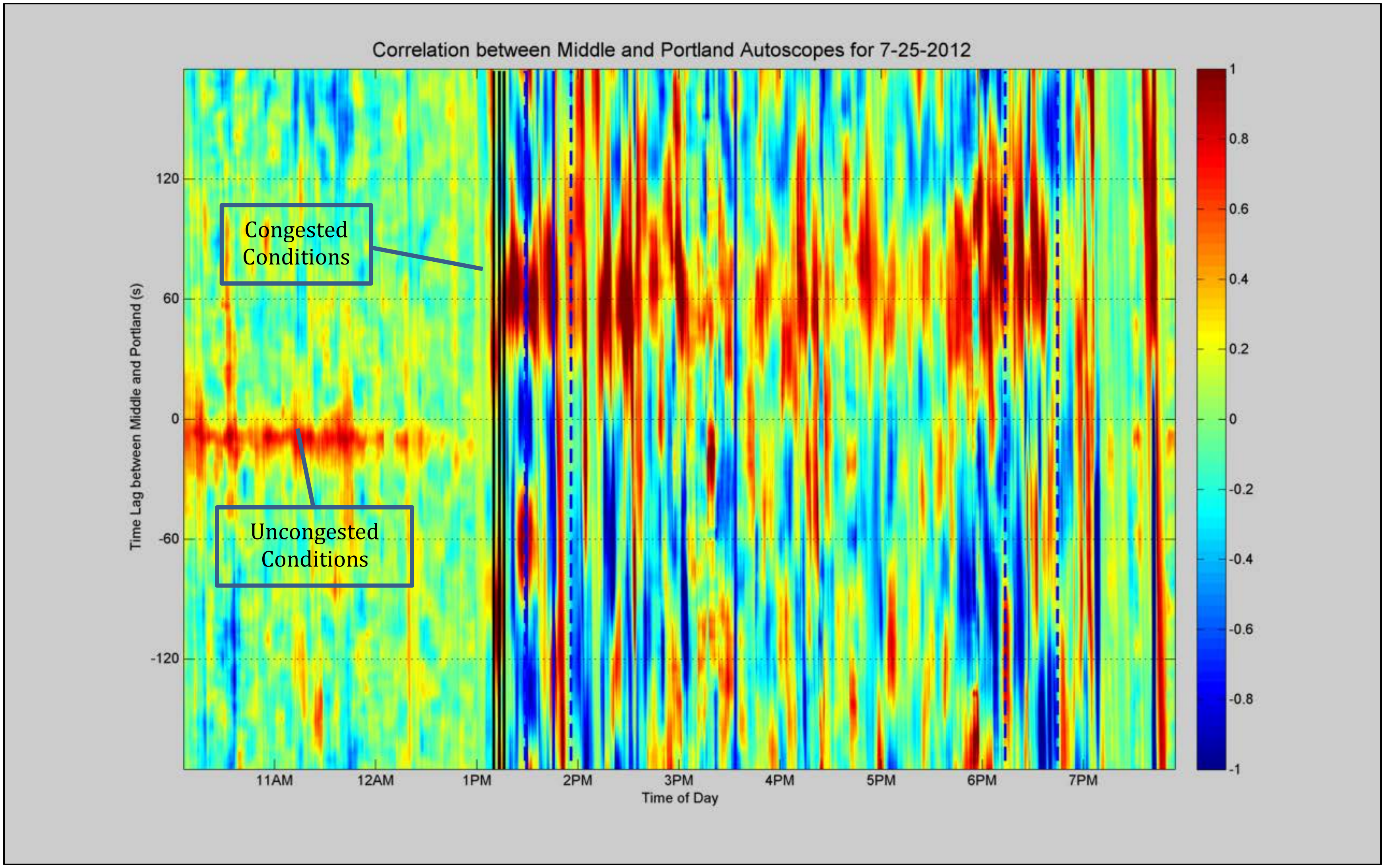

Figure 16. Correlogram for July 25, 2012

The highly positively-correlated band before noon and just bellow zero lag represents uncongested conditions. As vehicles pass from the upstream to downstream machine vision sensor at free flow speeds, very little time passes leading to strong correlation at low time differences. At roughly 12:30 PM the correlation drops off, with no significant correlation found at any lag. This represents the time interval when the downstream MVS began experiencing shockwaves that did not propagate sufficiently to reach the upstream MVS. Near 1:15 strong positive correlation regions begin appearing near the 60-second positive lag mark. These indicate shockwaves traveling upstream. This is confirmed by the three vertical black lines marking the first three shockwaves for the day as observed manually.

Looking at the same day one year later (after VSLS implementation), the actuations of the VSLS can be seen relative to the Correlogram. Figure 49 shows the correlation plot for July 25, 2013. Note the horizontal bands located near -90 seconds lag. These show the speed displayed on the VSL just upstream of the high crash region (with time aligned to the zero-lag line). This sample shows the typical response of the VSLS. Activations begin just after the beginning of significant and sustained shockwave activity and continue for a period of 15 to 45 minutes. During the majority of the congested afternoon period, the VSLS in this location is deactivated (since complete congestion has set in). Toward the end of congestion, the signs again activate for a period of time and finally remain dark as congestion clears.

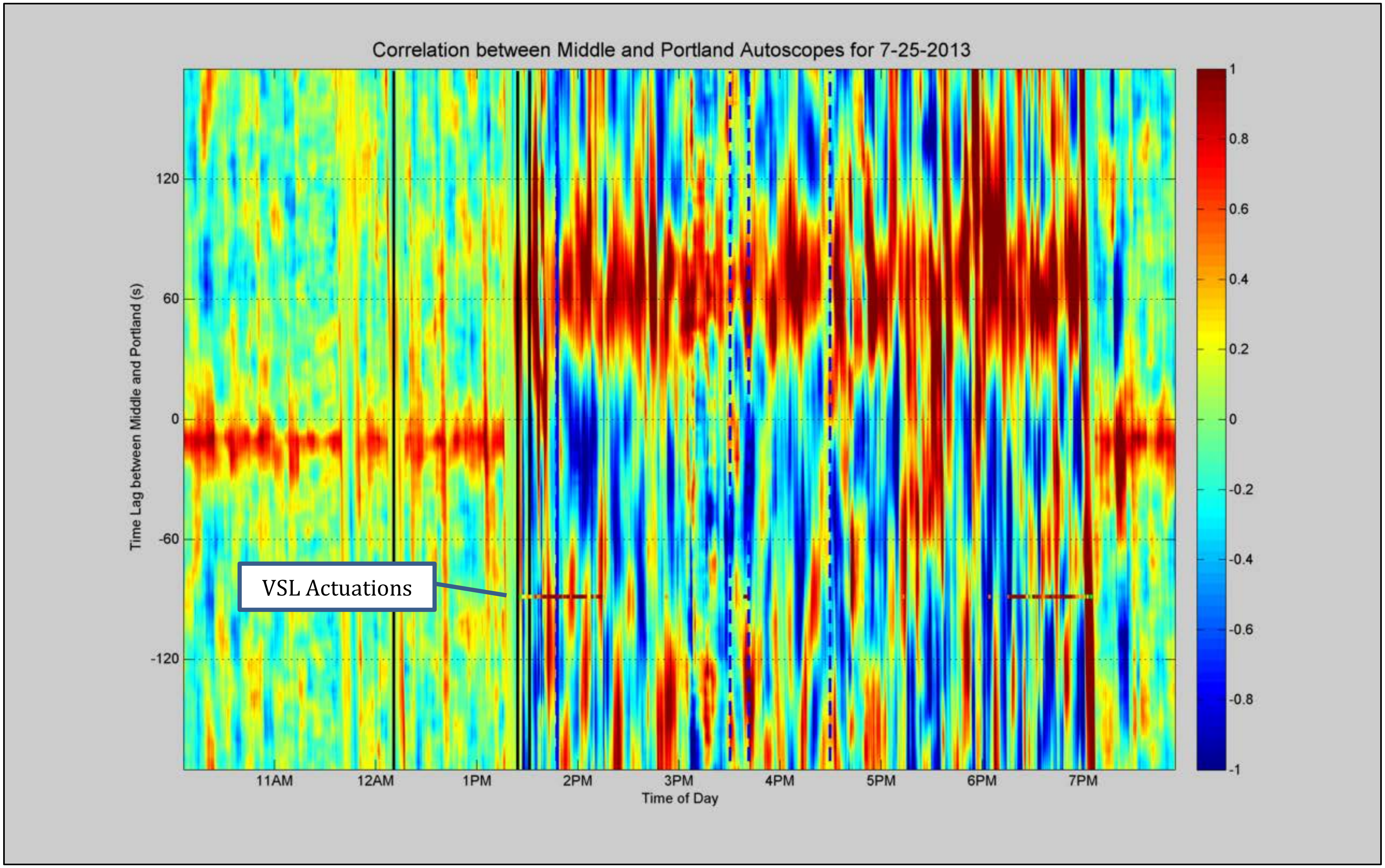

Figure 17. Correlogram for July 25, 2013

The highly correlated patterns in the early and latest portions of the figure representing free flow conditions and should be present at a small negative lag equal to the travel time between upstream and downstream locations. Due to slight desynchronization between sensors, these free flow condition regions were at varying lags. For each day, a synchronization factor was introduced to correct this issue, resulting in each Correlogram displaying free flow correlation patterns in the same region (at small negative lags).

Correlograms were generated for a select set of days before and after VSL implementation. These days were selected based on similarity of traffic demand patterns from loop detector data, weather conditions, and overall shockwave activity (shockwaves per hour).

5. RESULTS

For each of the methodologies described above, the results indicate no significant change in behavior along the high crash corridor due to the implementation of the Variable Speed Limit System. The following sections contain highlights of the results for each methodology, with additional material found in attached appendices.

CRASH AND NEAR CRASH ANALYSIS

As indicated in the methodology description, the crash and near crash analysis was broken into three segments in time: **Long Before** (2008), **Before** (2012), and **After** (2012 into 2013). The aggregated statistics for each period are presented in turn.

2008 DATA – BEFORE VARIABLE SPEED LIMIT SYSTEM ACTIVATION

The 2008 data were recorded immediately after the I-35W Bridge was opened to traffic. The incidents collected from the video stream were organized and analyzed with their corresponding average lane speed and average adjacent lane speed. Table 1 and Table 2 show the crash and near crash events collected during this period.

Table 1. 2008 near crash incidents

Camera	*Date*	*Time*	*Lane*	*Lane Speed (mph)*	*Adjacent Lane*	*Adjacent Lane Speed(mph)*
2	15-Sep	3:40:47 PM	3	24.33	-	-
2	16-Sep	2:56:54 PM	1	49.55	2	*48.63*
2	16-Sep	6:33:08 PM	1	12.15	2	*23.48*
1	18-Sep	1:15:01 PM	1	50.97	2	*49.78*
1	18-Sep	6:02:38 PM	3	25.15	-	-
1	23-Sep	2:53:05 PM	1	22.87	2	*39.44*
1	23-Sep	2:54:09 PM	1	22.87	2	*39.44*
2	23-Sep	3:11:32 PM	1	51.13	2	*51.49*
2	23-Sep	5:48:17 PM	1	13.19	2	*22.15*
2	23-Sep	5:49:32 PM	1	13.19	2	*22.15*
2	24-Sep	2:34:42 PM	1	55.80	2	*54.54*
2	24-Sep	4:26:18 PM	1	11.25	2	*20.90*
2	24-Sep	4:26:18 PM	3	25.40	-	-
2	24-Sep	4:59:03 PM	3	21.38	-	-
1	24-Sep	5:59:25 PM	1	14.41	2	*23.55*
1	24-Sep	6:11:39 PM	1	17.84	2	*31.47*
2	25-Sep	5:33:32 PM	1	17.12	2	*21.84*
2	25-Sep	5:56:05 PM	3	32.22	-	-
2	26-Sep	2:21:47 PM	3	22.67	-	-
2	26-Sep	2:59:42 PM	3	21.21	-	-
2	29-Sep	4:02:18 PM	1	18.38	2	*22.95*
1	1-Oct	2:50:45 PM	1	54.98	2	*55.34*
1	1-Oct	3:19:00 PM	1	53.22	2	*51.07*
2	1-Oct	3:23:52 PM	3	39.35	-	-
1	1-Oct	3:24:15 PM	3	39.35	-	-
1	1-Oct	3:48:40 PM	1	12.04	2	*19.83*
1	1-Oct	4:25:12 PM	1	13.83	2	*24.51*
2	1-Oct	4:39:27 PM	3	26.27	-	-
2	1-Oct	6:14:45 PM	1	24.92	2	*29.13*
2	2-Oct	6:45:31 PM	1	19.19	2	*24.79*
2	3-Oct	12:46:10 PM	1	48.42	2	*49.29*
2	3-Oct	2:14:05 PM	1	57.58	2	*54.13*
2	3-Oct	2:29:53 PM	1	14.76	2	*20.20*
1	3-Oct	2:57:35 PM	1	12.81	2	*23.93*
2	3-Oct	6:53:57 PM	1	24.07	2	*25.60*
2	6-Oct	4:04:50 PM	3	45.11	-	-
2	7-Oct	1:24:10 PM	1	51.12	2	*48.53*

Camera	*Date*	*Time*	*Lane*	*Lane Speed (mph)*	*Adjacent Lane*	*Adjacent Lane Speed(mph)*
3	7-Oct	2:24:12 PM	3	33.58	-	-
2	7-Oct	5:52:56 PM	1	16.60	2	*23.47*
1	7-Oct	6:26:29 PM	1	19.33	2	*22.50*
2	8-Oct	2:25:52 PM	1	53.07	**2**	*53.46*
1	10-Oct	1:34:35 PM	1	52.46	2	*54.00*
1	10-Oct	2:27:35 PM	1	52.56	2	*57.32*
2	10-Oct	2:30:01 PM	1	20.56	2	*57.32*
1	13-Oct	4:11:38 PM	3	22.46	-	-
2	15-Oct	12:58:34 PM	1	8.77	2	*10.49*
2	15-Oct	12:58:45 PM	1	8.77	2	*10.49*
2	15-Oct	12:58:55 PM	1	8.77	2	*10.49*
2	15-Oct	2:39:06 PM	1	35.82	2	*40.31*
1	15-Oct	2:40:42 PM	1	35.82	2	*40.31*
2	15-Oct	5:58:50 PM	3	18.12	-	-
2	16-Oct	1:17:08 PM	1	51.97	2	*50.73*
1	17-Oct	2:35:42 PM	1	33.62	2	*47.54*
2	17-Oct	2:59:12 PM	1	56.23	2	*58.65*
2	17-Oct	2:59:27 PM	1	56.23	2	*58.65*
1	17-Oct	2:59:35 PM	1	56.23	2	*58.65*
1	17-Oct	3:24:36 PM	1	53.40	2	*51.40*
2	17-Oct	5:55:04 PM	1	19.66	2	*21.37*
2	20-Oct	3:59:28 PM	1	13.17	**2**	*17.34*
1	21-Oct	2:55:59 PM	1	14.61	2	*23.22*
2	22-Oct	1:25:21 PM	1	45.37	2	*45.44*
2	22-Oct	1:34:17 PM	1	23.35	2	*36.01*
2	22-Oct	1:36:34 PM	1	25.49	2	*34.23*
1	22-Oct	1:39:49 PM	1	25.49	2	*34.23*
1	22-Oct	1:49:50 PM	1	15.98	2	*23.52*
2	22-Oct	5:40:07 PM	1	17.52	2	*28.77*
2	23-Oct	2:40:41 PM	1	51.04	2	*53.14*
2	24-Oct	2:18:18 PM	1	16.35	2	*19.71*

Table 2. 2008 crash incidents

Camera	Date	Time	Lane	Lane Speed (mph)	Adjacent Lane	Adjacent Lane Speed (mph)
2	18-Sep	2:36:46 PM	2	22.23	3	35.37
2	1-Oct	3:35:59 PM	1	15.64	2	*21.04*
1	1-Oct	3:51:25 PM	3	25.19	-	-
2	6-Oct	3:22:09 PM	1	51.61	2	50.37
1	7-Oct	6:38:24 PM	1	21.92	2	26.59
2	8-Oct	4:14:27 PM	1	11.51	2	23.17
2	8-Oct	6:18:19 PM	1	11.81	2	18.12
2	9-Oct	4:26:18 PM	2	22.80	3	27.11
1	10-Oct	3:36:30 PM	1	15.20	2	20.35
1	13-Oct	2:39:50 PM	1	15.06	2	20.97
3	13-Oct	3:07:54 PM	1	13.75	2	23.4
2	15-Oct	12:58:47 PM	1	8.77	2	10.49
2	22-Oct	2:34:36 PM	1	14.72	2	21.92

Figure 18 and Figure 19 present a graphical representation of the near crash and crash incidents from video collection data. These plots are chronologically organized by date and time recorded. Each point in these plots corresponds to the average lane speed of the lane where an incident took place and its adjacent lane. During peak times (3:30PM to 6:30PM), the majority of crashes and near crashes occurred at speeds below 30mph of speed, with an adjacent lane demonstrating a similar speed.

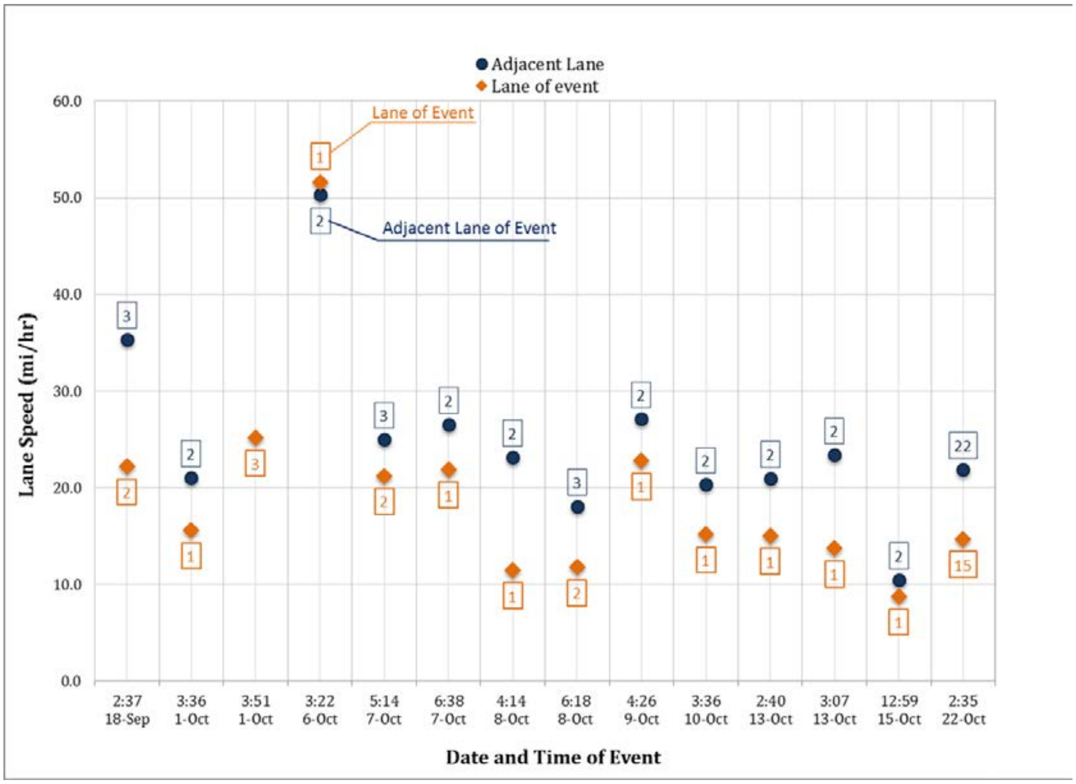

Figure 18. Crash events collected in 2008 - Average speed of event lane and adjacent lane

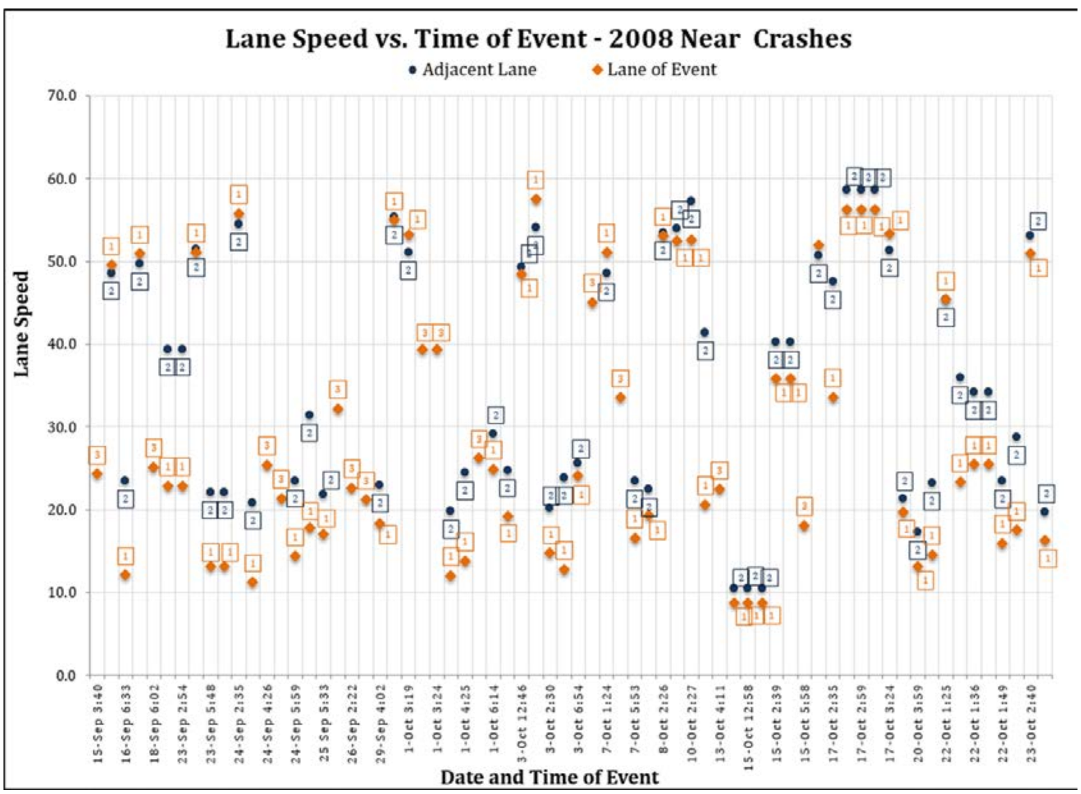

Figure 19. Near crash events collected in 2008 - Average speed of event lane and adjacent lane

Table 3 and Figure 20 show the average shockwave rate during the period of video collected.

Table 3. Average hourly shockwaves from 2008 data

Hour of Day	*Avg. Hourly Count*
11:00:00 AM	0.29
12:00:00 PM	1.39
1:00:00 PM	1.54
2:00:00 PM	9.46
3:00:00 PM	20.36
4:00:00 PM	22.54
5:00:00 PM	20.26
6:00:00 PM	8.69

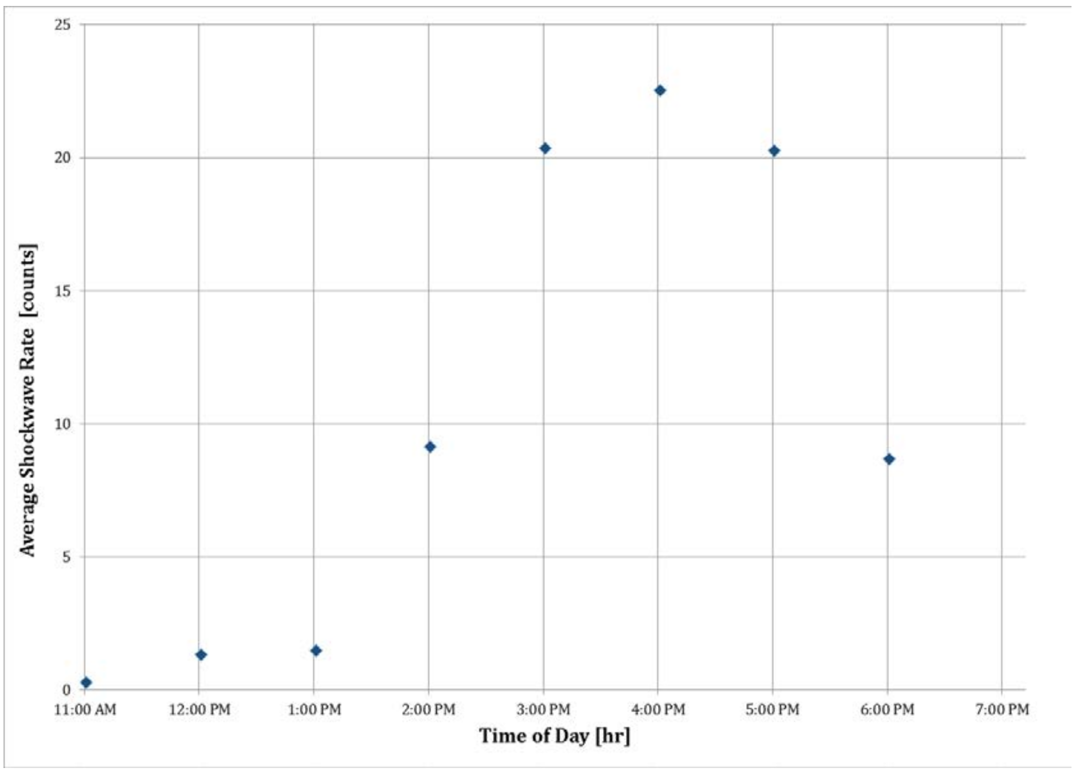

Figure 20. Average hourly shockwaves from 2008 data

2012 Data – Before Variable Speed Limit System Activation

The results presented in this section correspond to the incidents from April through September 27th, 2012, extracted from video and their respective average lane speed records.

All incidents prior to September 27th, 2012 have been chronologically organized. The data extraction program was used to determine average lane speeds. Unfortunately, no data was available from loop detectors before June 6, 2012 and consequently data needed to be extracted from the MVS, as described in the methodology section. The average speed at each individual event was estimated with speed data generated by the MVS, considering the same period of time (five minutes before the incident happened) that was used for the loop detectors.

The incidents collected from the observed video, were organized and analyzed with their corresponding average lane speed of event and adjacent lane. Table 4 and Figure 21 contain the crash incidents from video collection from April 2012 to September 7th, 2012, with average and adjacent lane speeds. The numerous near crash events for this same period, which were presented in the Task 2 report, are not reproduced here.

Table 4. 2012 Before VSL crash incidents

Camera	*Date*	*Time*	*Lane*	*Lane of Event speed (mph)*	*Adjacent Lane*	*Adjacent Lane Speed (mph)*
3	18-Apr	15:15:39	1	22.12	2	22.1
2	8-May	18:40:28	1	30.73	2	29.1
3	9-May	18:32:33	1	21.91	2	33.22
2	16-May	18:18:30	1	22.45	2	26.17
3	17-May	18:50:42	1	31.74	2	28.14
3	18-May	13:32:38	3	37.42	-	-
2	25-May	18:36:29	1	36.95	2	46.91
3	5-Jun	14:29:14	1	46.93	2	52.17
3	6-Jun	18:01:58	1	16.2	2	24.6
2	8-Jun	14:16:56	3	30.9	-	-
2	15-Jun	16:30:28	1	20.4	2	23
2	18-Jun	15:47:27	3	24.8	-	-
1	25-Jun	15:11:07	1	17.4	2	20.3
1	25-Jun	16:59:01	2	21.5	3	25.3
2	25-Jun	18:12:19	1	17.8	2	22.6
3	27-Jun	14:08:39	1	17.82	2	27.72
2	27-Jun	14:10:56	1	20.4	2	27
3	28-Jun	13:46:48	1	15.4	2	29.59
3	3-Jul	13:54:29	1	21.14	2	35.81
2	6-Jul	14:50:55	1	19.6	2	35.3
3	6-Jul	15:53:26	3	18.70	-	-
2	10-Jul	18:40:32	1	16.4	2	24
2	12-Jul	15:27:08	1	11.5	2	18.5
1	12-Jul	18:14:52	1	20.2	2	24.2
2	13-Jul	16:16:53	1	18.4	2	20.1
2	13-Jul	18:56:09	1	18.9	2	27.7
3	16-Jul	16:38:07	1	11.14	2	12.68
3	16-Jul	16:59:18	3	13.84	-	-
3	17-Jul	14:14:37	1	32.91	2	42.11
2	17-Jul	15:57:39	3	22.8	-	-
2	18-Jul	11:16:17	1	38	2	48.1
2	25-Jul	13:29:22	1	18.3	2	23.3
3	25-Jul	13:45:21	1	13.08	2	19.74
2	25-Jul	15:33:13	1	17.4	2	20.6
2	26-Jul	15:08:28	1	22.4	2	26.9
3	3-Aug	11:21:01	1	28.84	2	40.19
2	3-Aug	16:32:46	1	13.1	2	17.4
2	7-Aug	17:24:05	1	15	2	17.3
2	7-Aug	18:45:04	1	24.7	2	35.8
1	10-Aug	18:37:46	1	23.9	2	40.1
2	21-Aug	18:41:49	1	15.6	2	25
2	22-Aug	15:52:43	2	21	3	25.5
2	22-Aug	18:51:11	1	16.9	2	25.5
2	27-Aug	12:57:19	1	23	2	34.5
1	31-Aug	14:14:21	1	16.2	2	20.8
3	4-Sep	14:34:35	1	38.64	2	43.57
2	26-Sep	16:23:51	3	22.9	-	-

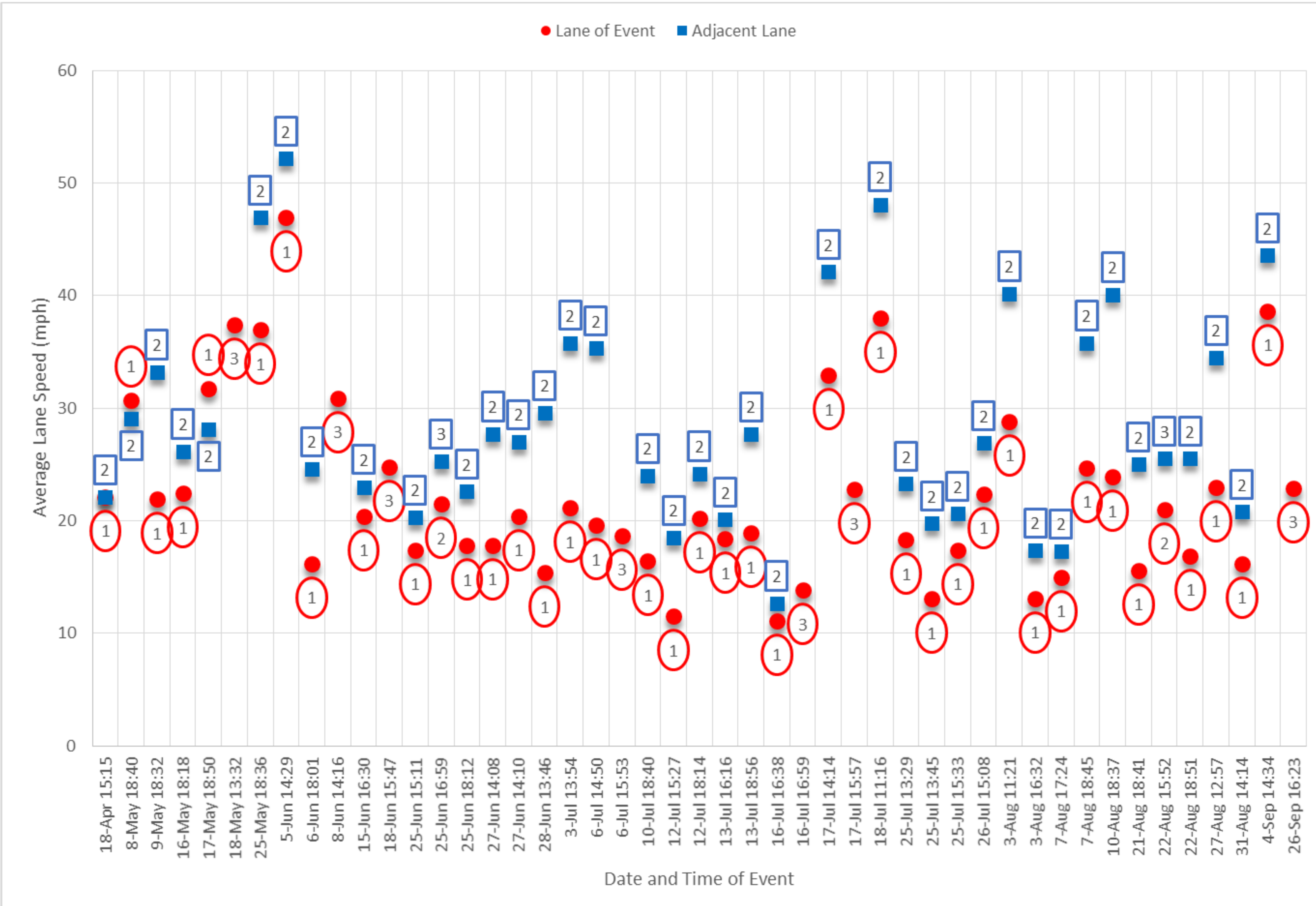

Figure 21. Crash events collected in 2012 Before VSL - Average speed of event lane and adjacent lane

A shockwave count was developed as the video data collection was completed. The average shockwave counts were also determined in order to observe the shockwave pattern during congested hours of the day. Table 5 and Figure 22 show the average hourly shockwave rate during the period of video collected prior to September 27th, 2012.

Table 5. Average hourly shockwaves from 2012 Before VSL data

Hour of Day	Avg. Hourly Count
11:00:00 AM	0.227
12:00:00 PM	1.517
1:00:00 PM	4.161
2:00:00 PM	7.318
3:00:00 PM	14.885
4:00:00 PM	20.895
5:00:00 PM	20.872
6:00:00 PM	18.988
7:00:00 PM	10.140

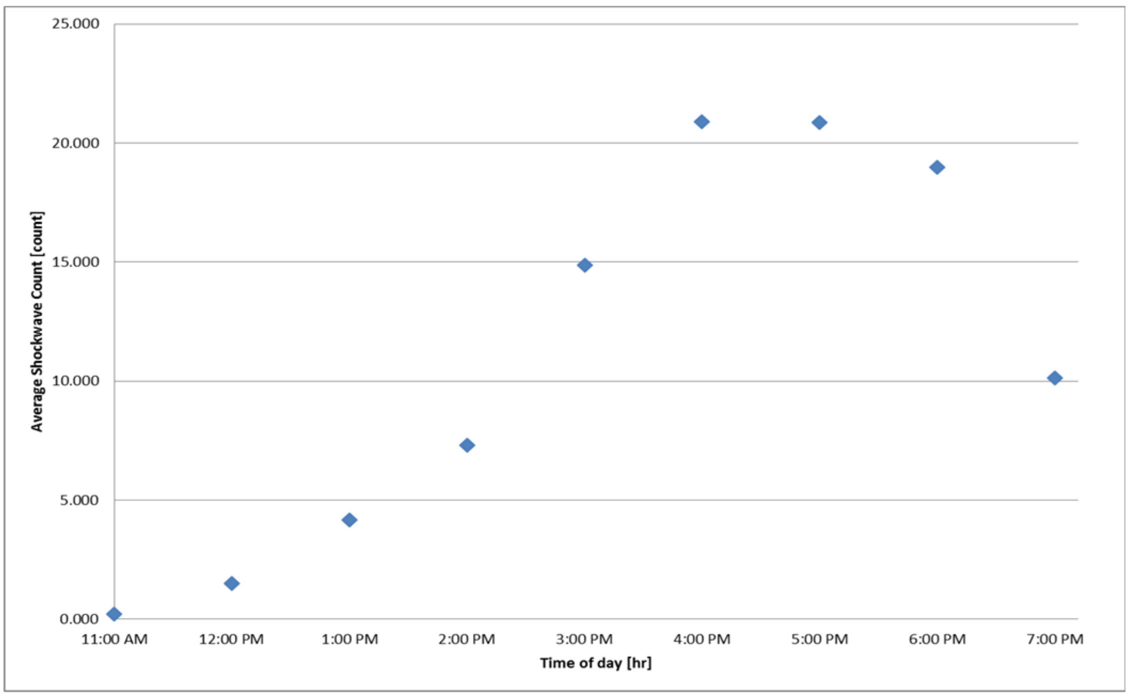

Figure 22. Average hourly shockwaves from 2012 Before VSL data

2012 - 2013 Data – After Variable Speed Limit System Activation

The results presented in this section correspond to the incidents observed in the video records from September 27th, 2012 through September 2013, and their corresponding average lane speed records.

Table 6, Figure 23, and Figure 24 contain the crash incidents recorded from video collection with average lane speeds collected from loop detector data. As with the 2012 Before VSL data, the near crash events are not listed in this report.

Table 6. 2012-2013 After VSL crash incidents

Camera	Date	Time	Lane	Lane of Event (mph)	Adjacent Lane	Adjacent Lane speed (mph)
1	5-Oct	16:07:09	2	21.7	3	25.8
2	9-Oct	15:33:02	1	17.9	2	22.1
1	12-Oct	16:41:30	2	17.2	3	27.4
2	12-Oct	16:50:42	1	16.7	2	21
1	16-Oct	16:44:59	1	15.8	2	22.6
1	18-Oct	18:44:37	1	21.3	2	38.4
3	19-Oct	14:17:31	3	28.1	-	-
2	22-Oct	16:27:35	2	23.4	3	31
2	25-Oct	13:49:02	1	16	2	23.1
2	31-Oct	17:35:20	1	13.9	2	16.8
3	31-Oct	17:35:20	3	12.8	-	-
3	16-Nov	13:41:06	1	20.2	2	26.9
1	20-Nov	17:02:42	1	16.1	2	21.1
2	21-Nov	12:33:36	3	39.4	-	-
2	29-Nov	15:06:15	1	21.8	2	24.5
3	3-Dec	14:36:40	1	38.3	2	47.5
2	5-Dec	14:32:31	1	18	2	35.1
2	5-Dec	16:14:19	1	13.4	2	12.5
1	14-Dec	14:16:50	3	21.3	-	-
2	27-Dec	15:03:52	1	18.3	2	29.7
3	27-Dec	15:04:25	1	16.1	2	26.3
2	31-Dec	16:37:27	1	19.5	2	29.9
2	2-Jan	14:43:17	2	35.5	3	44.1
3	4-Jan	14:58:43	1	14.4	2	29.2
2	4-Jan	17:40:52	3	29.5	-	-
3	4-Jan	18:09:38	3	22.7	-	-
2	8-Jan	14:15:45	1	54.8	2	56.8
1	9-Jan	16:44:35	1	18.4	2	22.8
2	23-Jan	18:24:05	2	23.2	3	28.8
2	24-Jan	14:58:15	1	14.7	2	21.6
2	25-Jan	18:47:52	1	22.2	2	37.3
2	30-Jan	15:58:23	3	28.1	-	-
2	5-Feb	14:37:59	3	34.2	-	-
2	7-Feb	16:06:26	3	23.5	-	-
2	12-Feb	13:58:17	1	12.4	2	13.6
2	14-Mar	16:56:17	1	15.1	2	23.2
3	19-Mar	14:38:04	1	12.7	2	29.6
2	20-Mar	15:49:08	1	13.4	2	20.3
1	2-Apr	17:42:48	1	11.44	2	19.74
2	5-Apr	14:12:56	1	33.82	2	45.89
2	5-Apr	14:40:44	1	26.95	2	30.27
1	16-May	13:53:57	1	23.02	2	39.55
2	16-May	15:07:02	1	20.85	2	23.26
2	17-May	14:04:31	1	19.21	2	25.33
2	20-May	18:14:05	1	35.98	2	39.96
2	23-May	15:25:50	2	24.55	3	28.40
2	24-May	18:34:29	1	19.75	2	37.51
1	31-May	12:14:27	1	35.89	2	44.34
3	6-Jun	17:34:42	3	31.74	-	-
2	6-Jun	18:14:03	1	30.58	2	35.28
1	13-Jun	13:56:09	2	26.94	3	35.97
2	14-Jun	14:21:16	1	26.01	2	32.31
2	14-Jun	16:05:03	1	36.12	2	37.75
2	14-Jun	18:29:09	3	20.54	-	-
3	17-Jun	14:25:23	1	24.52	2	35.45
2	20-Jun	14:27:29	1	22.98	2	30.33
1	8-Jul	18:18:00	1	19.27	2	28.09
2	16-Jul	17:17:35	1	17.32	2	18.46
2	17-Jul	18:07:29	1	17.41	2	26.29
2	22-Jul	14:25:18	1	15.78	2	31.81

Camera	Date	Time	Lane	Lane of Event (mph)	Adjacent Lane	Adjacent Lane speed (mph)
3	23-Jul	12:44:09	1	40.15	2	51.12
2	23-Jul	13:19:12	1	44.72	2	56.08
1	23-Jul	15:23:43	1	15.62	2	21.58
2	23-Jul	18:07:37	1	19.87	2	29.24
2	25-Jul	13:47:40	1	28.53	2	31.99
1	29-Jul	16:03:59	2	20.56	3	27.58
2	2-Aug	17:20:53	1	21.27	2	21.27
3	8-Aug	17:52:40	1	25.69	2	30.01
2	9-Aug	13:03:54	1	22.47	2	31.40
3	14-Aug	18:43:44	3	41.61	-	-
3	15-Aug	12:28:43	1	32.71	2	45.60
1	16-Aug	12:20:24	1	23.04	2	33.20
2	21-Aug	12:27:30	1	47.33	2	45.98
3	22-Aug	13:53:42	1	32.75	2	46.00
2	26-Aug	14:31:44	3	34.06	-	-
1	27-Aug	14:12:28	1	36.18	2	44.09
2	29-Aug	12:55:16	1	28.42	2	42.77
3	30-Aug	17:55:52	2	34.98	3	41.12
2	4-Sep	15:31:15	1	25.01	2	28.79
2	4-Sep	16:29:36	3	22.64	-	-
1	5-Sep	16:31:28	1	18.36	2	24.67
3	6-Sep	18:29:05	3	35.42	-	-
3	9-Sep	16:16:56	3	37.21	-	-
3	19-Sep	12:52:01	1	27.00	2	41.80
3	20-Sep	12:31:39	1	20.49	2	41.41
2	20-Sep	14:09:42	3	34.90	-	-

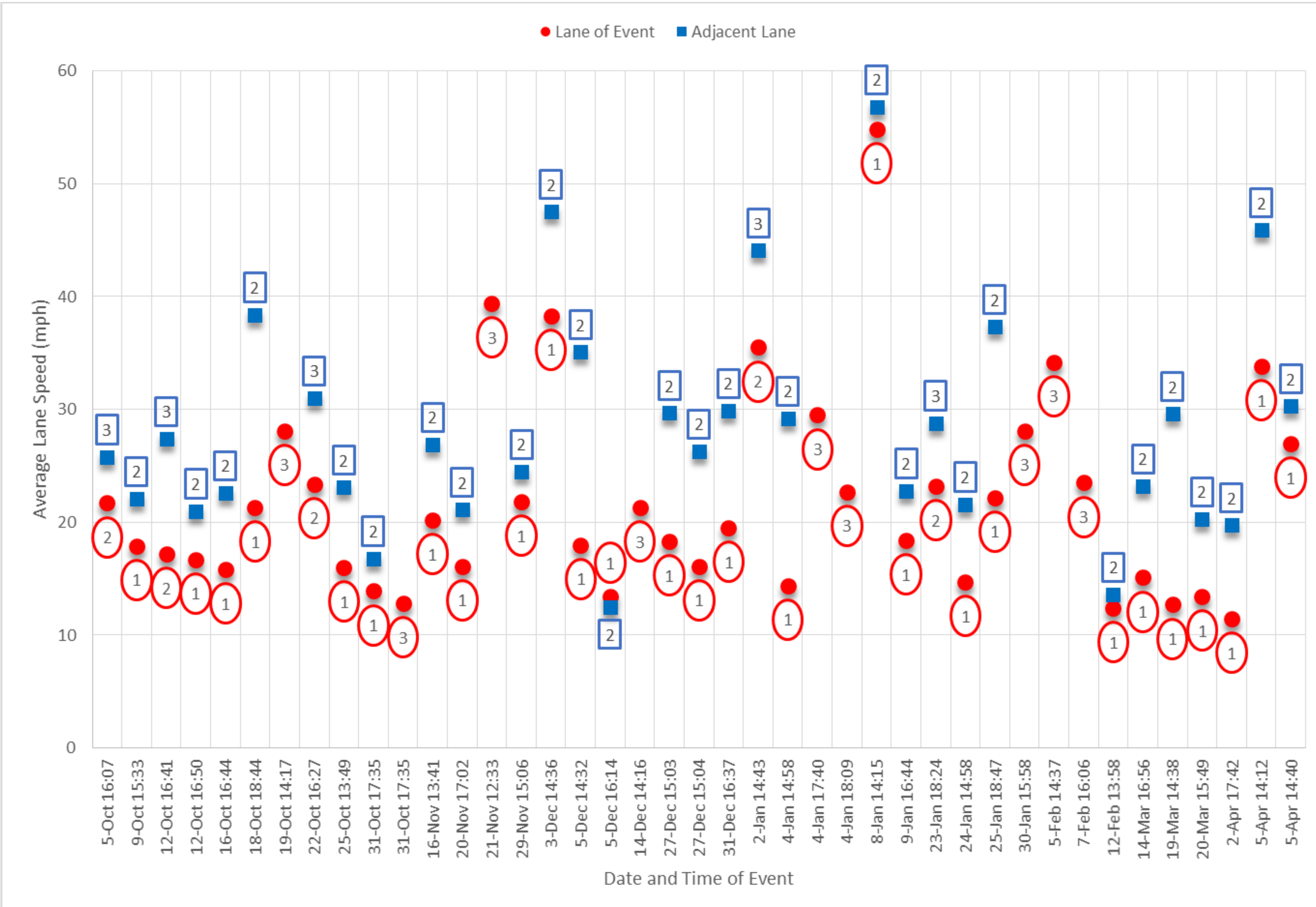

Figure 23. Crash events collected between October 2012 and April 2013 after VSL implementation

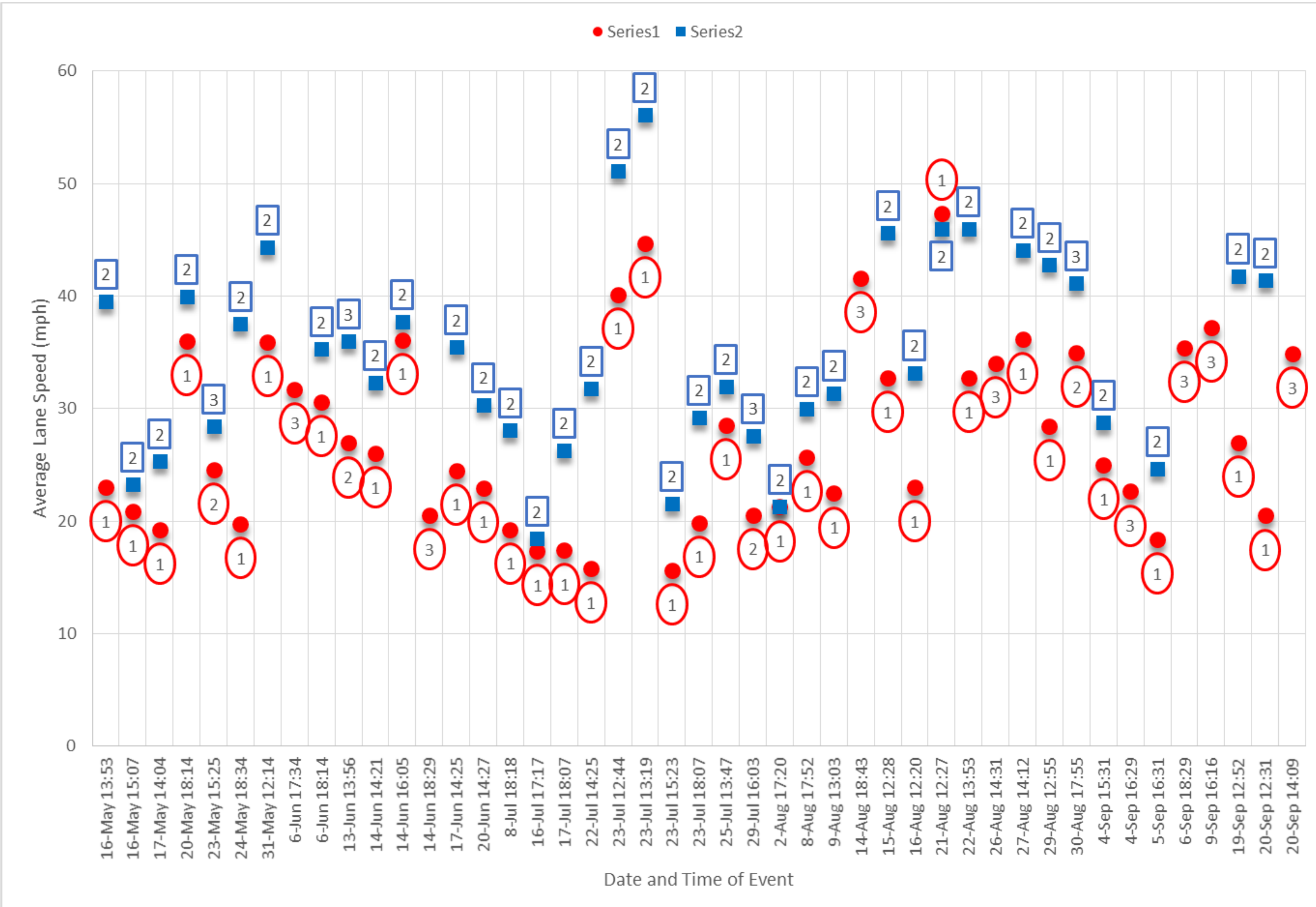

Figure 24. Crash events collected between May 2013 and September 2013 after VSL implementation

A shockwave count was developed as the video data collection was completed. The average shockwave counts were also completed to observe the shockwave pattern during congested hours of the day. Table 7 and Figure 25 show the average shockwave rate during the period of video collected after VSL activation.

Table 7. Average hourly shockwaves from After VSL data

Hour of Day	Avg. Hourly Count
11:00:00 AM	0.60
12:00:00 PM	1.40
1:00:00 PM	3.84
2:00:00 PM	7.34
3:00:00 PM	13.84
4:00:00 PM	18.28
5:00:00 PM	18.98
6:00:00 PM	17.87
7:00:00 PM	11.90

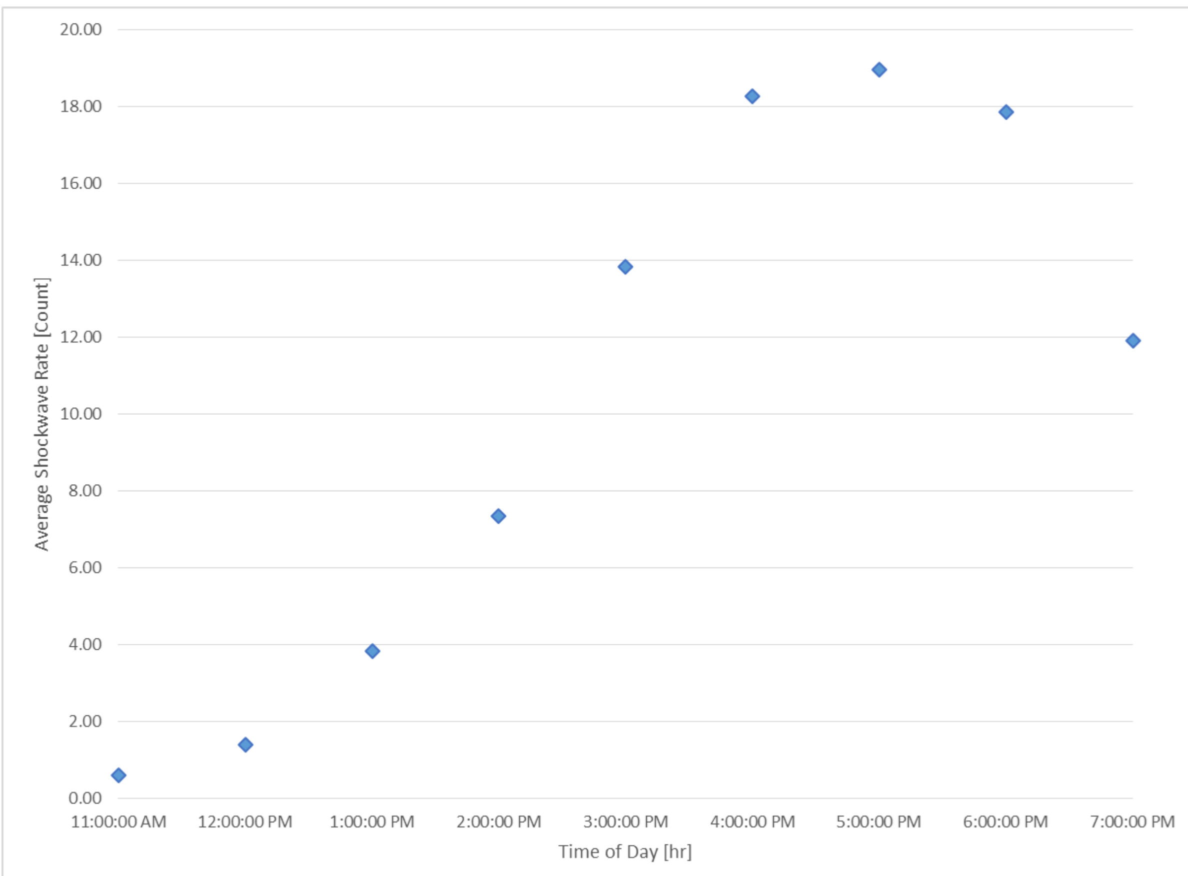

Figure 25. Average hourly shockwaves from 2012-2013 After VSL data

INCIDENT RATE COMPARISON – BEFORE V. AFTER

The data collected in 2008 and 2012, prior to September 7th, were compared to the data collected between September 8th, 2012 and March 2013. The comparison resulted in Table 8, which shows the rate of incident per million vehicles traveled (MVT), along the I-94 section, per month of collection.

Table 8. Incidents per million vehicles for each month of data collection

	Month	Incidents			Vehicle Volume	Rate
		NC	C	Total		Incidents/MVT
Before	September 2008	22	1	23	382407	60.15
	October 2008	56	11	67	741381	90.37
	April 2012	6	1	7	244677	28.61
	May 2012	38	5	43	727481	59.11
	June 2012	82	9	91	764570	119.02
	July 2012	128	20	148	772112	191.68
	August 2012	107	10	117	643864	181.72
	September 2012	30	2	32	250906	127.54
After	September 2012	12	0	12	73251	163.82
	October 2012	98	9	107	833893	128.31
	November 2012	34	3	37	463693	79.79
	December 2012	52	8	60	692010	86.70
	January 2013	45	10	55	791488	69.49
	February 2013	22	3	25	520694	48.01
	March 2013	31	3	34	625552	54.35
	April 2013	22	3	25	325998	76.69
	May 2013	45	7	52	479985	108.34
	June 2013	136	12	148	776118	190.69
	July 2013	102	11	113	825148	136.95
	August 2013	91	12	103	805673	127.84
	September 2013	47	9	56	549402	101.93

Table 9 displays the total rate of incidents/MVT for the data collected before and after the VSL system was activated. These are broken into four groupings for comparison: the Before data including and not including the 2008 data, and the After data including and not including the winter months of 2013. In aggregate, from the Before to the After data set the total incident rate dropped slightly from roughly 116 to 107 incidents per MVT. However, using only the non-winter months for both sets, the rate increased from 116 to 132 incidents per MVT. If the much earlier data from 2008 are excluded, so that only year-on-year changes are examined (Before not incl. 2008 v. After excluding Winter), the rate increased only slightly from 129 incidents/MVT to 132 incidents/MVT. Examining the overall trends, the Before and After excluding Winter sets show a similar pattern, but offset by one month from Before to After (peaking in July Before and June After).

Table 9. Total incidents per million vehicles for Before and After VSL system activations

	Total Incidents	Total Vehicle Volume	Rate
		Million Vehicles	Incidents/MVT
Before incl. 2008	528	4.53	116.62
Before not incl. 2008	438	3.40	128.69
After	827	7.76	106.53
After excluding Winter	616	4.67	131.92

LANE SPEED COMPARISON

A distribution, shown in Table 10 and Table 11, was created to demonstrate the lane speed difference between the lane of event and the adjacent lane, for all near crashes and crashes that occurred in lane one. Figure 26 shows the data collected in 2008 and prior to September 27th, 2012. Figure 27 is the data collected from September 27th, 2012 and in 2013 (not just the same months as the Before data). Incidents that occurred in lane three were not included in the distribution, due to not having an adjacent lane to compare with, and lane two was not included because there were very few incidents that took place in the lane. The lane speeds were grouped in five mile per hour intervals. The results show that the largest number of incidents take place when the lane speeds differ by speeds from 5 mph to 10 mph, in both the Before and After data.

Table 10. Histogram for lane 1 incidents in Before data

Intervals (mph)	Frequency
5	112
10	142
15	73
20	31
25	4
30	0
35	0
40	1
More	0

Table 11. Histogram for lane 1 incidents in After data

Intervals (mph)	Frequency
5	120
10	230
15	174
20	73
25	11
30	0
More	0

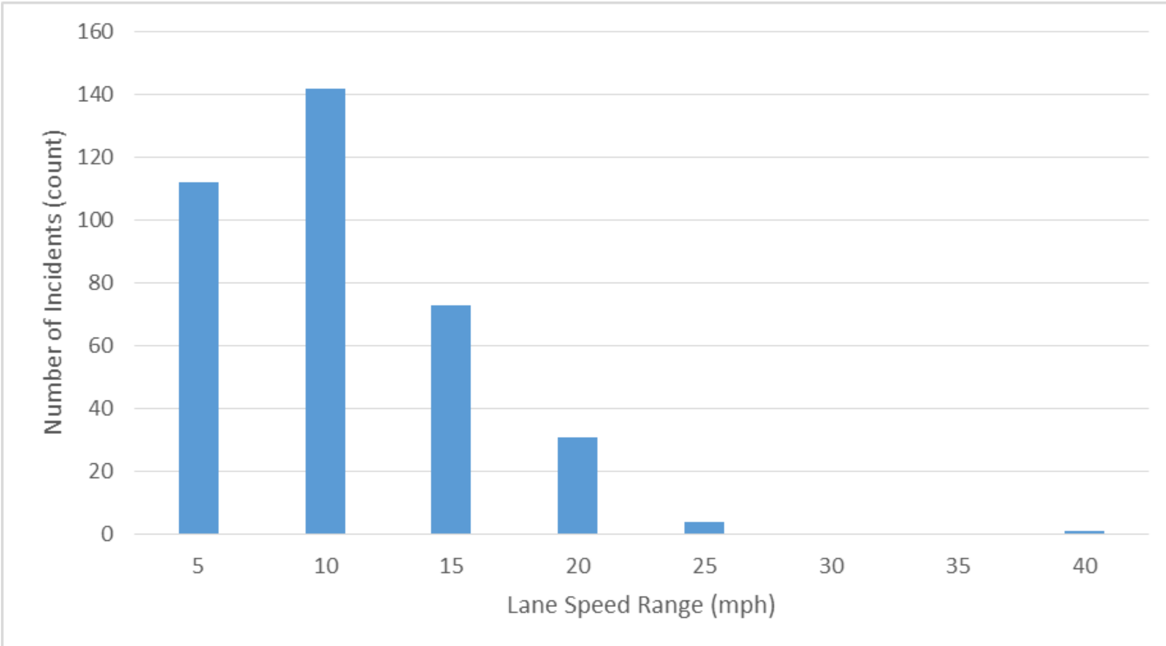

Figure 26. Histogram of lane speed variance for Before data

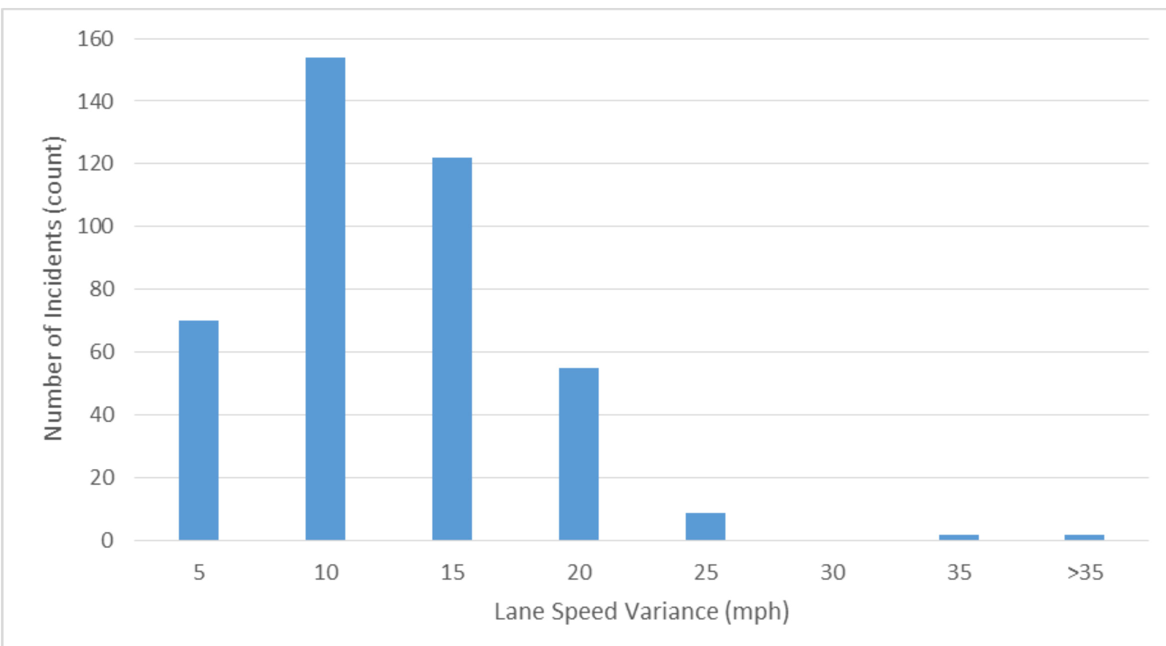

Figure 27. Histogram of lane speed variance for After data

VIDEO-BASED SHOCKWAVE ANALYSIS

The first three shockwaves of each day were analyzed to uncover differences between pre-VSL and post-VSL behavior. Across the Before dates, the first shockwaves of each day ranged from 12 PM to nearly 4 PM. In the After dates, the first shockwaves started slightly later and ended slightly earlier (ranging between 12:15 and 3:30 pm). Figure 28 shows the frequency across the afternoon for both Before and After.

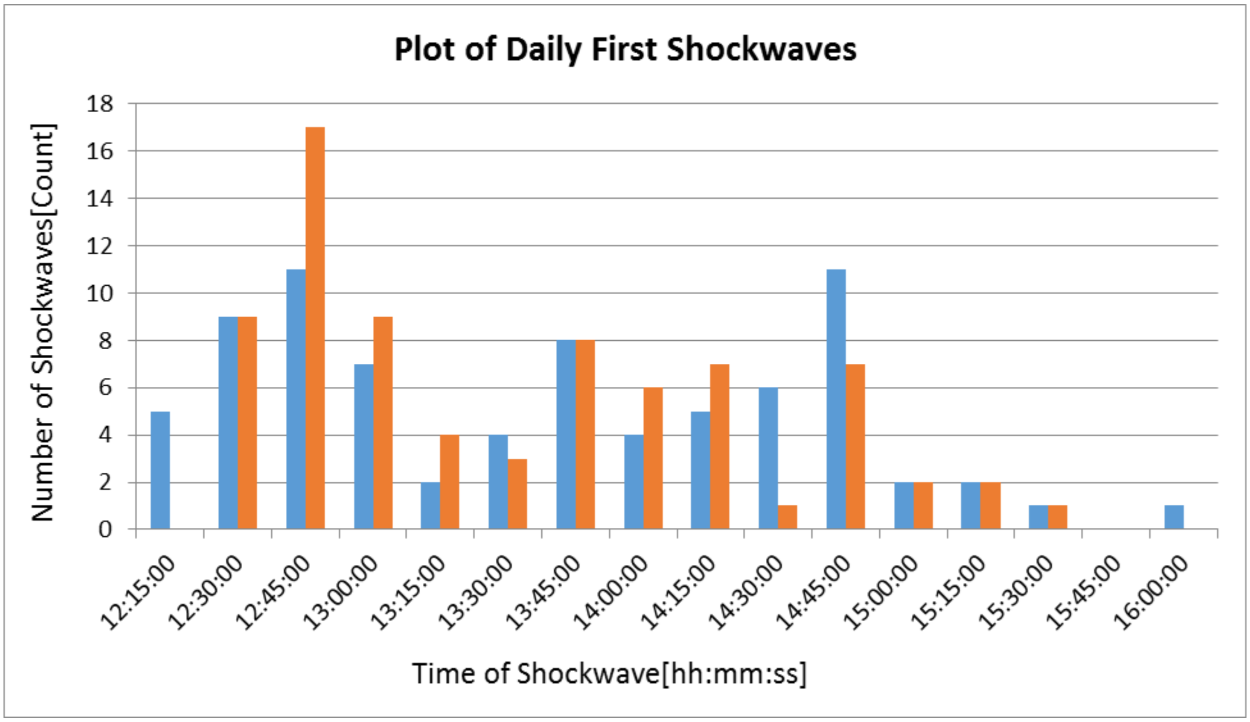

Figure 28. Time of onset of the first shockwave Before and After VSL

In the Before data, the highest incident of first shockwaves occurs in two peaks: the first occurs around 12:45 with a secondary peak nearer to 2:45. In contrast, the After data shows a much larger peak (17 v. 11) at 12:45 and a smaller, more evenly distributed onset of shockwaves through the mid-afternoon.

The second shockwave for each day follows a similar pattern for both the Before and After data. The Before data shows a local peak at around 12:45, but a more significant peak after 2:30 pm. The After data is, again, more heavily weighted toward the earlier peak at 12:45-1:00 with a more even spread across the rest of the afternoon. The overall trends occur between 15 and 30 minutes later than those of the first shockwave (for both Before and After) and are shown in Figure 29.

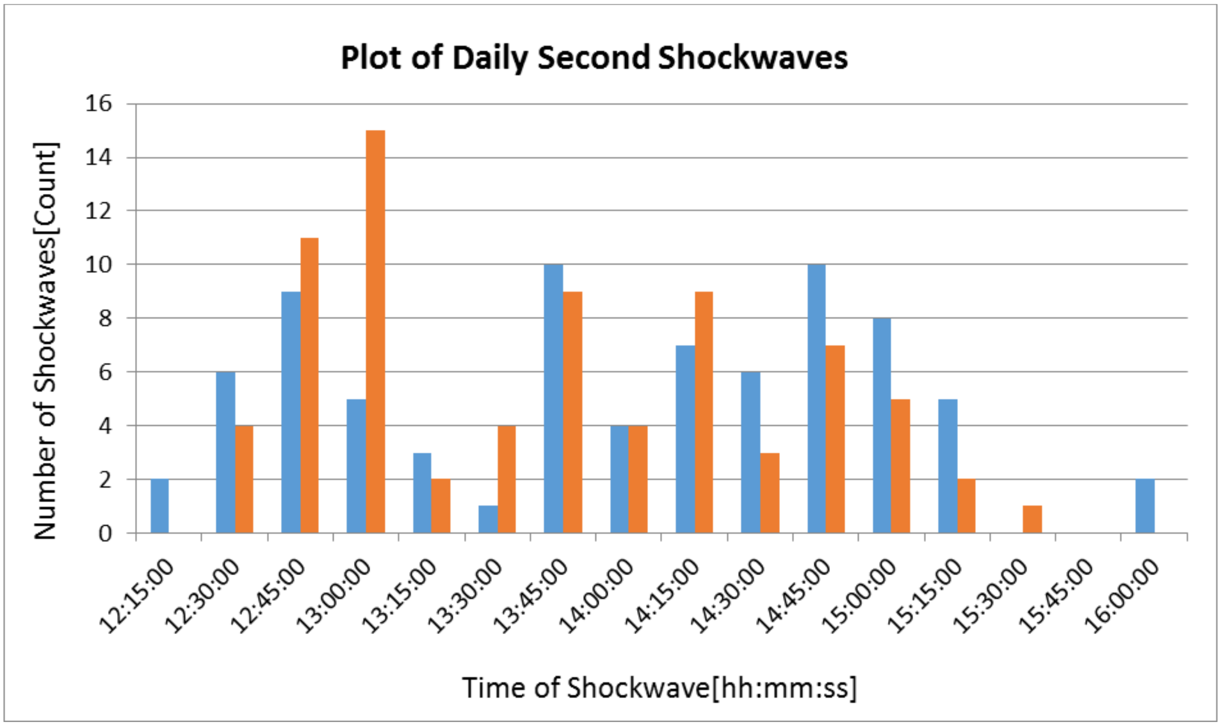

Figure 29. Time of onset of the second shockwave Before and After VSL

The third shockwaves are further delayed in the afternoon and show the same overall trends as suggested by the first and second shockwaves. In the Before data, the early peak has diminished and the later peak (between 2:30 and 3:15 pm) has become dominant. The After data continues to be dominated by the early peak (now at 1:00 pm) with an approximately even distribution later in the afternoon (see Figure 30).

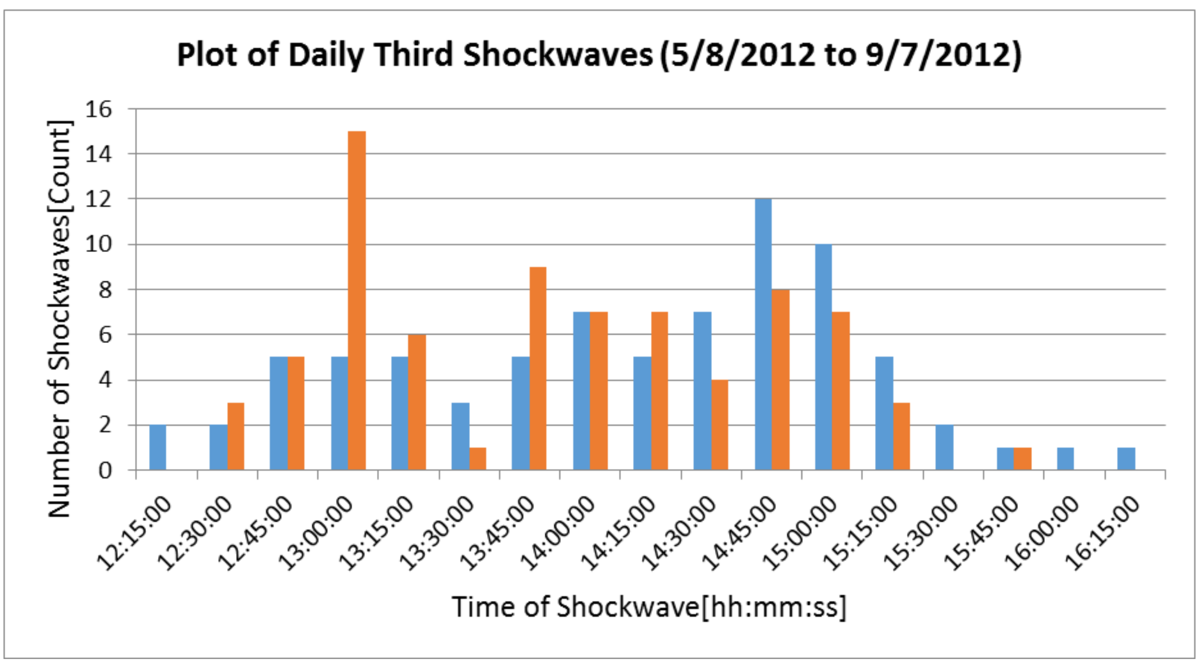

Figure 30. Time of onset of the third shockwave Before and After VSL

The time difference between consecutive observed shockwaves was also examined for differences between the before and after conditions. The results indicate that most first and second shockwaves are separated by five minutes or less, as can be seen in Figure 31.

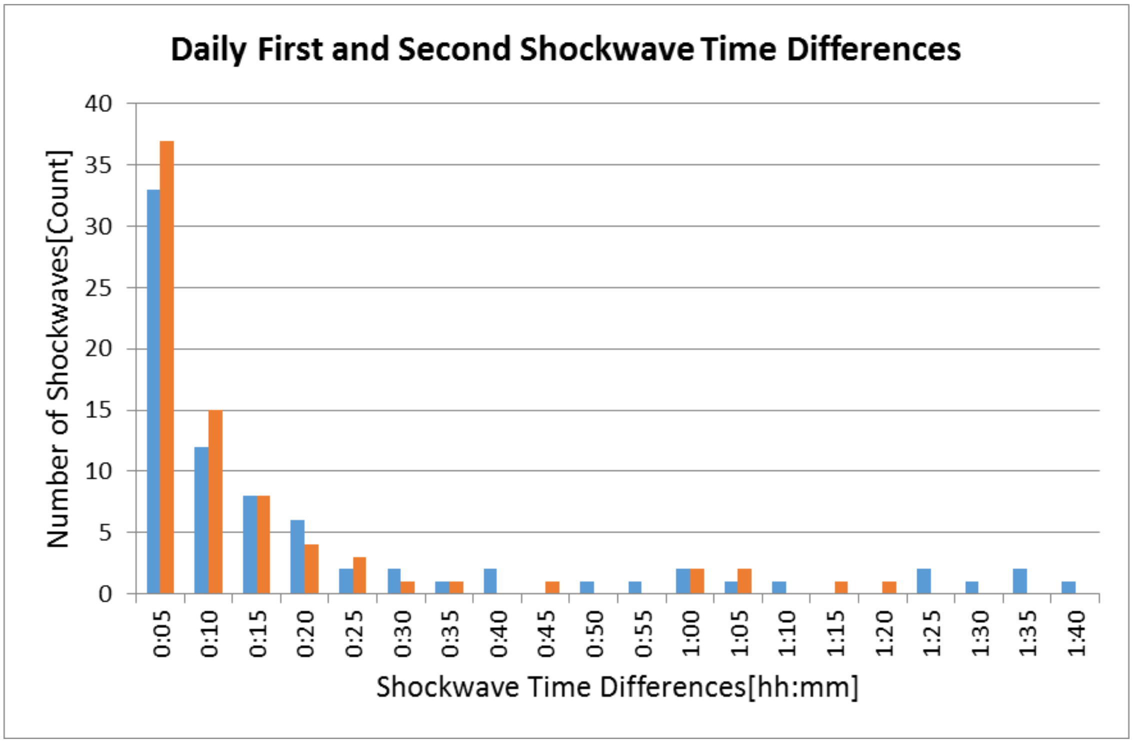

Figure 31. Gap between first and second shockwave onset Before and After VSL

In the Before data, 33 shockwave pairs occurred at less than 5 minutes apart (42.3%) and 53 occurred at less than 15 minutes apart (67.9%). The shockwave after the VSL are clustered even closer together with 37 pairs less than 5 minutes apart (48.7%) and 60 within 15 minutes (78.9%). The longest gaps between the first and second shockwave were over and hour and a half in the Before data, while the longest in the After data is somewhat shorter at just under one hour and twenty minutes.

The time gap between the second and third shockwave of each day is shorter than the gap between the first and second. In the Before data, 33 (42.3%) are separated by less than 5 minutes while a strong majority are under 15 minutes apart (82.1%). Similarly, the After data is highly weighted toward short separation times. 46 pairs are less than 5 minutes apart (60.1%) and 66 are under 15 minutes (86.8%). Figure 32 shows the frequency of these gaps.

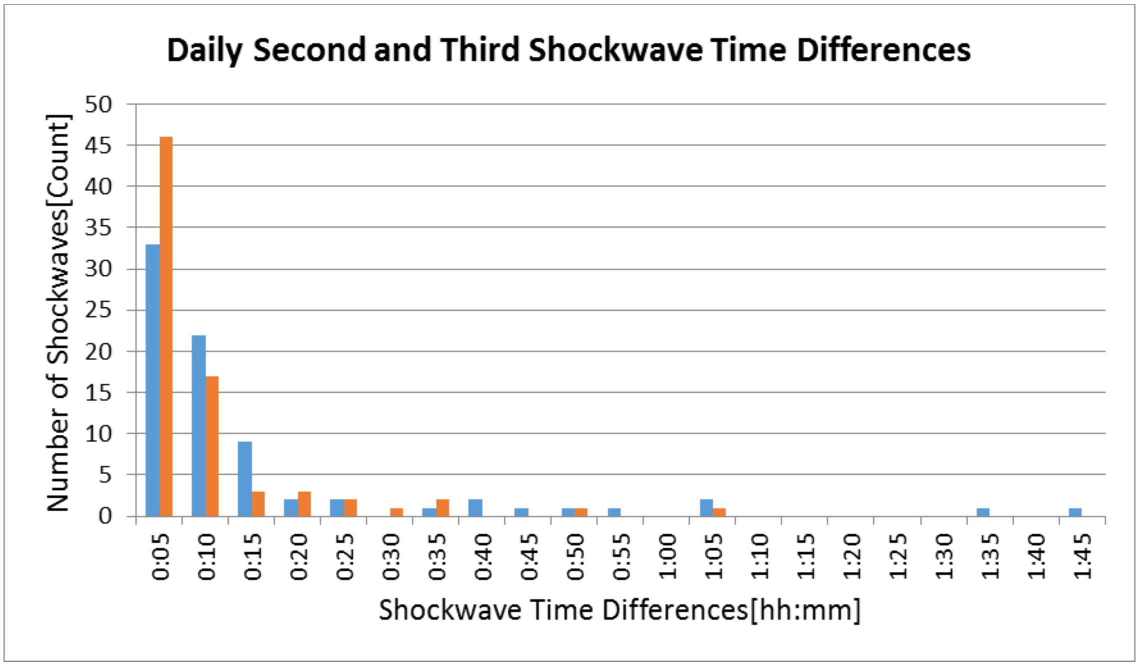

Figure 32. Gap between second and third shockwave onset Before and After VSL

Loop Detector-Based Shockwave Analysis

As indicated in the methodology section, loop detector data was analyzed to detect congestion emanating from the bottleneck at the I-35W to I-94 merge point (roughly Station 76). By observing the speed for each detector in the region over time, the progression of the tail of congestion was tracked. Figure 33 shows the map of the region, including the station immediately upstream of the bottleneck which is used to synchronize breakdowns.

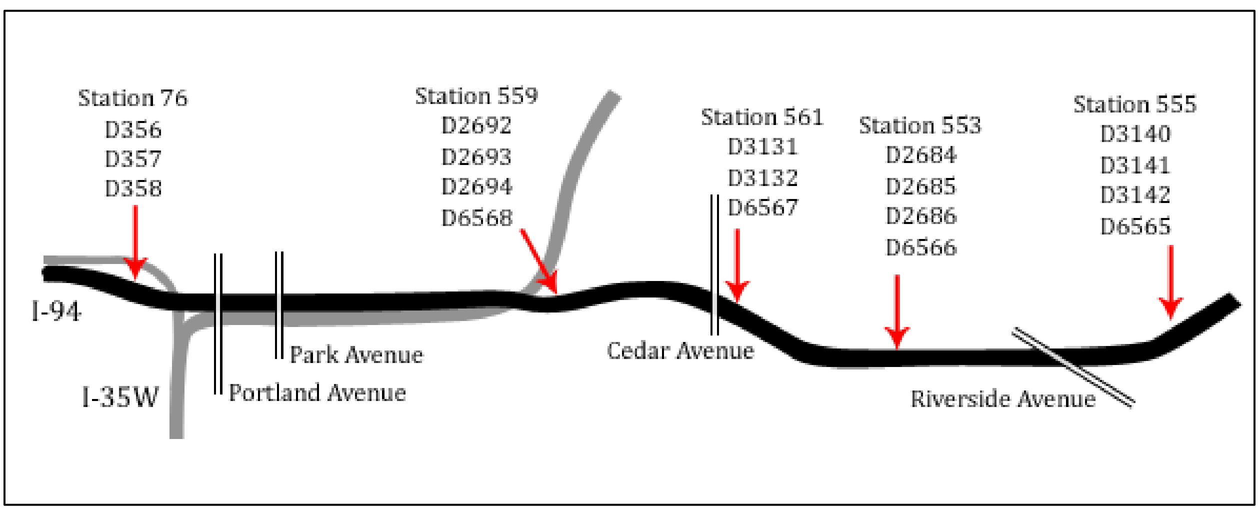

Figure 33. Map of detectors upstream of the bottleneck station (Station 76)

Before and after analysis of VSLS implementation was performed by comparing sequential 5-minute average speeds during one hour after the breakdown at station 76. Statistical tests were performed on the average speed for summer pairs (1) 2011 versus 2013, and

(2) 2012 versus 2013. The analysis presented in the following sections is restricted to those stations and corresponding detectors which are:

1. Close enough that the effect of breakdown is felt at those stations
2. Far enough upstream that drivers have time to react to the VSLS indications

Table 12 shows relevant stations (shown from downstream to upstream) and detectors that satisfy the above criteria.

Table 12. Detectors for VSL speed analysis

Station	Lane	Detector
559	R1	2692
	L1	2693
	L2	2694
	L3	6568
561	R1	3131
	L1	3132
	L2	6567
553	R1	2684
	L1	2685
	L2	2686
	L3	6566
555	R1	3140
	L1	3141
	L2	3142
	L3	6565

The results presented focus on the rightmost detector for each station (similar results were obtained for the other lanes at each location). Figure 34, Figure 35, Figure 36, and Figure 37 show the twelve 5-minute interval speeds throughout the analysis period for the right lane detectors. A horizontal line at 40 mph is shown on each plot to aid in identifying breakdown conditions. The vertical red bar indicates the date of VSL implementation. The effect of shockwaves created at station 76 begin to affect stations 559, 561, 553, and 555 after roughly 10 minutes, 15 minutes, 20 minutes, and 30 minutes, respectively. These are indicated by arrows identifying times with more frequent speed drops.

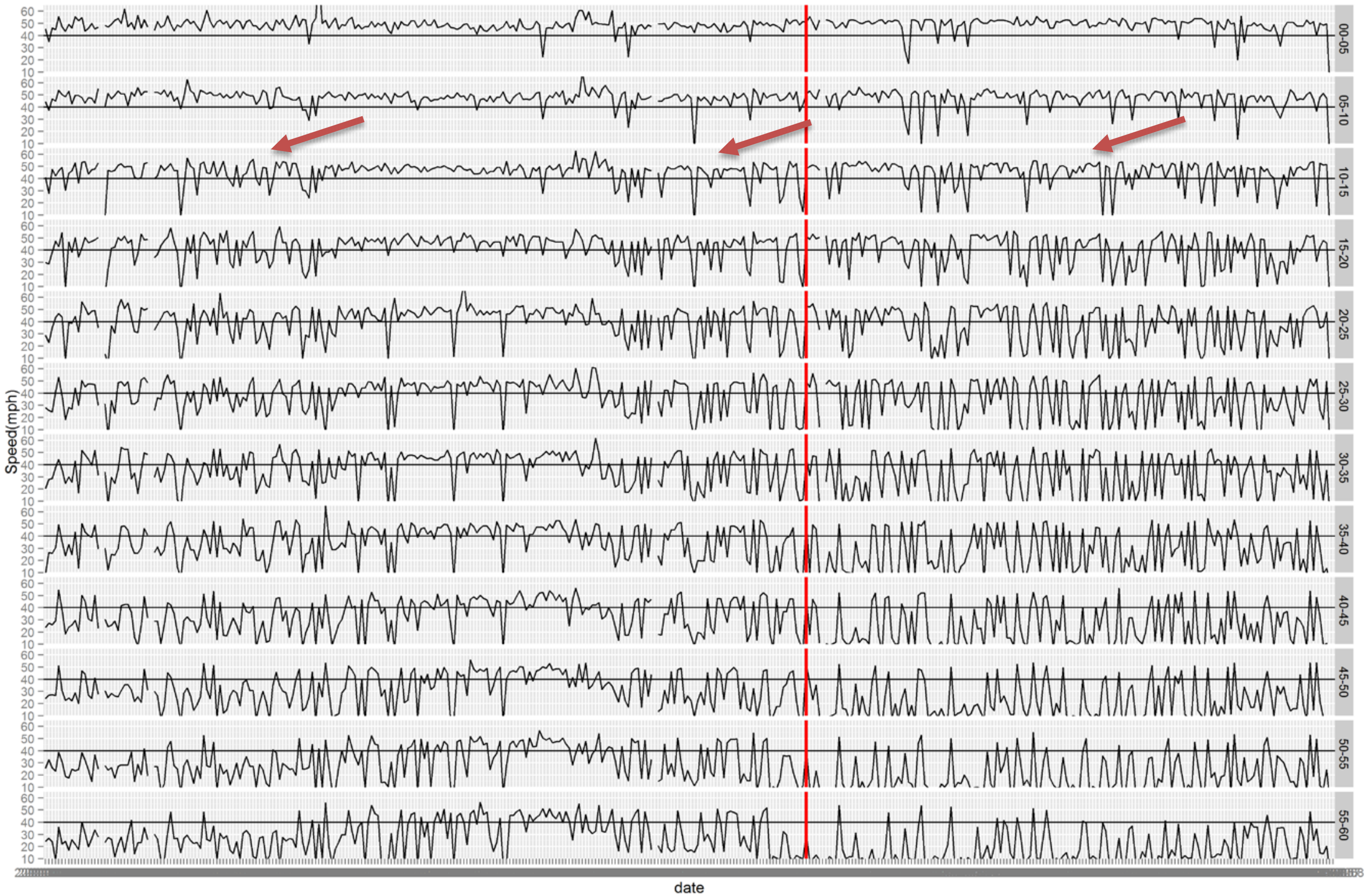

Figure 34. Evolution of speed over time for detector D2692

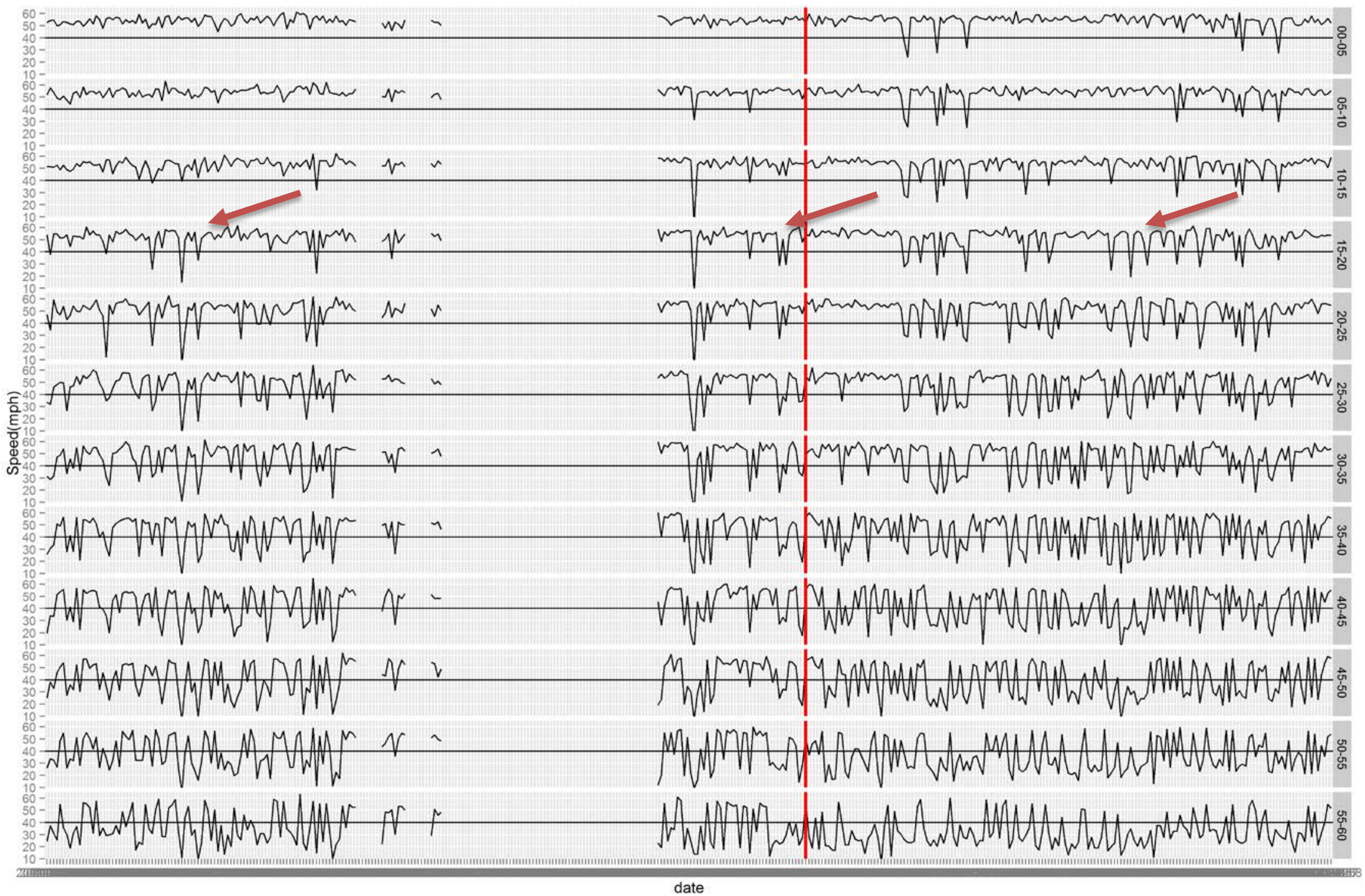

Figure 35. Evolution of speed over time for detector D3131

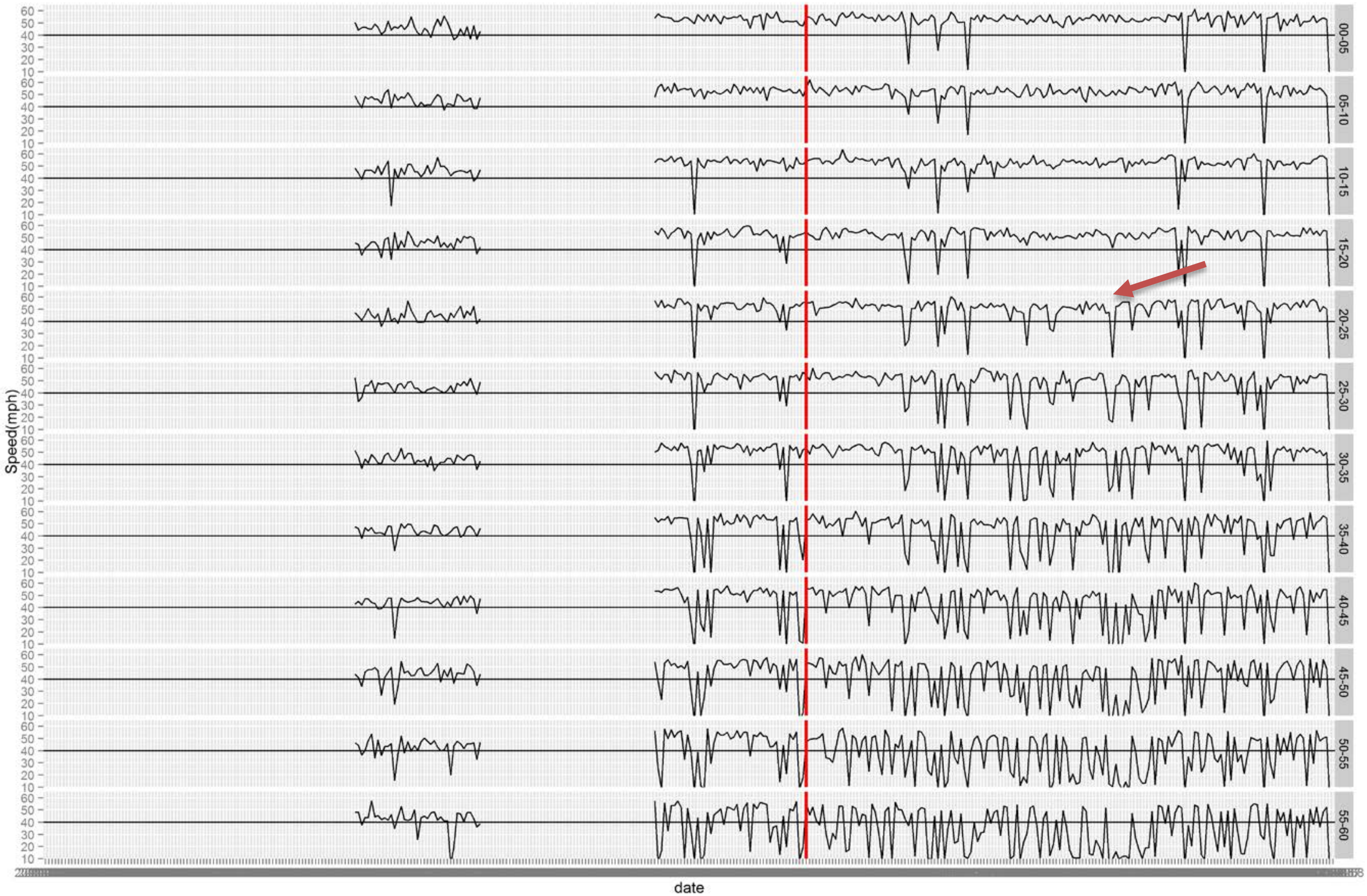

Figure 36. Evolution of speed over time for detector D2684

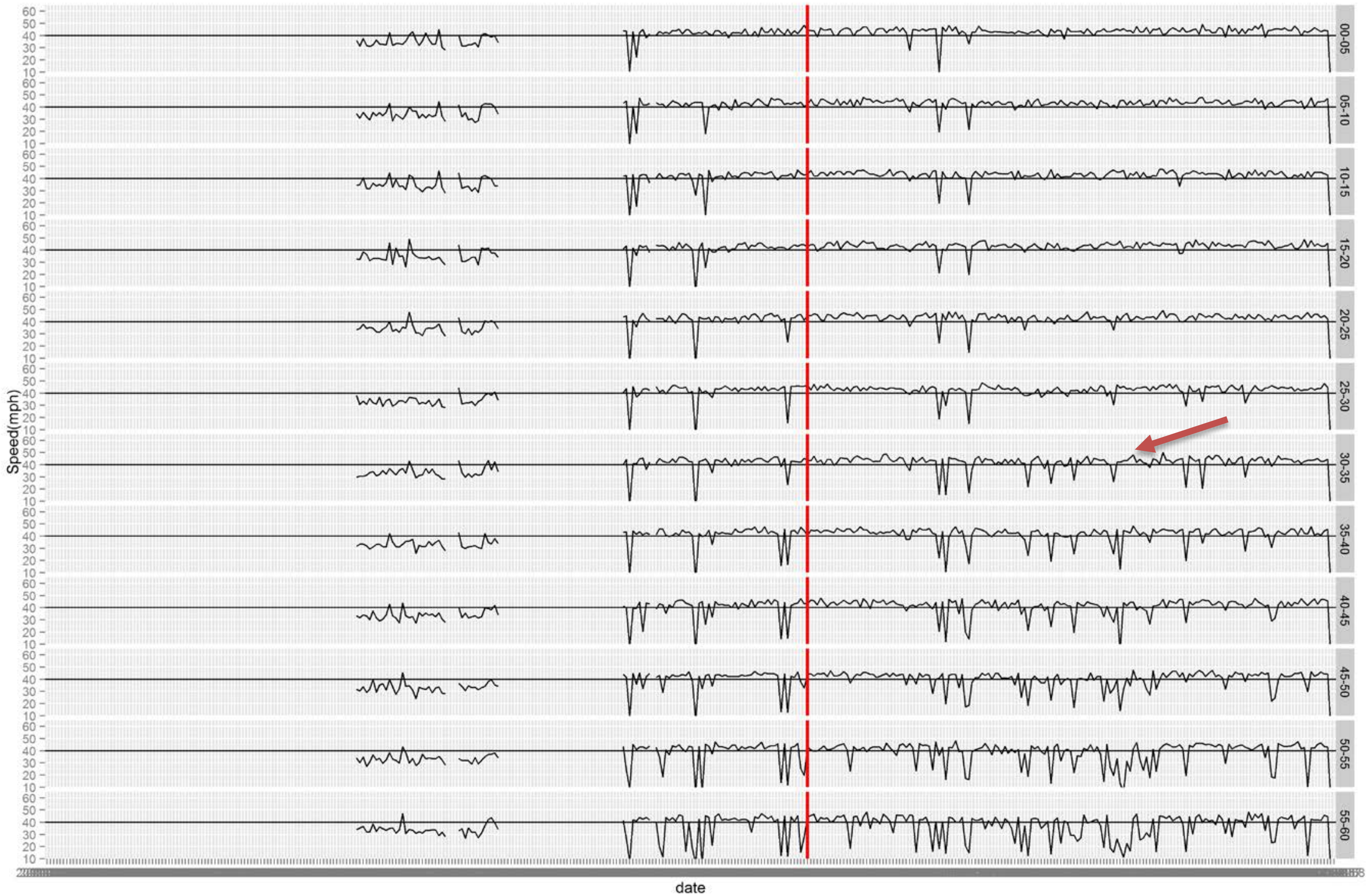

Figure 37. Evolution of speed over time for detector D3140

Isolating the first three five-minute intervals for each station, the onset of congestion can be more closely examined. After congestion has set in, drivers are restricted to a particular speed range (depending on the congestion level) and therefore VSLS becomes ineffective at absorbing shockwaves.

Figure 38, Figure 39, and Figure 40 show the speed profile of all detectors at station 559 at the onset of breakdown at station 76. Congestion at station 559 started roughly 10 minutes following breakdown. During these first 15 minutes, not all shockwaves carried the congestion wave to station 559. As further shockwaves were generated, the already slightly congested conditions worsened and the average speed decreased for subsequent five minute intervals. The VSLS does not appear to considerably change the average speed. Similar results were found for each of the subsequent upstream stations.

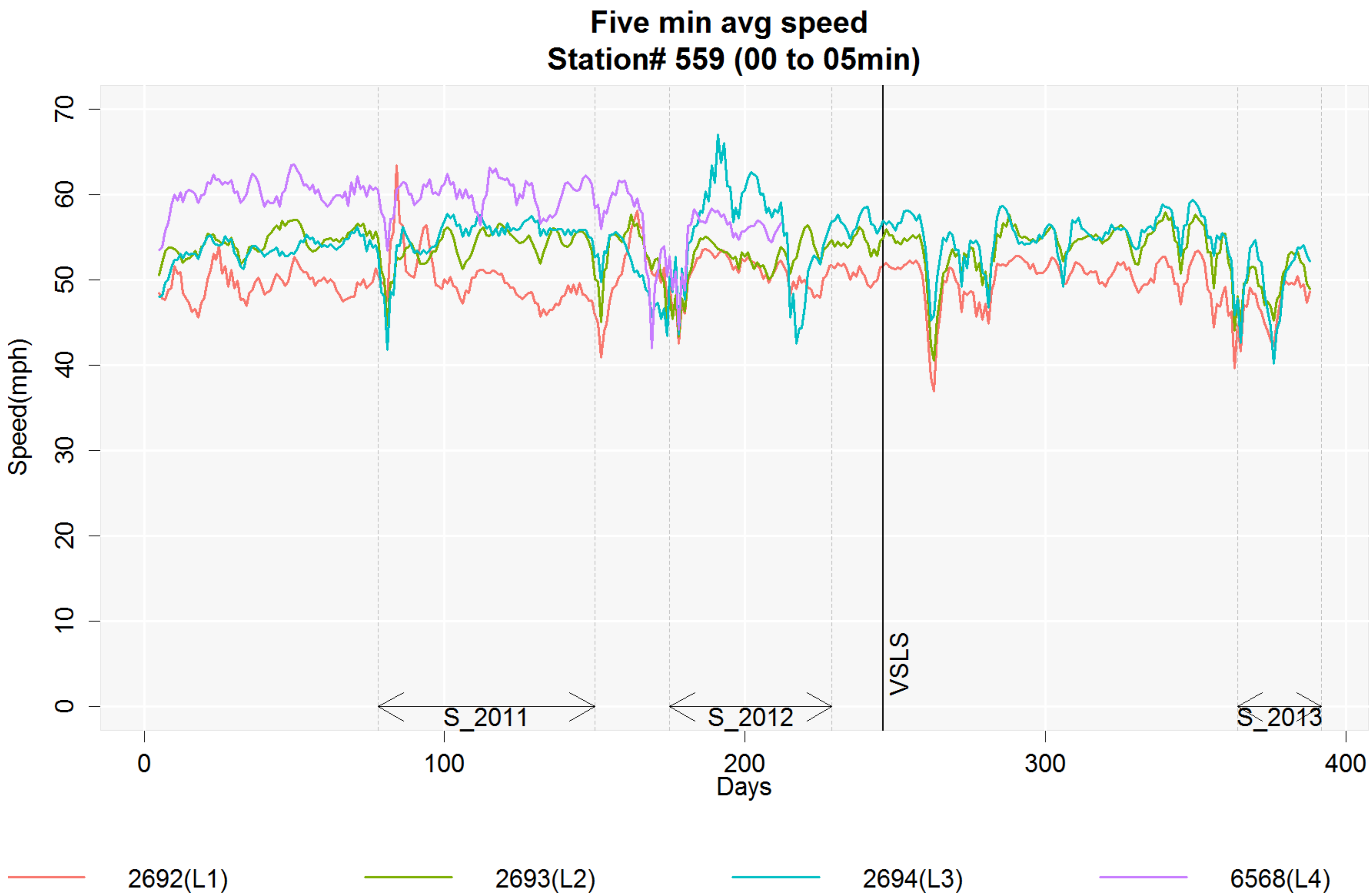

Figure 38. Five minute average speed (0 to 5 minutes after breakdown) for station 559

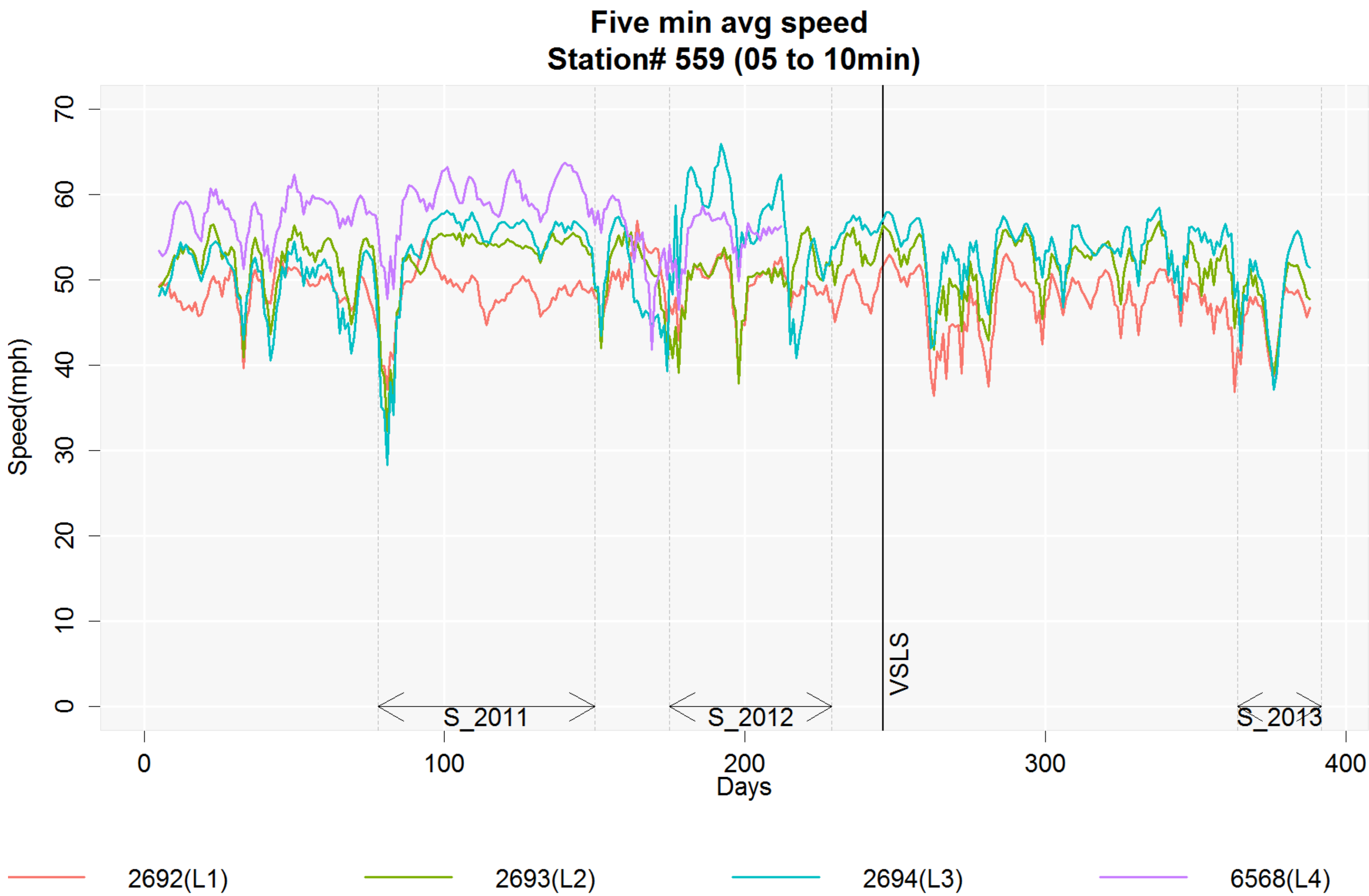

Figure 39. Five minute average speed (5 to 10 minutes after breakdown) for station 559

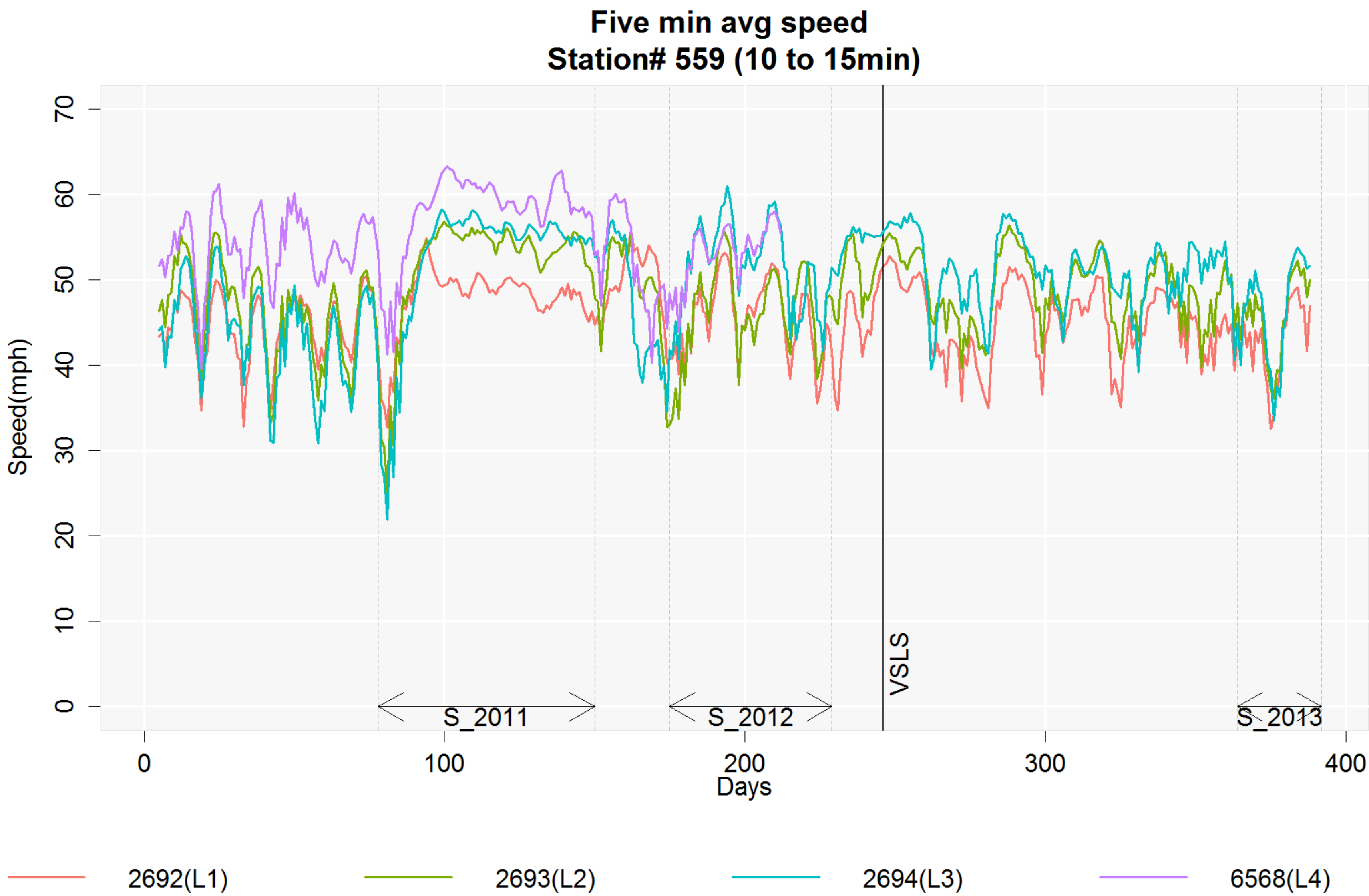

Figure 40. Five minute average speed (10 to 15 minutes after breakdown) for station 559

After visually comparing the speeds from each 5-minute period Before and After VSL activation, significant differences are found between the 2011 and 2013 data, but not between the 2012 and 2013 data. Only dates from the summer of each year were used. Figure 41, Figure 42, and Figure 43 show the speed profiles for 2011 v. 2013 for the detectors at station 559 (nearest to the bottleneck). Above each 5-minute interval, the p-value is printed to show whether the two data sets are significantly different (0.05 or less indicating greater than 95% confidence of significant difference).

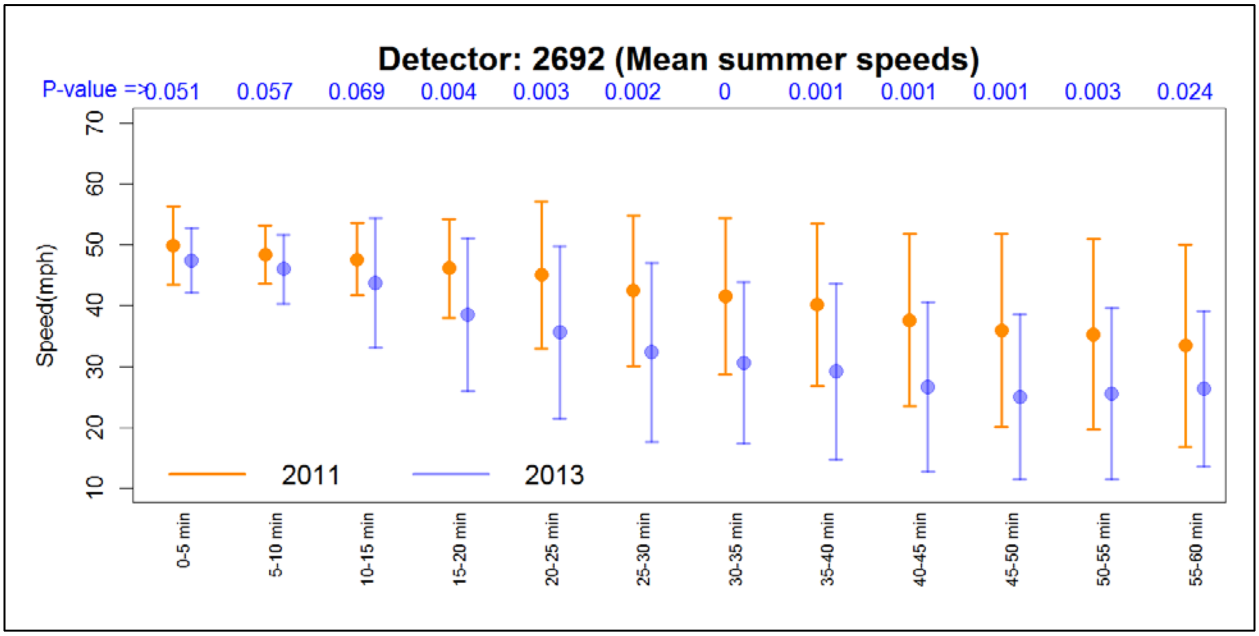

Figure 41. Mean speed ± 1 standard deviation for detector D2692 between Summer 2011 and 2013; significance test p-value indicated above

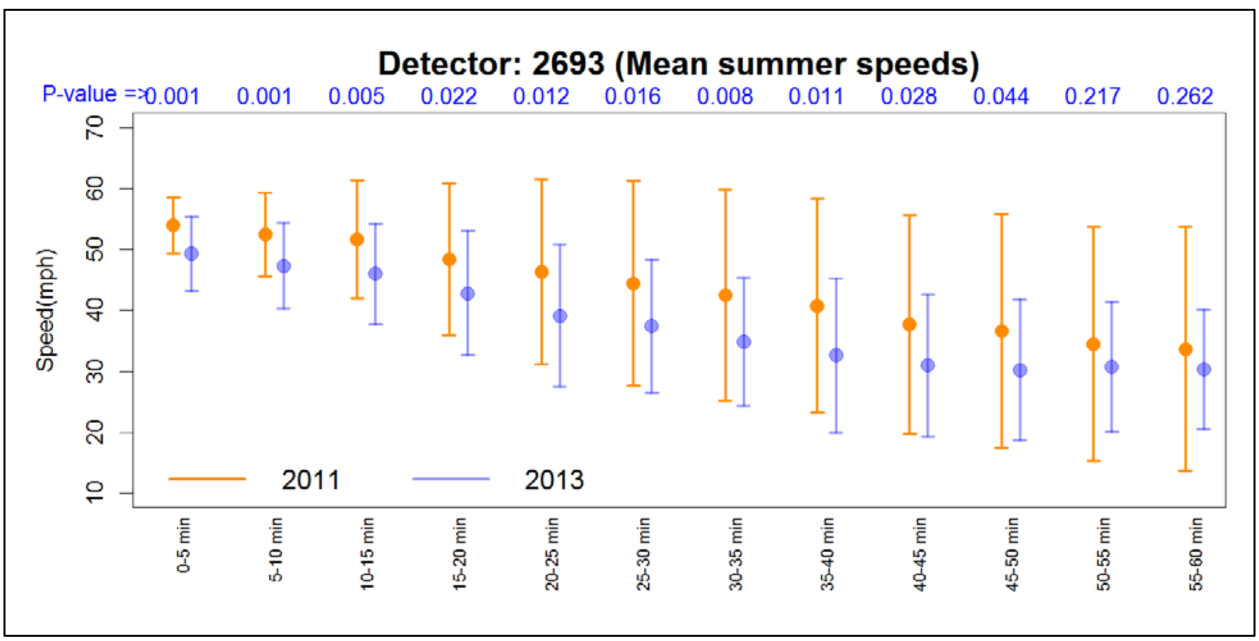

Figure 42. Mean speed ± 1 standard deviation for detector D2693 between Summer 2011 and 2013

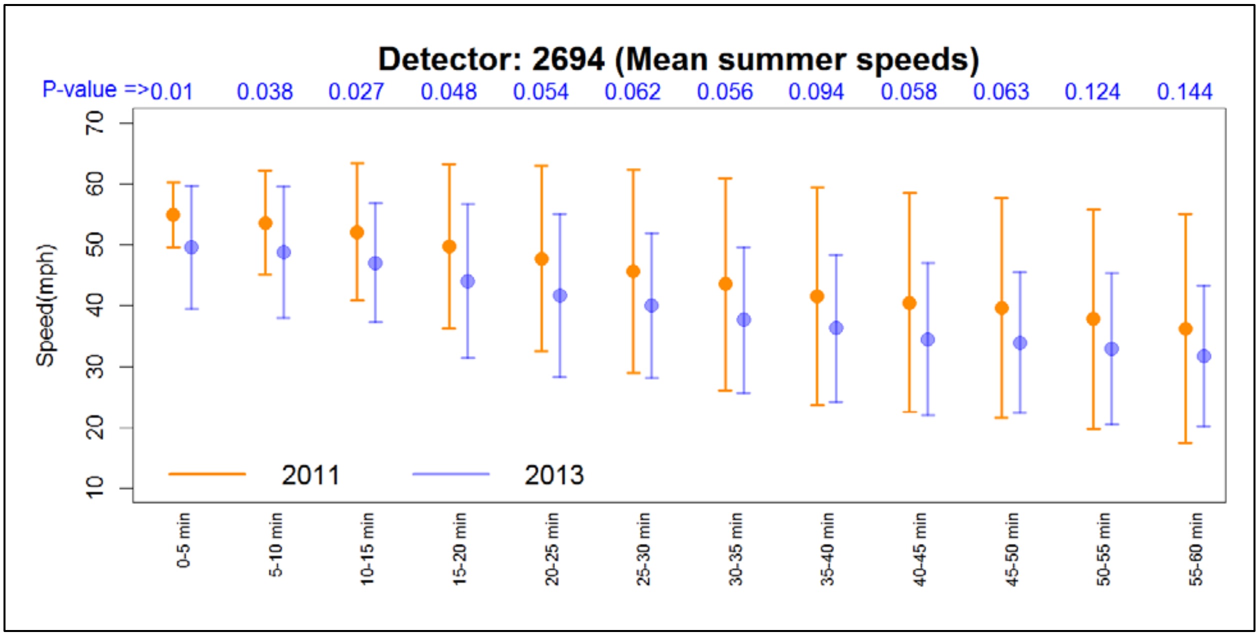

Figure 43. Mean speed ± 1 standard deviation for detector D2694 between Summer 2011 and 2013

Note that detector D6568 was excluded for lack of data during 2013. For the remaining detectors, it can be seen that the speed distributions have a lower mean during 2013 than 2011 which is statistically significant in most cases. In the right lane (detector 2692), the entire distribution of speeds appears to have dropped by roughly 10 MPH starting 15 minutes after breakdown. In contrast, the next upstream station shows a slightly higher speed for the first few segments in 2013, although this is not statistically significant. This is demonstrated by the right-lane detector in Figure 44.

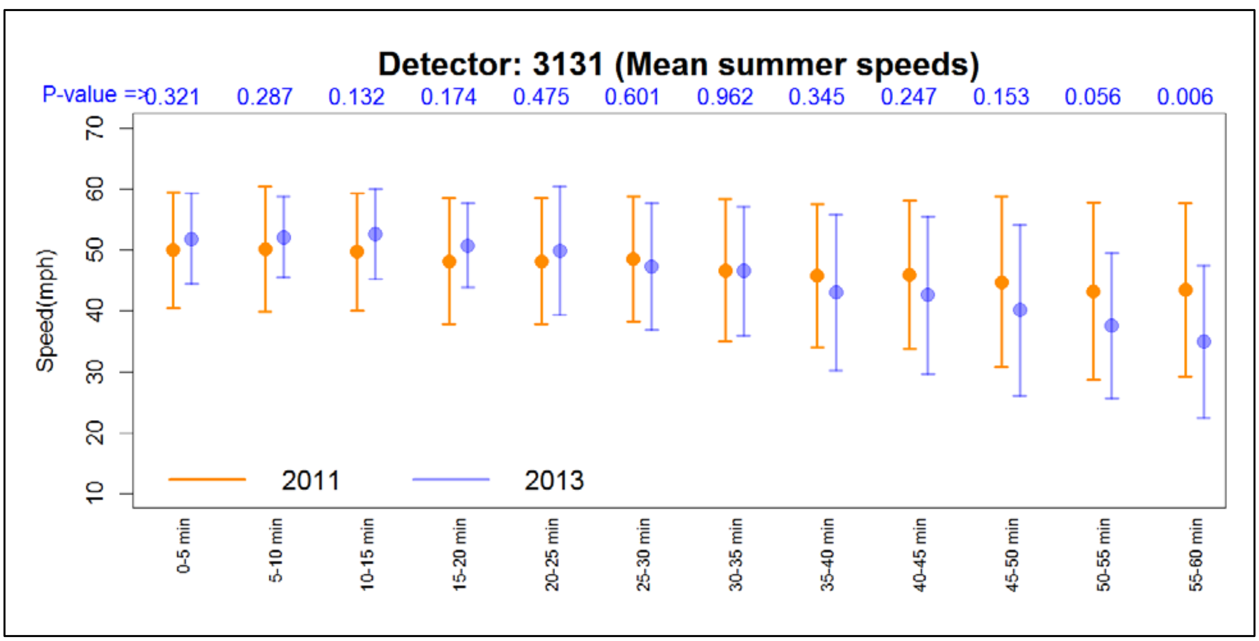

Figure 44. Mean speed ± 1 standard deviation for detector D3131 between Summer 2011 and 2013

Less pronounced effects are found between the 2012 and 2013 data. Again, the 2013 mean speeds tend to be lower than the 2012 data, but the t-test indicates that in most cases these differences are not significant. Figure 45, Figure 46, and Figure 47 below show the 2012 v. 2013 figures corresponding to the detectors at station 559. Again, the next most upstream right lane (detector 3131) shows no significant change past the first 5-minute period, as shown in Figure 48.

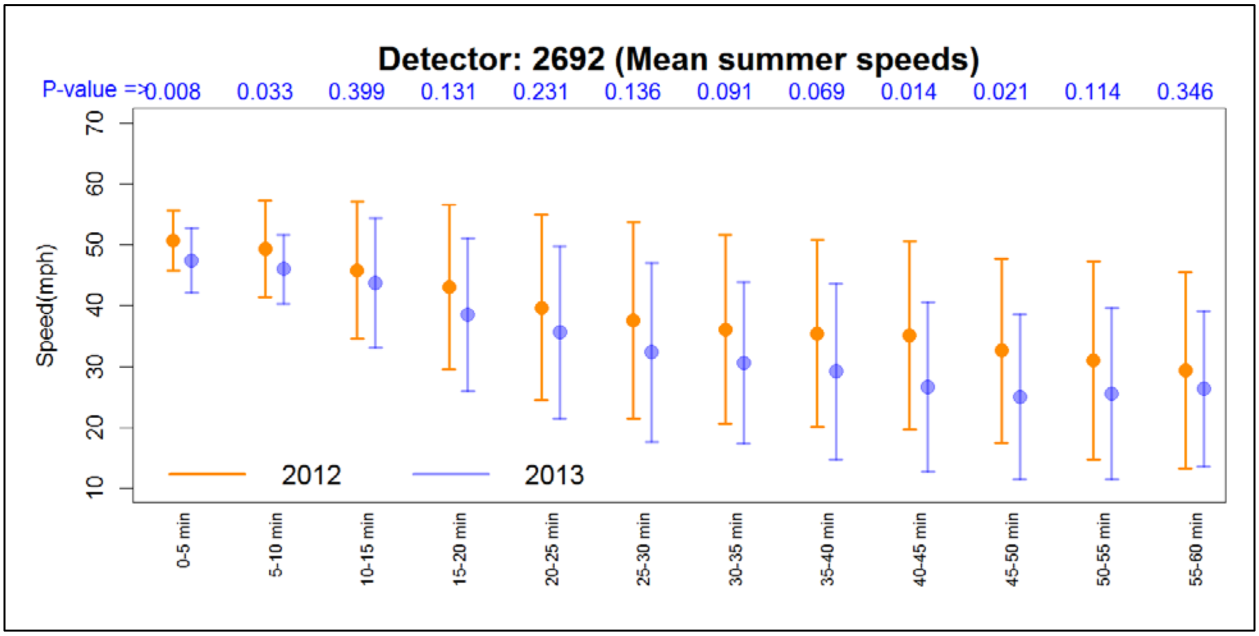

Figure 45. Mean speed ± 1 standard deviation for detector D2692 between Summer 2012 and 2013

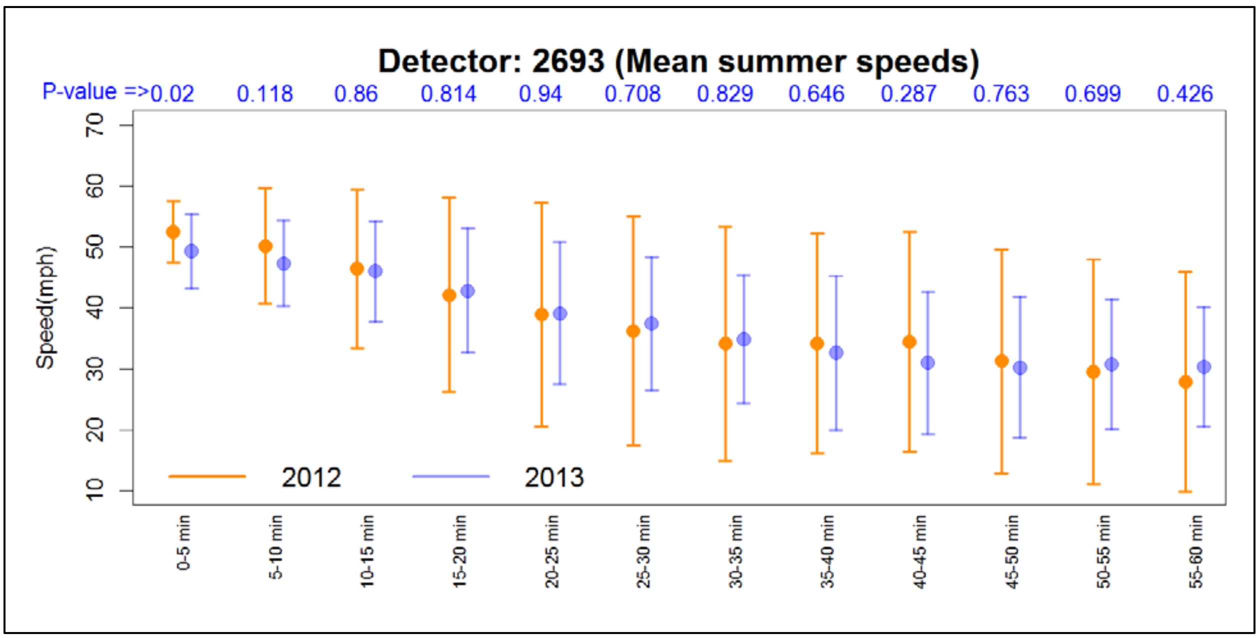

Figure 46. Mean speed ± 1 standard deviation for detector D2693 between Summer 2012 and 2013

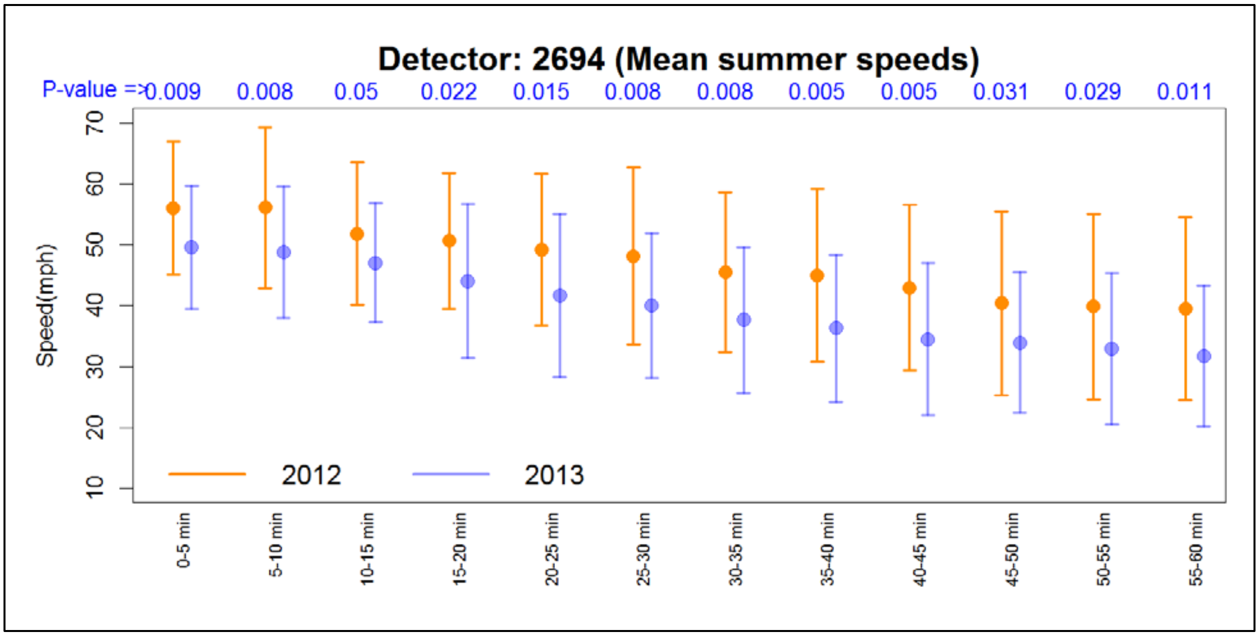

Figure 47. Mean speed ± 1 standard deviation for detector D2694 between Summer 2012 and 2013

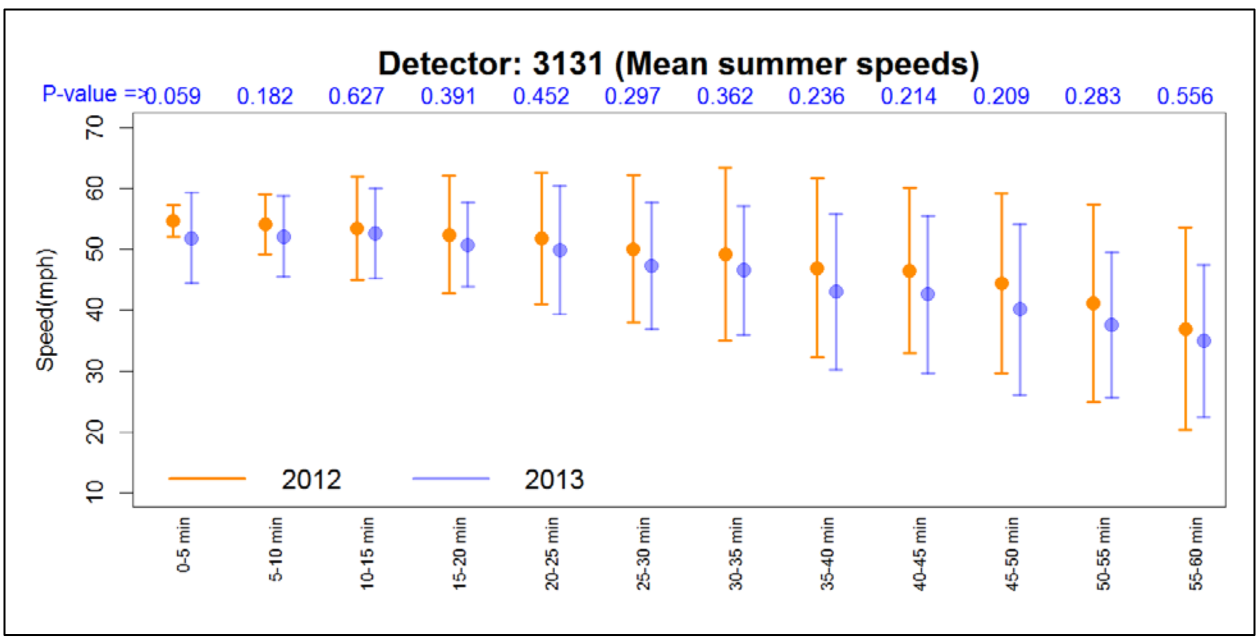

Figure 48. Mean speed ± 1 standard deviation for detector D3131 between Summer 2012 and 2013

CORRELATION ANALYSIS

Using the Correlograms generated for the analysis period, shockwave activity was examined. Shockwave activity on the Correlogram is indicated by strong positive correlation regions in the 30 to 90 second positive lag band. In both the Before and After periods, the shockwaves were approximately centered on 60-70 second lags, as can be seen in Figure 49 and Figure 52.

The 'gap' between the uncongested pattern and the onset of shockwave activity varied both before and after VSL implementation. Some days, such as July 25, 2012 (Figure 51) and June 4, 2013 (Figure 53), show a notable gap while others, such as July 12, 2012 (Figure 50) and August 6, 2013 (Figure 54), do not.

The first three shockwaves manually isolated for each day corresponded to the beginning of congested conditions (noted as vertical black lines) and intersect with high correlation regions within the shockwave band. Similarly, crash (vertical solid blue lines) and near crash events (vertical dashed blue lines) correspond to high correlation regions.

The VSL actuations captured for 2013 show that as shockwave activity begins, the VSL begin showing reduced speed. However, the signs only become active just after high correlation activity begins in the shockwave band of the Correlograms. The signs remain active for some period less than one hour before deactivating. They reactivate for the last piece of shockwave activity, covering approximately 10-20 minutes. Regardless, it doesn't seem to be a Before-After change in compression wave activity or propagation speed.

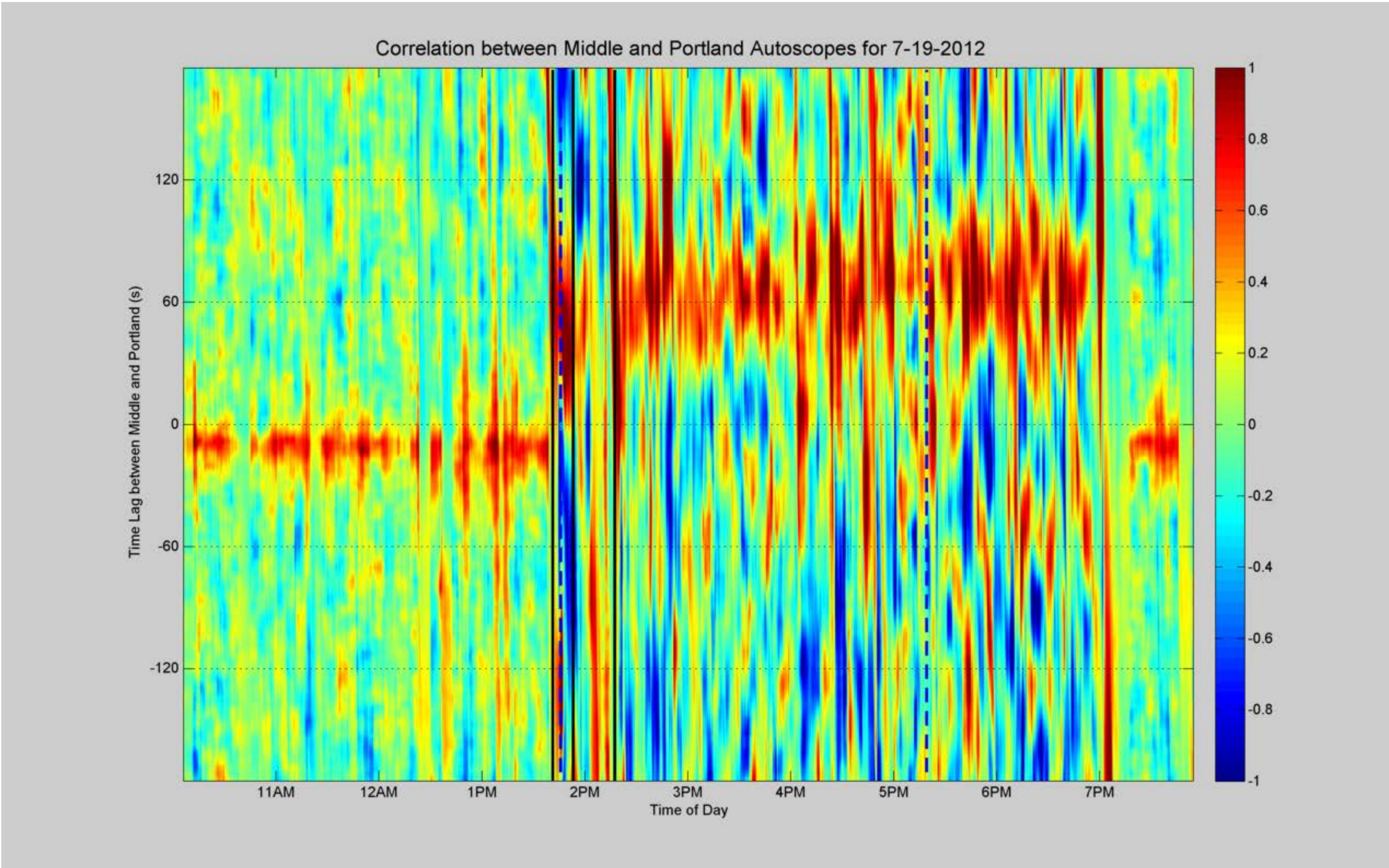

Figure 49. Correlogram for July 10, 2012

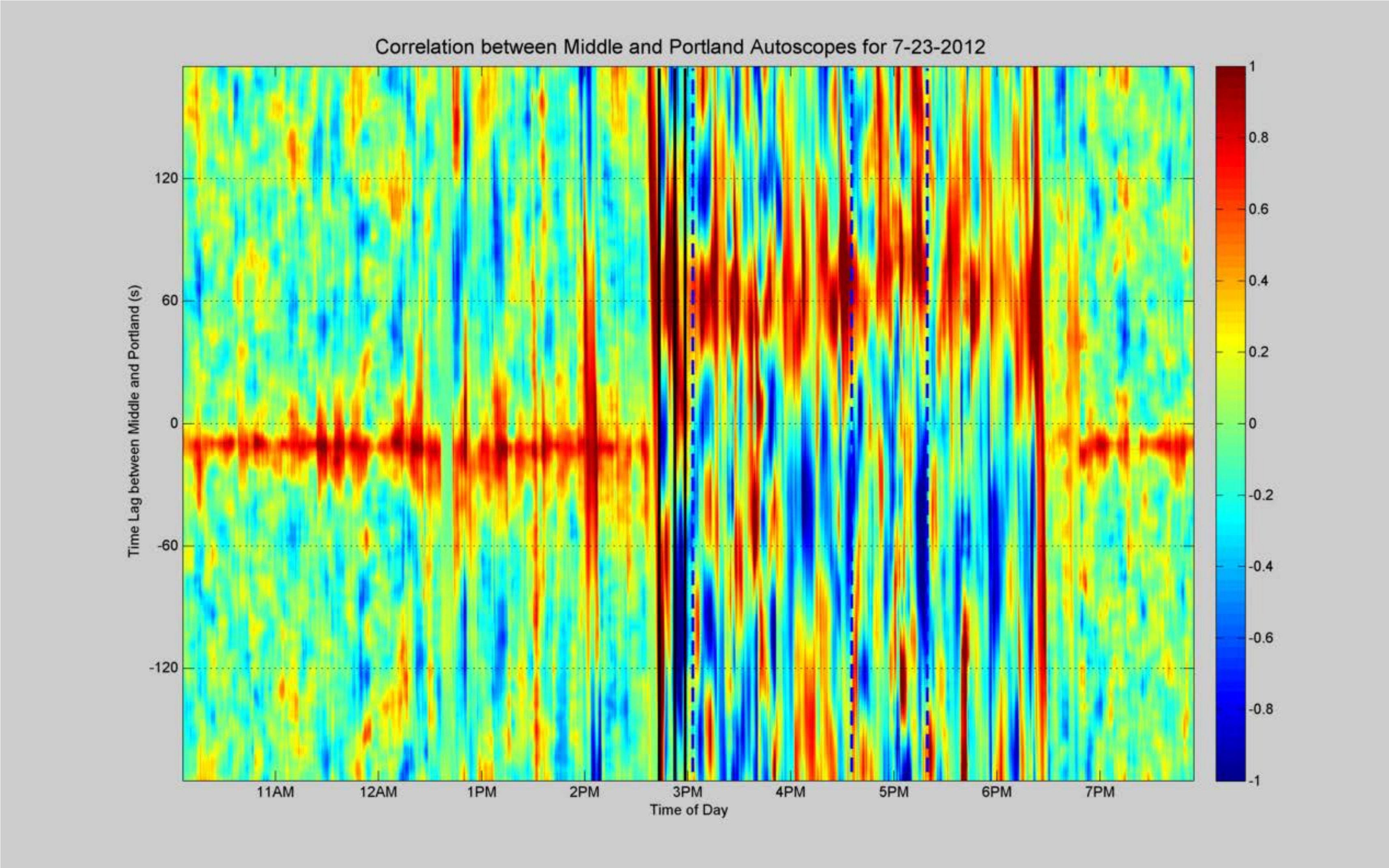

Figure 50. Correlogram for July 23, 2012

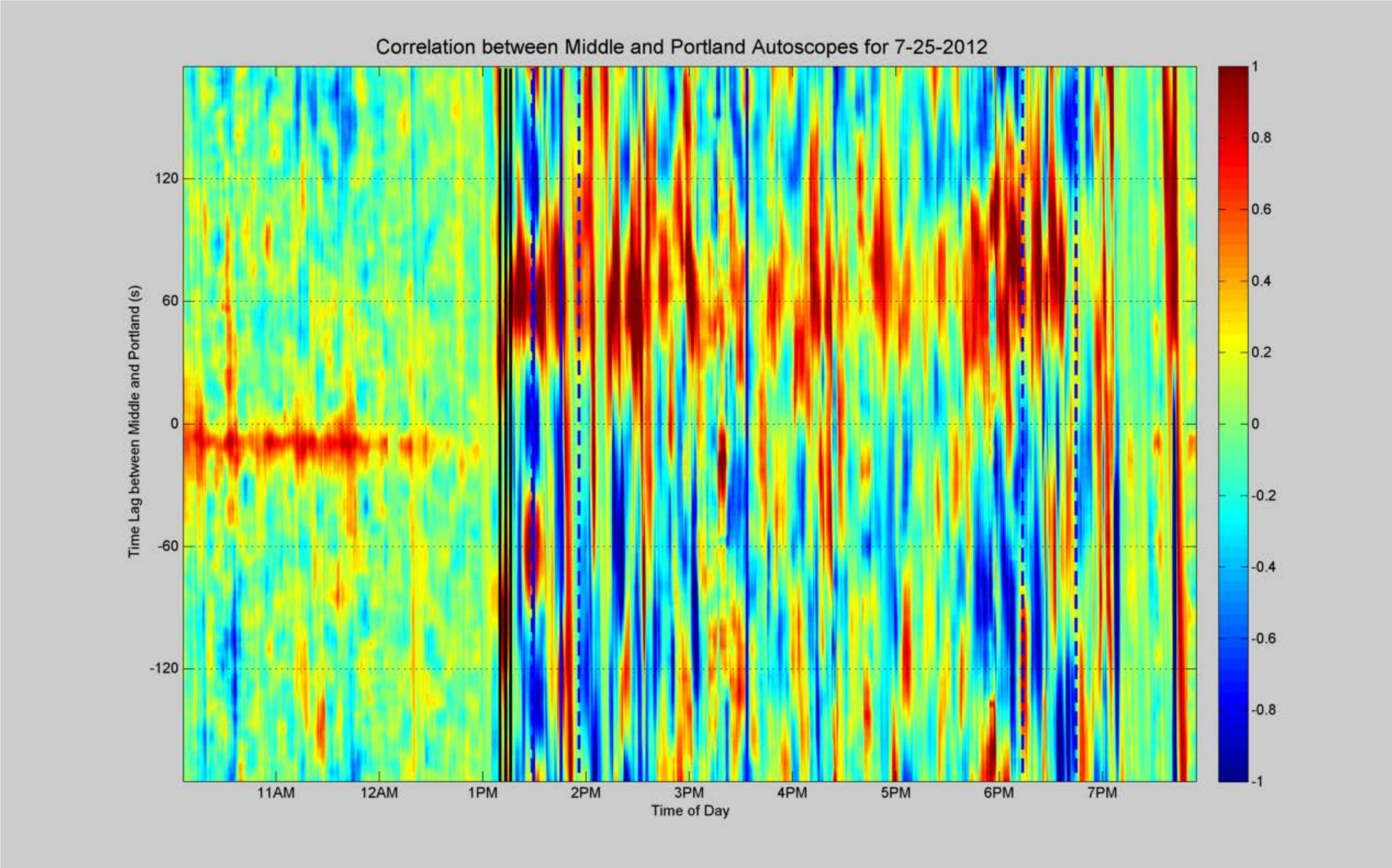

Figure 51. Correlogram for July 25, 2012

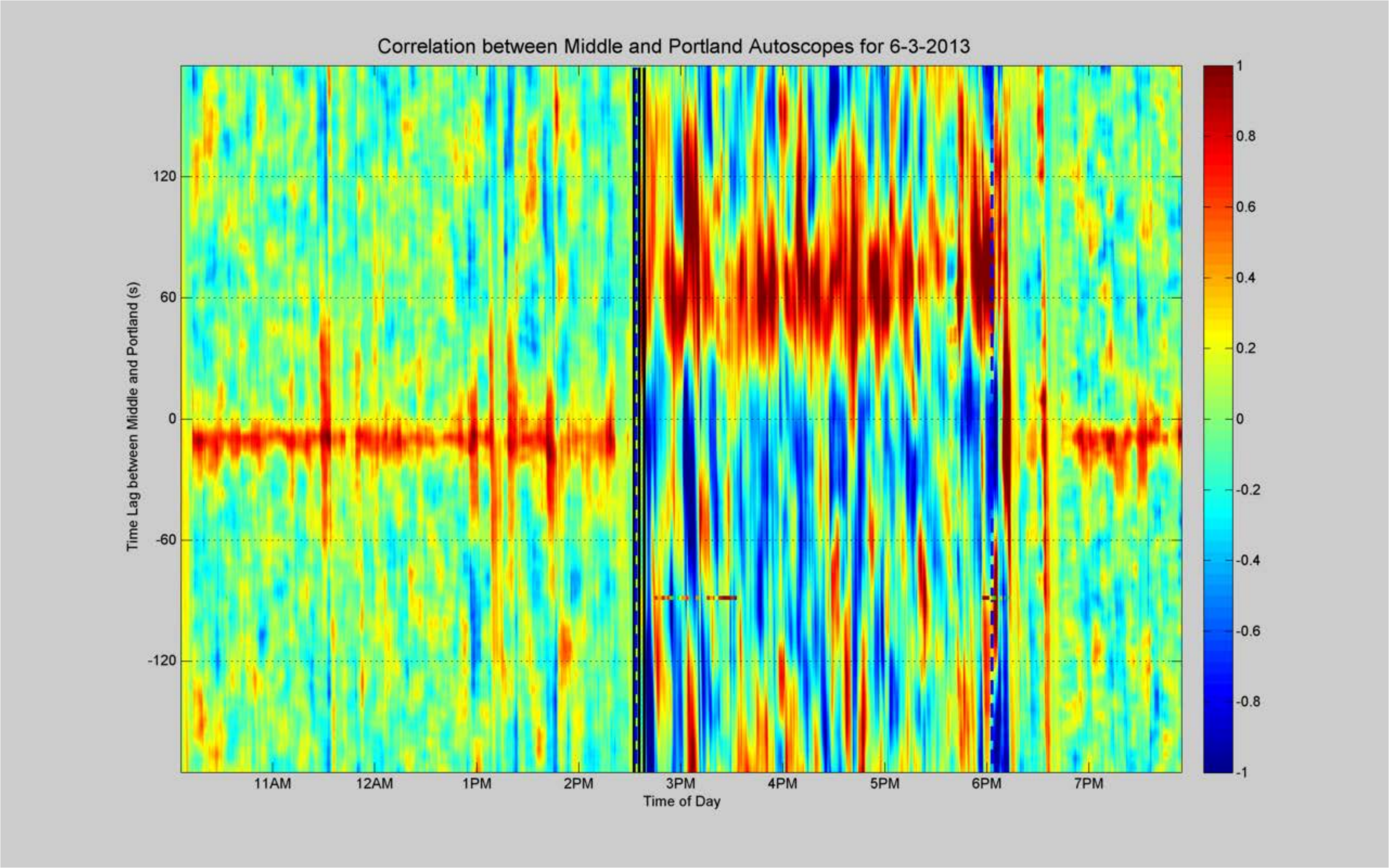

Figure 52. Correlogram for June 3, 2013

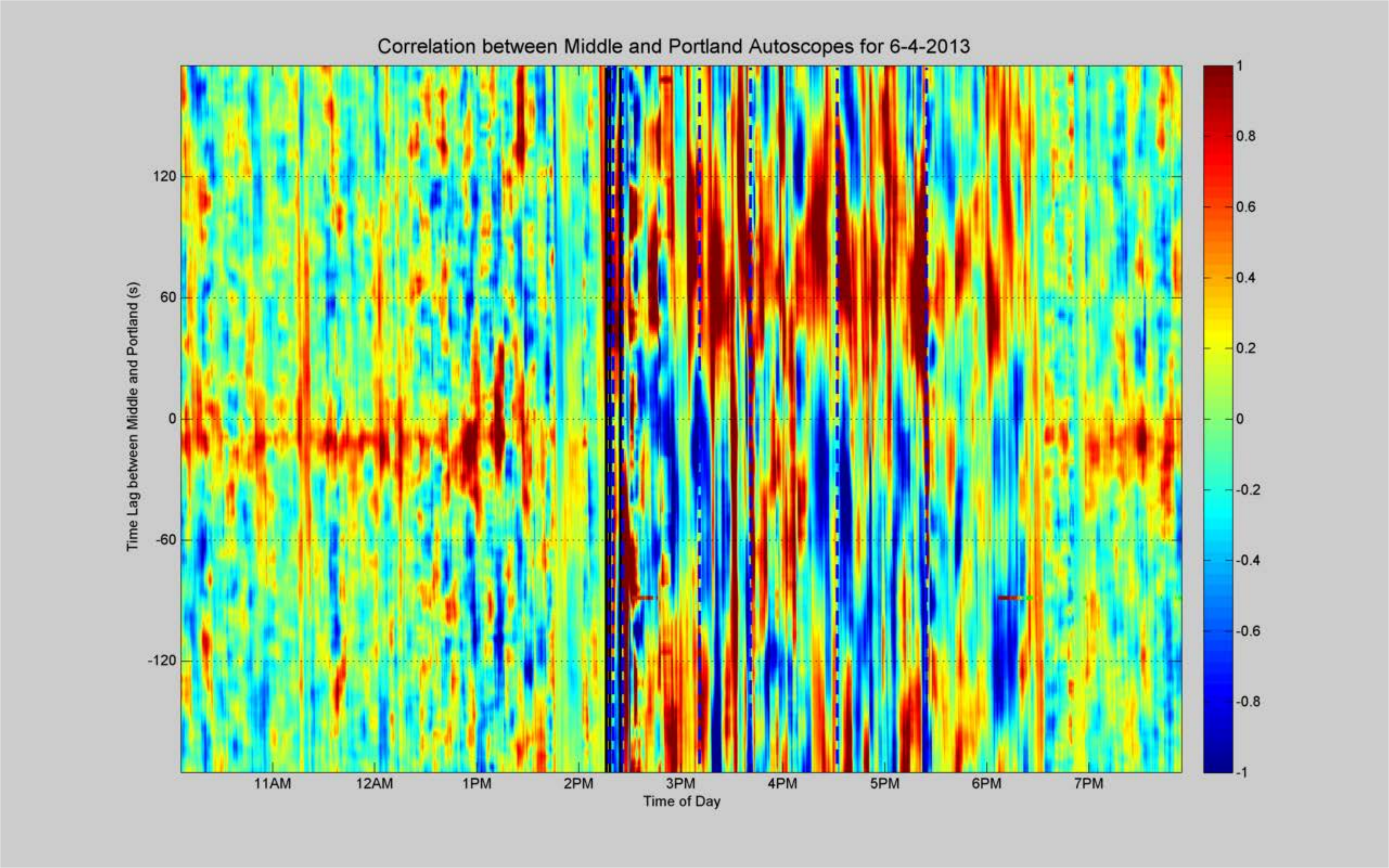

Figure 53. Correlogram for June 4, 2013

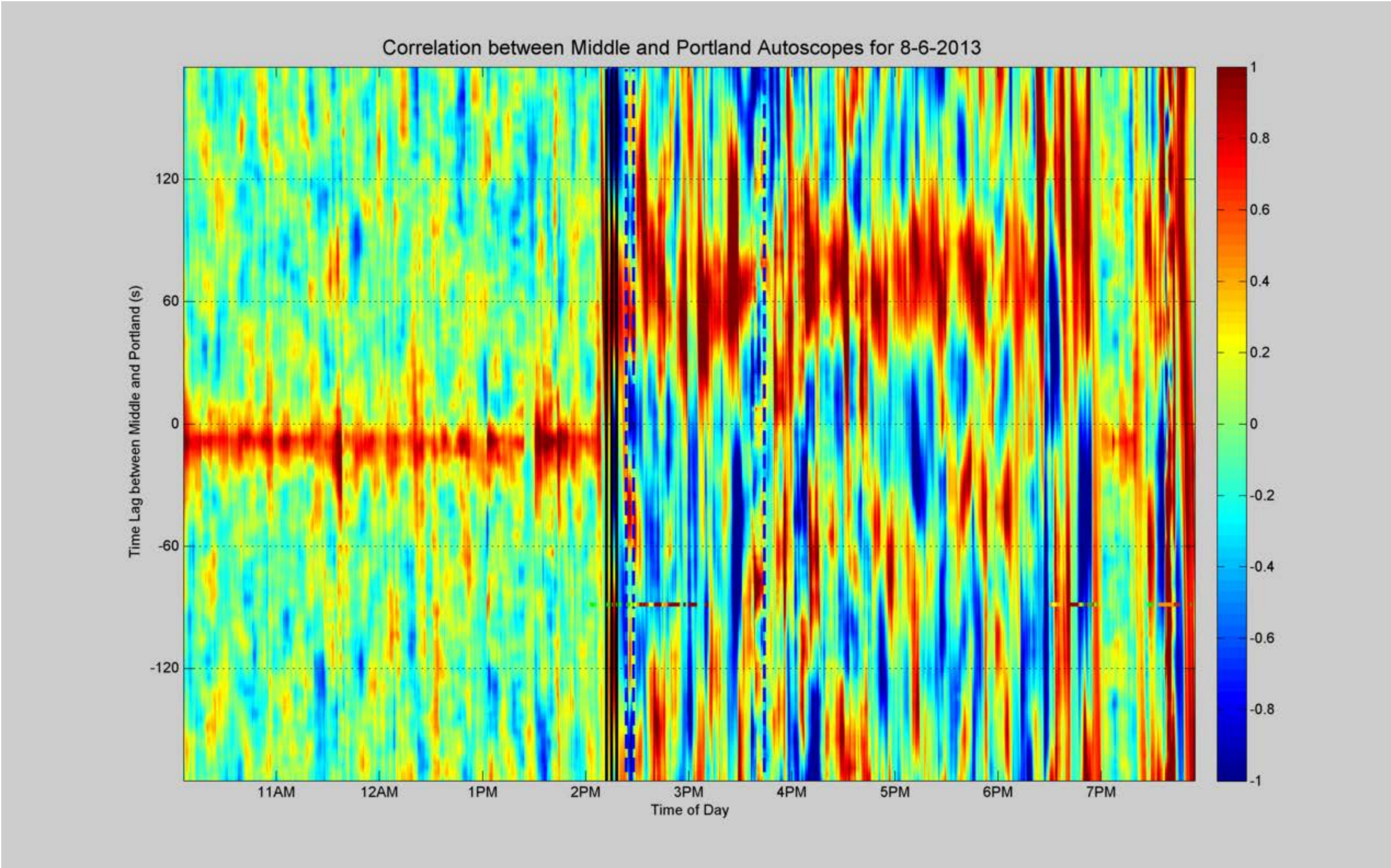

Figure 54. Correlogram for August 6, 2013

CRASH AND NEAR CRASH TRAJECTORIES

Using the trajectory extrapolation methodology described, vehicle paths were generated for all crash and near crash vehicles reported during the study period. Each vehicle path was checked to determine if it passed VSLS gantries while messages were displayed or if all gantries were dark (no message). Vehicles that passed active VSLS signs were potentially influenced by the system, while those that received no message had no additional information or instruction similar to the pre-VSL condition. Table 13 shows the results of the analysis.

Table 13. Last active VSL gantries encountered by estimated vehicle trajectories

	Last Active Variable Speed Limit Gantry Encountered						
Event Type	Huron	Riverside	Cedar	11th	Park	One or more (sum)	None
Near Crash	89	29	26	54	182	380	209
Crash	15	2	6	5	18	46	27
Total	104	31	32	59	200	426	236

Of those vehicles that would have encountered an active sign, roughly half received a warning from the signs at Park Avenue, immediately upstream of the crash location. About one quarter received their last speed message from the gantry at Huron Avenue, on the east side of the Mississippi River. Relatively few received their last warning from the signs at 11th, Cedar, and Riverside Avenues. Across all events, about one third did not receive a warning from any of the signs along the corridor.

Roughly 39% of all vehicles involved in incidents received VSL instruction to reduce speed prior immediately upstream from signs at either Park Avenue or 11th Avenue. The remaining 61% observed signs either much further from the crash location (Cedar Avenue or east), or did not encounter any active signs along the entire region.

6. CONCLUSION

Based on the results found in Table 9, it can be seen that the total incident rate for the High Crash Area increased marginally year-on-year based on the 2012 and 2013 data. The increase of roughly 2% over the rate in the "Before no incl. 2008" period also shows similar trends in incident rate, although offset by one month.

Looking at the speed difference between the incident and adjacent lanes, differentials of 5-15 mph increased relative to the 5 mph or less incidents from Before to After. Crashes and near crashes in the first lane tended to experience a greater disparity in lane speeds after the VSL implementation. However, the majority of crashes and near crashes in both the Before and After data sets occurred with speed differences of less than 15 mph.

Based on the shockwave analysis, the After data showed generally earlier onset of shockwave activity through the afternoon and the first few shockwaves of each day were nearer together than in the Before data. The first shockwave of each day tended to occur between 12:00 PM and 1:45 PM, the second between 12:30 PM and 3:00 PM, and the third between 1:30 PM and 3:30 PM in the Before data. This tendency for the first few shockwaves to be spread through the afternoon is less present in the After data. Strong peaks are present at 12:45 PM, between 12:45 PM and 1:00 PM, and 1:00 PM respectively within the After data and more evenly distributed shockwaves across the remainder of the early to mid-afternoon. Overall, shockwave onset has become more concentrated in those earlier times. Given that the first shockwave is the initiator of the VSL system response, its onset time is irrelevant to the VSL. The second and third waves that show significant increase are theoretically affected by the VSL signs but it is unclear whether this is due to the system directly or to changes in demand patterns.

Therefore, using the time difference between the first, second, and third shockwaves, the general pattern noted above becomes apparent. In the Before data, shockwaves tended to occur less than 15 minutes apart for both the first to the second and the second to the third. The After data is more heavily skewed toward gap times of less than 10 minutes. The maximum time gaps are also less in the After data than the Before. So, not only do the shockwaves tend to start earlier in the afternoon but they also are more closely spaced.

Based on the loop detector data and speed-based shockwave analysis performed, no significant change in behavior was noted anywhere along the corridor due to the VSL. The main congestion shockwave propagated upstream from the bottleneck location at similar rates, reaching each station at similar times relative to the onset of congestion at the bottleneck itself. Some changes in speeds were noted between 2011 and 2013, but these differences became statistically insignificant between 2012 and 2013.

The machine vision sensor data did not reveal any change in shockwave characteristics due to the VSL. Shockwaves were generated at similar rates and propagated at similar speeds at the high crash region, thus signaling no improvement in safety.

Finally, using the trajectory estimation methodology, about 40% of vehicles involved in crashes or near crashes received advanced information to reduce speed while in the region immediately upstream of the event (between Portland and Cedar Avenues). The remaining vehicles were only issued warning information relatively far from the site of the incident (Cedar Avenue or farther east) or received no indication from the VSL signs whatsoever.

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Appendix I

Preliminary Examination of Computer Aided Dispatch Records

Using the crash events collected from video, a preliminary analysis of record keeping effectiveness could be performed using State Patrol's Computer Aided Dispatch (CAD) records. CAD records from 2008 and 2010 through 2013 were retrieved from the Regional Traffic Management Center (RMTC) for analysis. The data were analyzed using the same time segments as the larger VSL study: 2008, 2012 ahead of September 27th, and 2012 after September 27th through 2013. This analysis concluded after examining through March 2013 as effort was not intended as a direct before/after comparison.

To validate the database, crash records were correlated to the dates and times at which the incidents from video collection took place. After analyzing the data contained in the databases, it was concluded that the following categories contain relevant information about the incidents collected by TMC and reported to the State Patrol dispatch:

- EID: Unique identification number for every event.
- AD_TS: Date and approximate time at which an incident happened.
- XD_TS: Time stamp containing date and time when an incident log was closed. Due to the similarity to other time stamps, only this one is used to validate the data since it can be used as limitation when finding a specific incident.
- AR_TS: Time at which a state patrol unit or a TMC unit showed up to the scene.
- DS_TS: Time at which the state patrol or TMC units leave the scene.
- TYCOD: Code to identify the type of event.
- TYP_ENG: Description of the type code.
- SUB_TYCOD: Specific description of the TYCOD. The user should use this column to identified crashes under TMC TYCOD.
- EAREA: Area defined for incidents.
- ECOMPL: Common location at which the event took place. Closest intersection to the exact location of the event.
- XSTREET 1 & 2: Two streets close to the actual event location.

Based on the categories listed above, the database was filtered using the following criteria:

- Date and Times from the XD_TS field were limited to dates and times matching with events found using video data.
- The incidents with an event description as *property damage crash* or *Traffic Mgmt Center/Crash*.
- The type code corresponding to the event description are 1050 and TMC, respectively.
- The area for this study (the High Crash Area along I-94) is Area 27.

The records from video collection in the section of I-94 westbound being studied are located between Park Ave S and 3rd Ave S along I-94. However, for statistical purposes of crash occurrence due to shockwaves, all reported crashes from Cedar Ave up to Groveland Ave need to be searched and organized accordingly. Therefore, in the database the following ECOMPLs were included in the validation:

- WB 94 I AT HIAWATHA AVE
- WB 94 I AT 11TH AVE S
- WB 94 I AT CEDAR AVE
- WB 94 I AT PARK AVE
- WB 94 I AT PORTLAND AVE
- WB 94 I AT 35W
- WB 94 I AT 3RD AVE S
- WB 94 I AT 1ST AVE
- WB 94 I AT CHICAGO AVE

Once all possible incidents were grouped together, the dates and times of the incidents collected from video were selected and located in the condensed database. An incident is considered missing if after 30 minutes from the time of the incident occurrence no record is found within the database.

The following tables show the records for 2008, 2012, and 2013. For each time window, three sets of records are presented: records within the CAD which are outside of the region covered by video collection, records present in the CAD which are within the time and region covered by video collection, and a comparison table showing matching and unmatched records between the CAD database and manual observations from video.

2008 Data

Within the 2008 data, 24 events were recorded during the observation period but were outside of the observation area or time period for video collection. Seven events within the CAD were inside the video collection period, and were compared against the event records collected manually. All events within the CAD were validated by video collection. However, seven additional events were observed within the video which were not present in the CAD records.

Reported Incidents by TMC or State Patrol dispatch out of video range (2008 data).

EID	ADTS-Date	ADTS-Time	CDTS-Date	CDTS-Time	TYCOD	TYP_ENG	ECOMPL	XSTREET1	XSTREET2
2746876	9/15/2008	3:56:40 PM	9/15/2008	5:01:28 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH AVE	WB 94 I TO 5TH ST S RMP	SB 35W I TO WB 94 RMP
2748406	9/16/2008	4:59:35 PM	9/16/2008	5:45:11 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 3RD AVE	WB 94 I TO 11TH ST S RMP	NB 65 HWY TO WB 94 RMP
2751562	9/18/2008	6:29:11 PM	9/18/2008	6:32:37 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I MP233	WB 94 I TO 11TH ST S RMP	NB 65 HWY TO WB 94 RMP
2751570	9/18/2008	6:35:11 PM	9/18/2008	7:29:59 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 3RD AVE	WB 94 I TO 11TH ST S RMP	NB 65 HWY TO WB 94 RMP
2757830	9/23/2008	6:50:38 AM	9/23/2008	6:58:56 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT LYNDALE AVE	WB 94 I TO LYNDALE AVE S RMP	NB 94 I
2759951	9/24/2008	3:54:09 PM	9/24/2008	4:26:42 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH AVE	WB 94 I TO 5TH ST S RMP	SB 35W I TO WB 94 RMP
2760970	9/25/2008	11:08:50 AM	9/25/2008	11:19:00 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT GROVELAND AVE	NB 65 HWY TO WB 94 RMP	WB 94 I TO LYNDALE AVE S RMP
2762767	9/26/2008	1:52:07 PM	9/26/2008	2:23:54 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE	NB 65 HWY TO WB 94 RMP	WB 94 I TO LYNDALE AVE S RMP
2769949	10/1/2008	10:22:54 AM	10/1/2008	10:54:30 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PARK AVE	SB 35W I TO WB 94 RMP	WB 94 I TO 11TH ST S RMP
2772830	10/3/2008	7:59:58 AM	10/3/2008	8:51:27 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE	NB 65 HWY TO WB 94 RMP	WB 94 I TO LYNDALE AVE S RMP
2773443	10/3/2008	2:58:32 PM	10/3/2008	3:53:58 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I MP233	WB 94 I TO 11TH ST S RMP	NB 65 HWY TO WB 94 RMP
2773650	10/3/2008	4:46:43 PM	10/3/2008	6:17:05 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH AVE	WB 94 I TO 5TH ST S RMP	SB 35W I TO WB 94 RMP
2777894	10/6/2008	2:57:19 PM	10/6/2008	2:57:43 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT GROVELAND AVE	NB 65 HWY TO WB 94 RMP	WB 94 I TO LYNDALE AVE S RMP
2778015	10/6/2008	4:15:22 PM	10/6/2008	4:44:42 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I AT PORTLAND AVE	WB 94 I TO 11TH ST S RMP	NB 65 HWY TO WB 94 RMP
2778694	10/7/2008	8:15:32 AM	10/7/2008	8:40:18 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT GROVELAND AVE	NB 65 HWY TO WB 94 RMP	WB 94 I TO LYNDALE AVE S RMP
2779073	10/7/2008	2:22:38 PM	10/7/2008	3:02:42 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I AT PARK AVE	SB 35W I TO WB 94 RMP	WB 94 I TO 11TH ST S RMP
2784457	10/10/2008	7:01:44 PM	10/10/2008	7:37:35 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE	WB 94 I TO 11TH ST S RMP	NB 65 HWY TO WB 94 RMP
2791766	10/15/2008	8:02:50 AM	10/15/2008	8:56:06 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE	WB 94 I TO 11TH ST S RMP	NB 65 HWY TO WB 94 RMP
2791766	10/15/2008	8:02:50 AM	10/15/2008	8:56:06 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE	WB 94 I TO 11TH ST S RMP	NB 65 HWY TO WB 94 RMP
2795787	10/17/2008	8:20:57 AM	10/17/2008	8:24:54 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH AVE	WB 94 I TO 5TH ST S RMP	SB 35W I TO WB 94 RMP
2802549	10/21/2008	7:56:28 AM	10/21/2008	8:17:31 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PARK AVE	SB 35W I TO WB 94 RMP	WB 94 I TO 11TH ST S RMP
2804730	10/22/2008	5:14:57 PM	10/22/2008	5:43:43 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT LYNDALE AVE	WB 94 I TO LYNDALE AVE S RMP	NB 94 I
2806354	10/23/2008	6:19:49 PM	10/23/2008	6:41:12 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I MP233	WB 94 I TO 11TH ST S RMP	NB 65 HWY TO WB 94 RMP
2804616	10/22/2008	3:45:54 PM	10/22/2008	3:54:03 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I AT PORTLAND AVE	WB 94 I TO 11TH ST S RMP	NB 65 HWY TO WB 94 RMP

Reported Incidents by TMC or State Patrol dispatch coincident with video collected incidents (2008 data).

EID	*ADTS-Date*	*ADTS-Time*	*CDTS-Date*	*CDTS-Time*	*TYCOD*	*TYP_ENG*	*ECOMPL*	*XSTREET1*	*XSTREET2*	*Notes*
2751157	*9/18/2008*	*2:39:52 PM*	*9/18/2008*	*3:48:56 PM*	*1050*	*PROPERTY DAMAGE CRASH*	*WB 94 I AT PORTLAND AVE*	*WB 94 I TO 11TH ST S RMP*	*NB 65 HWY TO WB 94 RMP*	REPORTED TO STATE PATROL
2770431	*10/1/2008*	*3:41:39 PM*	*10/1/2008*	*3:43:51 PM*	*TMC*	*TRAFFIC MGMT CENTER*	*WB 94 I AT PORTLAND AVE*	*WB 94 I TO 11TH ST S RMP*	*NB 65 HWY TO WB 94 RMP*	TMC REPORTED CRASH
2777948	*10/6/2008*	*3:25:37 PM*	*10/6/2008*	*4:15:26 PM*	*1050*	*PROPERTY DAMAGE CRASH*	*WB 94 I AT PORTLAND AVE*	*WB 94 I TO 11TH ST S RMP*	*NB 65 HWY TO WB 94 RMP*	REPORTED TO STATE PATROL
2779322	*10/7/2008*	*5:16:14 PM*	*10/7/2008*	*6:07:24 PM*	*1050*	*PROPERTY DAMAGE CRASH*	*WB 94 I AT PORTLAND AVE*	*WB 94 I TO 11TH ST S RMP*	*NB 65 HWY TO WB 94 RMP*	REPORTED TO STATE PATROL
2784040	*10/10/2008*	*3:19:24 PM*	*10/10/2008*	*5:33:28 PM*	*TMC*	*TRAFFIC MGMT CENTER*	*WB 94 I MP233*	*WB 94 I TO 11TH ST S RMP*	*NB 65 HWY TO WB 94 RMP*	TMC REPORTED CRASH
2788814	*10/13/2008*	*3:15:10 PM*	*10/13/2008*	*4:08:43 PM*	*TMC*	*TRAFFIC MGMT CENTER*	*WB 94 I MP233*	*WB 94 I TO 11TH ST S RMP*	*NB 65 HWY TO WB 94 RMP*	TMC REPORTED CRASH
2804561	*10/22/2008*	*2:51:52 PM*	*10/22/2008*	*2:52:20 PM*	*TMC*	*TRAFFIC MGMT CENTER*	*WB 94 I AT PORTLAND AVE*	*WB 94 I TO 11TH ST S RMP*	*NB 65 HWY TO WB 94 RMP*	TMC/ STATE PATROL REPORT

Crashes from video collection and equivalent records from TMC/ State Patrol incidents (2008 data).

Date	Time	ADTS-Time	TYP_ENG
18-Sep	2:37:00 PM	2:39:52 PM	PROPERTY DAMAGE CRASH
1-Oct	3:36:00 PM	3:41:39 PM	TRAFFIC MGMT CENTER
1-Oct	3:51:00 PM		
6-Oct	3:22:00 PM	3:25:37 PM	PROPERTY DAMAGE CRASH
7-Oct	5:14:00 PM	5:16:14 PM	PROPERTY DAMAGE CRASH
7-Oct	6:38:00 PM		
8-Oct	4:14:00 PM		
8-Oct	6:18:00 PM		
9-Oct	4:26:00 PM		
10-Oct	3:36:00 PM	3:19:24 PM	TRAFFIC MGMT CENTER
13-Oct	2:40:00 PM		
13-Oct	3:07:00 PM	3:15:10 PM	TRAFFIC MGMT CENTER
15-Oct	12:59:00 PM		
22-Oct	2:35:00 PM	2:51:52 PM	TRAFFIC MGMT CENTER

2012 Data – Before VSL

The 2012 data includes records prior to September 27th, 2012. 41 events were recorded but were outside of the observation area or time period for video collection. Seven events within the CAD were inside the video collection period, and were compared against the event records collected manually. All events within the CAD were validated by video collection. However, seven additional events were observed within the video which were not present in the CAD records.

Reported Incidents by TMC or State Patrol dispatch out of video range, reported before September 27th, 2012.

EID	ADTS-Date	ADTS-Time	XDTS-Date	XDTS-Time	TYCOD	TYP_ENG	ECOMPL	XSTREET1	XSTREET2
5125936	04/16/12	3:34:06 PM	04/16/12	4:02:24 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
5128397	04/17/12	10:04:53 PM	04/18/12	4:34:08 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT LYNDALE AVE		
5128435	04/17/12	11:01:03 PM	04/18/12	4:34:09 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT LYNDALE AVE		
5129517	04/18/12	3:31:13 PM	04/18/12	4:51:09 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
5166549	05/08/12	11:30:54 AM	05/08/12	11:51:47 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
5169112	05/09/12	6:38:04 PM	05/09/12	6:39:12 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5178724	05/14/12	3:51:41 PM	05/14/12	4:46:09 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT HIAWATHA AVE		
5184946	05/17/12	6:52:13 PM	05/17/12	6:52:17 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I AT 65 HWY		
5186036	05/18/12	12:21:30 PM	05/18/12	12:30:16 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5190959	05/21/12	7:13:15 AM	05/21/12	8:09:32 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE		
5196816	05/23/12	4:44:20 PM	05/23/12	5:25:49 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PARK AVE		
5209134	05/29/12	7:40:58 AM	05/29/12	8:02:51 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
5215542	05/31/12	5:32:29 PM	05/31/12	6:01:46 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PARK AVE		
5215573	05/31/12	5:45:12 PM	05/31/12	6:25:42 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT HIAWATHA AVE		
5224634	06/04/12	9:58:00 PM	06/05/12	4:27:33 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5228330	06/06/12	6:04:04 PM	06/06/12	7:32:23 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I MP233	WB 94 I TO 11TH ST S RMP	NB 65 HWY TO WB 94 RMP
5240098	06/12/12	3:53:07 PM	06/12/12	4:00:46 PM	TMC	TRAFFIC MGMT CENTER		WB 94 I	WB 94 I TO LYNDALE AVE S RMP
5242395	06/13/12	4:46:25 PM	06/13/12	5:05:53 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT HIAWATHA		
5246435	06/15/12	3:33:20 PM	06/15/12	3:48:50 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5254279	06/19/12	6:00:25 PM	06/19/12	6:43:15 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT HIAWATHA		
5255670	06/20/12	1:40:07 PM	06/20/12	2:17:44 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE		
5256225	06/20/12	6:24:48 PM	06/20/12	7:13:47 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5269591	06/27/12	1:03:34 PM	06/27/12	1:16:27 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE		
5270585	06/27/12	8:44:05 PM	06/28/12	4:37:51 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5271947	06/28/12	2:28:25 PM	06/28/12	2:30:52 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE		
5271987	06/28/12	2:47:37 PM	06/28/12	3:06:37 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT HIAWATHA		
5272379	06/28/12	5:25:22 PM	06/28/12	6:33:41 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PARK AVE		
5274624	06/29/12	6:04:06 PM	06/29/12	6:09:48 PM	TMC	TRAFFIC MGMT CENTER		WB 94 I	WB 94 I TO 11TH ST S RMP
5281889	07/03/12	8:09:46 AM	07/03/12	8:49:17 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
5282623	07/03/12	1:49:55 PM	07/03/12	2:02:17 PM	TMC	TRAFFIC MGMT CENTER		WB 94 I	WB 94 I TO 11TH ST S RMP
5282646	07/03/12	1:58:49 PM	07/03/12	2:21:51 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
5283202	07/03/12	5:36:19 PM	07/03/12	5:54:34 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT HIAWATHA		
5289571	07/06/12	2:53:47 PM	07/06/12	3:36:16 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 65 HWY		
5289878	07/06/12	4:53:37 PM	07/06/12	5:13:55 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 65 HWY		
5297538	07/10/12	1:47:51 PM	07/10/12	1:57:49 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT GROVELAND AVE		
5297063	07/10/12	9:50:59 AM	07/10/12	10:40:29 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5299728	07/11/12	3:21:10 PM	07/11/12	4:07:24 PM	TMC	TRAFFIC MGMT CENTER		WB 94 I	WB 94 I TO SB 35W RMP
5301578	07/12/12	2:26:21 PM	07/12/12	3:21:32 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT GROVELAND AVE		
5302450	07/12/12	10:32:40 PM	07/13/12	4:41:15 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT LYNDALE AVE		
5313172	07/18/12	11:25:54 AM	07/18/12	12:22:20 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5314521	07/19/12	3:59:08 AM	07/19/12	4:52:03 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE		

EID	ADTS-Date	ADTS-Time	XDTS-Date	XDTS-Time	TYCOD	TYP_ENG	ECOMPL	XSTREET1	XSTREET2
5324551	07/24/12	7:03:07 AM	07/24/12	7:58:19 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE		
5325037	07/24/12	11:56:01 AM	07/24/12	12:30:50 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE		
5325323	07/24/12	2:25:32 PM	07/24/12	2:29:11 PM	TMC	TRAFFIC MGMT CENTER		WB 94 I	SB 35W I TO WB 94 RMP
5327576	07/25/12	3:36:39 PM	07/25/12	4:31:28 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 65 HWY		
5327716	07/25/12	4:38:12 PM	07/25/12	5:18:35 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5329018	07/26/12	11:01:19 AM	07/26/12	12:17:22 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PARK AVE		
5337140	07/30/12	3:50:27 PM	07/30/12	4:47:27 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5343429	08/02/12	4:36:49 PM	08/02/12	4:40:17 PM	TMC	TRAFFIC MGMT CENTER		WB 94 I	WB 94 I TO SB 35W RMP
5345396	08/03/12	3:48:56 PM	08/03/12	4:04:07 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT HIAWATHA AVE		
5345508	08/03/12	4:39:29 PM	08/03/12	4:57:52 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
5345199	08/03/12	2:18:35 PM	08/03/12	2:50:54 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5345450	08/03/12	4:12:55 PM	08/03/12	4:20:18 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I AT HIAWATHA		
5350943	08/06/12	4:48:30 PM	08/06/12	5:38:22 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
5352739	08/07/12	4:44:35 PM	08/07/12	5:02:43 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I AT PARK AVE		
5362532	08/13/12	12:06:21 PM	08/13/12	12:59:22 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE		
5362757	08/13/12	2:22:23 PM	08/13/12	2:42:28 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE		
5383805	08/24/12	1:19:41 PM	08/24/12	1:41:24 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5392572	08/28/12	10:05:04 PM	08/29/12	4:50:46 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5396607	08/30/12	8:46:29 PM	08/30/12	8:50:27 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
5396612	08/30/12	8:49:05 PM	08/31/12	4:38:28 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
5396507	08/30/12	7:56:57 PM	08/30/12	8:50:42 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5414713	09/07/12	3:35:04 PM	09/07/12	3:44:24 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT LYNDALE AVE		

Reported Incidents by TMC or State Patrol dispatch coincident with video collected incidents before September 27th, 2012.

EID	ADTS-Date	ADTS-Time	XDTS-Date	XDTS-Time	TYCOD	TYP_ENG	ECOMPL	XSTREET1	XSTREET2	Notes
5129492	04/18/12	3:20:50 PM	04/18/12	3:31:27 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I AT PORTLAND AVE			TMC REPORTED CRASH- VIDEO AVAILABLE
5167236	05/08/12	6:46:11 PM	05/08/12	6:52:45 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I AT PORTLAND AVE			TMC REPORTED CRASH- VIDEO AVAILABLE
5201545	05/25/12	6:38:21 PM	05/25/12	6:52:51 PM	TMC	TRAFFIC MGMT CENTER		WB 94 I TO 11TH ST S RMP	WB 94 I	TMC REPORTED CRASH- VIDEO AVAILABLE
5225845	06/05/12	2:31:13 PM	06/05/12	3:26:46 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE			STATE PATROL REPORTED CRASH- VIDEO AVAILABLE
5246566	06/15/12	4:36:12 PM	06/15/12	4:43:30 PM	TMC	TRAFFIC MGMT CENTER		WB 94 I	WB 94 I TO 11TH ST S RMP	TMC REPORTED CRASH- VIDEO AVAILABLE
5266332	06/25/12	6:15:06 PM	06/25/12	6:50:23 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE			REPORTED CRASH TO STATE PATROL. VIDEO AVAILABLE
5269724	06/27/12	2:13:09 PM	06/27/12	2:58:01 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PARK AVE			REPORTED CRASH TO STATE PATROL. VIDEO AVAILABLE
5269737	06/27/12	2:18:51 PM	06/27/12	2:57:51 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE			REPORTED CRASH TO STATE PATROL. VIDEO AVAILABLE
5282639	07/03/12	1:55:16 PM	07/03/12	1:59:28 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I AT PORTLAND AVE			TMC REPORTED CRASH- VIDEO AVAILABLE
5301717	07/12/12	3:30:25 PM	07/12/12	4:05:02 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE			REPORTED CRASH TO STATE PATROL. VIDEO AVAILABLE
5302104	07/12/12	6:16:55 PM	07/12/12	6:33:32 PM	1052	PERSONAL INJURY CRASH	WB 94 I AT 65 HWY			REPORTED CRASH TO STATE PATROL. VIDEO AVAILABLE
5329538	07/26/12	3:12:47 PM	07/26/12	3:56:44 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE			REPORTED CRASH TO STATE PATROL. VIDEO AVAILABLE
5345500	08/03/12	4:36:54 PM	08/03/12	4:44:42 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I AT PORTLAND AVE			TMC REPORTED CRASH- VIDEO AVAILABLE
5344843	08/03/12	11:23:28 AM	08/03/12	11:43:32 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE			REPORTED CRASH TO STATE PATROL. VIDEO AVAILABLE
5380087	08/22/12	3:55:24 PM	08/22/12	4:48:35 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE			REPORTED CRASH TO STATE PATROL. VIDEO AVAILABLE
5389658	08/27/12	1:04:21 PM	08/27/12	1:18:41 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE			REPORTED CRASH TO STATE PATROL. VIDEO AVAILABLE
5448766	09/26/12	4:26:25 PM	09/26/12	4:33:57 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I AT PORTLAND AVE			TMC REPORTED CRASH- VIDEO AVAILABLE

Crashes from video and equivalent from TMC/ State Patrol records before September 27th, 2012.

Date	Time	ADTS-Time	TYP_ENG
18-Apr	3:15:39 PM	3:20:50 PM	TRAFFIC MGMT CENTER
8-May	6:40:28 PM	6:46:11 PM	TRAFFIC MGMT CENTER
9-May	6:32:33 PM		
16-May	6:18:30 PM		
17-May	6:50:42 PM		
18-May	1:32:38 PM		
25-May	6:36:29 PM	6:38:21 PM	TRAFFIC MGMT CENTER
5-Jun	2:29:14 PM	2:31:13 PM	PROPERTY DAMAGE CRASH
6-Jun	6:01:58 PM		
8-Jun	2:16:56 PM		
15-Jun	4:30:28 PM	4:36:12 PM	TRAFFIC MGMT CENTER
18-Jun	3:47:27 PM		
25-Jun	3:11:07 PM		
25-Jun	4:59:01 PM		
25-Jun	6:12:19 PM	6:15:06 PM	PROPERTY DAMAGE CRASH
27-Jun	2:08:39 PM	2:13:09 PM	PROPERTY DAMAGE CRASH
27-Jun	2:10:56 PM	2:18:51 PM	PROPERTY DAMAGE CRASH
28-Jun	1:46:48 PM		
3-Jul	1:54:29 PM	1:55:16 PM	TRAFFIC MGMT CENTER
6-Jul	2:50:55 PM		
6-Jul	3:53:26 PM		
10-Jul	6:40:32 PM		
12-Jul	3:27:08 PM	3:30:25 PM	PROPERTY DAMAGE CRASH
12-Jul	6:14:52 PM	6:16:55 PM	PERSONAL INJURY CRASH
13-Jul	4:16:53 PM		
13-Jul	6:56:09 PM		
16-Jul	4:38:07 PM		
16-Jul	4:59:18 PM		
17-Jul	2:14:37 PM		
17-Jul	3:57:39 PM		
18-Jul	11:16:17 AM	11:25:54 AM	PROPERTY DAMAGE CRASH
25-Jul	1:29:22 PM		
25-Jul	1:45:21 PM		
25-Jul	3:33:13 PM		
26-Jul	3:08:28 PM	3:12:47 PM	PROPERTY DAMAGE CRASH
3-Aug	11:21:01 AM	11:23:28 AM	PROPERTY DAMAGE CRASH
3-Aug	4:32:46 PM	4:36:54 PM	TRAFFIC MGMT CENTER
7-Aug	5:24:05 PM		
7-Aug	6:45:04 PM		
10-Aug	6:37:46 PM		
21-Aug	6:41:49 PM		
22-Aug	3:52:43 PM	3:55:24 PM	PROPERTY DAMAGE CRASH
22-Aug	6:51:11 PM		
27-Aug	12:57:19 PM	1:04:21 PM	PROPERTY DAMAGE CRASH
31-Aug	2:14:21 PM		
4-Sep	2:34:35 PM		
26-Sep	4:23:51 PM	4:26:25 PM	TRAFFIC MGMT CENTER

2012 to 2013 Data – After VSL

The following tables indicate incident records after September 27th, 2012 through March 2013, reported by the TMC and The Minnesota State Patrol Dispatch. The data reports from January through March 2013 do not contain the TMC reports, as 2013 data was not available at the time of the analysis. Nine events were noted under type code 1050 (Property Damage Crash), all of which were confirmed by video records. 29 other events were observed manually, but were not confirmed by the CAD. Again, note that 2013 records with type code TMC were not available for comparison.

Reported incidents by TMC or State Patrol Dispatch out of video range

EID	AD-Date	AD-Time	XD-Date	XD-Time	TYCOD	TYP-ENG	ECOMPL	XSTREET1	XSTREET2
5448901	09/26/12	5:28:26 PM	09/26/12	6:04:12 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT GROVELAND AVE		
5452596	09/28/12	7:11:02 PM	09/28/12	8:14:10 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I MP233	WB 94 I TO 11TH ST S RMP	NB 65 HWY TO WB 94 RMP
5456574	10/01/12	7:54:15 AM	10/01/12	7:54:41 AM	TMC	TRAFFIC MGMT CENTER		WB 94 I	CEDAR AVE S
5459900	10/02/12	11:09:51 PM	10/03/12	4:45:41 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT LYNDALE AVE		
5461436	10/03/12	7:10:49 PM	10/03/12	7:58:46 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
5463143	10/04/12	6:28:02 PM	10/04/12	7:01:22 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT CHICAGO AVE		
5471878	10/09/12	6:35:35 PM	10/09/12	7:30:42 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT HIAWATHA AVE		
5483392	10/15/12	2:55:42 PM	10/15/12	4:13:55 PM	TMC	TRAFFIC MGMT CENTER		WB 94 I	NB 65 HWY TO WB 94 RMP
5485354	10/16/12	1:31:25 PM	10/16/12	1:41:13 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 1ST AVE		
5486175	10/16/12	5:56:49 PM	10/16/12	6:00:30 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I AT CHICAGO AVE		
5488877	10/18/12	9:14:08 AM	10/18/12	9:36:09 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT GROVELAND AVE		
5489972	10/18/12	6:47:13 PM	10/18/12	6:59:48 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5492008	10/19/12	7:28:02 PM	10/19/12	7:54:27 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT CHICAGO AVE		
5496955	10/22/12	2:47:40 PM	10/22/12	3:20:19 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT CHICAGO AVE		
5497954	10/22/12	9:45:15 PM	10/22/12	9:58:31 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT GROVELAND AVE		
5498153	10/23/12	4:45:48 AM	10/23/12	4:58:37 AM	TMC	TRAFFIC MGMT CENTER		WB 94 I	WB 94 I TO LYNDALE AVE S RMP
5501056	10/24/12	1:15:40 PM	10/24/12	1:47:33 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT LYNDALE AVE		
5511508	10/29/12	4:02:20 PM	10/30/12	5:21:47 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5517203	11/01/12	7:18:37 PM	11/01/12	7:43:20 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
5544049	11/15/12	5:18:07 PM	11/15/12	6:02:32 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5546329	11/16/12	6:54:59 PM	11/16/12	7:21:45 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT CHICAGO AVE		
5553836	11/20/12	7:22:32 PM	11/20/12	7:31:45 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT HIAWATHA		
5555368	11/21/12	1:16:36 PM	11/21/12	1:47:05 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
5567694	11/27/12	3:40:47 PM	11/27/12	4:15:58 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PARK AVE		
5568479	11/28/12	6:45:52 AM	11/28/12	7:32:06 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE		
5573103	11/30/12	1:04:40 PM	11/30/12	1:41:51 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I AT GROVELAND AVE		
5577514	12/03/12	7:24:47 AM	12/03/12	7:36:29 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5580189	12/04/12	4:06:40 PM	12/04/12	4:35:57 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
5593548	12/10/12	6:39:03 PM	12/10/12	8:08:39 PM	TMC	TRAFFIC MGMT CENTER	WB 94 I AT CHICAGO AVE		
5594621	12/11/12	11:58:01 AM	12/11/12	12:17:06 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT CHICAGO AVE		
5594889	12/11/12	2:30:45 PM	12/11/12	4:06:59 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5596851	12/12/12	5:34:16 PM	12/12/12	5:39:35 PM	TMC	TRAFFIC MGMT CENTER		WB 94 I	WB 94 I TO SB 35W RMP
5607351	12/18/12	7:45:53 AM	12/18/12	7:53:55 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT CHICAGO AVE		
5608560	12/18/12	5:40:44 PM	12/18/12	5:47:39 PM	TMC	TRAFFIC MGMT CENTER		WB 94 I	WB 94 I TO SB 35W RMP
5608570	12/18/12	5:46:56 PM	12/18/12	6:58:52 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH AVE		
5613691	12/21/12	12:02:04 PM	12/21/12	12:22:36 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5625489	12/27/12	11:47:26 PM	12/28/12	4:28:28 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
5625490	12/27/12	11:49:13 PM	12/28/12	4:28:29 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT CHICAGO AVE		
5626989	12/28/12	5:36:05 PM	12/28/12	5:46:40 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT HIAWATHA		
26597	1/4/13	9:59:10 AM	1/4/13	10:09:35 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT CHICAGO AVE		
26662	1/4/13	4:10:22 PM	1/4/13	4:23:33 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH AVE		

EID	AD-Date	AD-Time	XD-Date	XD-Time	TYCOD	TYP-ENG	ECOMPL	XSTREET1	XSTREET2
26736	1/4/13	7:58:44 PM	1/4/13	7:58:44 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
27341	1/8/13	6:26:00 PM	1/8/13	6:26:00 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT CHICAGO AVE		
27900	1/11/13	1:52:27 PM	1/11/13	2:52:17 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PARK AVE		
28563	1/15/13	8:54:32 AM	1/15/13	9:36:43 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH AVE		
28586	1/15/13	11:13:10 AM	1/15/13	11:53:37 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
28694	1/15/13	9:01:14 PM	1/15/13	9:19:05 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 3RD AVE		
32584	1/29/13	3:56:16 AM	1/29/13	4:27:59 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH AVE		
33002	1/31/13	8:35:04 AM	1/31/13	8:51:16 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
33101	1/31/13	3:55:42 PM	1/31/13	3:59:56 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
33243	2/1/13	6:39:29 AM	2/1/13	6:46:38 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
33516	2/1/13	6:56:03 PM	2/1/13	7:00:24 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE		
34993	2/4/13	8:20:11 AM	2/4/13	8:20:11 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT HIAWATHA		
35197	2/4/13	8:09:53 PM	2/4/13	8:09:53 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PARK AVE		
35398	2/5/13	7:36:38 AM	2/5/13	7:37:18 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT CHICAGO AVE		
35684	2/5/13	4:58:29 PM	2/5/13	5:22:09 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE		
35740	2/6/13	2:15:06 AM	2/6/13	2:15:06 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT FRANKLIN AVE		
36249	2/7/13	3:13:41 PM	2/7/13	3:13:41 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH AVE		
36298	2/7/13	6:21:35 PM	2/7/13	6:21:35 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
36402	2/8/13	9:41:04 AM	2/8/13	9:41:04 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT FRANKLIN AVE		
38967	2/14/13	2:51:58 PM	2/14/13	3:13:38 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
40547	2/20/13	8:12:39 AM	2/20/13	8:35:03 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT GROVELAND AVE		
40803	2/21/13	4:13:20 PM	2/21/13	4:13:29 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH AVE		
40815	2/21/13	5:00:38 PM	2/21/13	5:28:21 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH AVE		
40850	2/21/13	7:14:23 PM	2/21/13	8:01:53 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I MP233	WB 94 I TO 11TH ST S RMP	NB 65 HWY TO WB 94 RMP
40890	2/22/13	3:13:00 AM	2/22/13	3:23:20 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT HIAWATHA		
41364	2/22/13	2:05:42 PM	2/22/13	2:06:58 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT HIAWATHA		
42286	2/27/13	8:42:35 PM	2/27/13	8:43:10 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH AVE		
42379	2/28/13	11:52:26 AM	2/28/13	12:10:07 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 3RD AVE		
42465	3/1/13	6:39:24 AM	3/1/13	6:39:29 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
42555	3/1/13	4:51:22 PM	3/1/13	4:51:29 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT CHICAGO AVE		
44630	3/7/13	7:00:12 PM	3/7/13	7:23:15 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH AVE		
44637	3/7/13	8:12:34 PM	3/7/13	9:54:54 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT CHICAGO AVE		
44697	3/8/13	11:36:55 AM	3/8/13	9:56:25 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
46812	3/14/13	11:16:54 AM	3/14/13	2:38:48 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST		
46832	3/14/13	1:10:47 PM	3/14/13	1:24:35 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT CHICAGO AVE		
47296	3/15/13	8:24:31 PM	3/15/13	8:51:36 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT FRANKLIN AVE		
49239	3/19/13	5:08:11 PM	3/19/13	5:08:11 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE		
49315	3/19/13	9:33:59 PM	3/19/13	10:33:01 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT GROVELAND AVE		
46181	3/21/13	7:46:58 PM	3/21/13	11:10:42 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT CHICAGO AVE		
49754	3/21/13	9:42:04 PM	3/21/13	9:42:04 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT HIAWATHA		
49764	3/22/13	12:06:00 AM	3/22/13	12:19:33 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT FRANKLIN AVE		
50257	3/25/13	4:48:15 PM	3/25/13	5:08:15 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH AVE		
50376	3/26/13	5:28:34 PM	3/26/13	5:28:35 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 3RD AVE		

EID	AD-Date	AD-Time	XD-Date	XD-Time	TYCOD	TYP-ENG	ECOMPL	XSTREET1	XSTREET2
50432	3/27/13	8:57:07 AM	3/27/13	8:57:08 AM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT NICOLLET AVE		

Reported incidents by TMC or State Patrol Dispatch coincident with video collected incidents

EID	ADTS-Date	ADTS-Time	XDTS-Date	XDTS-Time	TYCOD	TYP_ENG	ECOMPL	Notes
5477643	10/12/12	4:56:22 PM	10/12/12	5:11:50 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE	STATE PATROL REPORTED CRASH- VIDEO AVAILABLE
5489972	10/18/12	6:47:13 PM	10/18/12	6:59:48 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 11TH ST	STATE PATROL REPORTED CRASH- VIDEO AVAILABLE
5491263	10/19/12	2:33:16 PM	10/19/12	2:55:26 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PARK AVE	TMC REPORTED CRASH- VIDEO AVAILABLE
5545620	11/16/12	1:45:07 PM	11/16/12	3:07:41 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE	STATE PATROL REPORTED CRASH- VIDEO AVAILABLE
5581712	12/05/12	2:35:03 PM	12/05/12	3:01:18 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE	STATE PATROL AND TMC REPORTED CRASH- VIDEO AVAILABLE
5624625	12/27/12	3:07:58 PM	12/27/12	3:27:20 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE	STATE PATROL REPORTED CRASH- VIDEO AVAILABLE
27296	1/8/2013	2:21:35 PM	1/8/2013	2:44:50 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE	STATE PATROL REPORTED CRASH- VIDEO AVAILABLE
27510	1/9/2013	4:49:43 PM	1/9/2013	5:26:35 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT 3RD AVE	STATE PATROL REPORTED CRASH- VIDEO AVAILABLE
46874	3/14/2013	4:49:43 PM	3/14/2013	5:14:00 PM	1050	PROPERTY DAMAGE CRASH	WB 94 I AT PORTLAND AVE	STATE PATROL REPORTED CRASH- VIDEO AVAILABLE

Crashes from video collection and equivalent records from TMC/ State Patrol incidents

Date	Time	ADTS-Time	TYP_ENG
10/05/12	4:07:09 PM		
10/09/12	3:33:02 PM		
10/12/12	4:41:30 PM		
10/12/12	4:50:42 PM	4:56:22 PM	PROPERTY DAMAGE CRASH
10/16/12	4:44:59 PM		
10/18/12	6:44:37 PM	6:47:13 PM	PROPERTY DAMAGE CRASH
10/19/12	2:17:31 PM	2:33:16 PM	PROPERTY DAMAGE CRASH
10/22/12	4:27:35 PM		
10/25/12	1:49:02 PM		
10/31/12	5:35:20 PM		
10/31/12	5:35:20 PM		
11/16/12	1:41:06 PM	1:45:07 PM	PROPERTY DAMAGE CRASH
11/20/12	5:02:42 PM		
11/21/12	12:33:36 PM		
11/29/12	3:06:15 PM		
12/03/12	2:36:40 PM		
12/05/12	2:32:31 PM	2:35:03 PM	PROPERTY DAMAGE CRASH
12/05/12	4:14:19 PM		
12/14/12	2:16:50 PM		
12/27/12	3:03:52 PM	3:07:58 PM	PROPERTY DAMAGE CRASH
12/27/12	3:04:25 PM		
12/31/12	4:37:27 PM		
1/2/2013	2:43:17 PM		
1/4/2013	2:58:43 PM		
1/4/2013	5:40:52 PM		

Date	Time	ADTS-Time	TYP_ENG
1/4/2013	6:09:38 PM		
1/8/2013	2:15:45 PM	2:21:35 PM	PROPERTY DAMAGE CRASH
1/9/2013	4:44:35 PM	4:49:43 PM	PROPERTY DAMAGE CRASH
1/23/2013	6:24:05 PM		
1/24/2013	2:58:15 PM		
1/25/2013	6:47:52 PM		
1/30/2013	3:58:23 PM		
2/5/2013	2:37:59 PM		
2/7/2013	4:06:26 PM		
2/12/2013	1:58:17 PM		
3/14/2013	4:56:17 PM	4:49:43 PM	PROPERTY DAMAGE CRASH
3/19/2013	2:38:04 PM		
3/20/2013	3:49:08 PM		

CAD Database Reference

The following list is a detailed description of the categories used by The Traffic Management Center (TMC) in the database. These categories are found in the 2008, 2010, 2011 and 2012 database provided.

- EID: Unique event ID No. generated by the system
- NUM_1: Agency event number
- ADTS-Date: Added Date
- ADTS-Time: Added Timestamp
- CDTS-Time: Timestamp for record creation
- CDTS-Date: Date of record creation
- ARTS-Date: Arrival date of PRIM UNIT
- ARTS-Time: Arrival time of PRIM UNIT
- DSTS-Date: Dispatched Date
- DSTS-Time: Dispatched Time
- UDTS-Date: Date for record update
- UDTS-Time: Timestamp for record update
- XDTS-Date: Closing Date
- XDTS-Time: Closing Time
- CREATE_TERM: The terminal where scheduled event was originally created - will not change when row is updated
- CTERM: Creation terminal-node name of workstation where record was created
- PRIM_UNIT: Primary Unit. ID of unit that reported the disposition code, requested case number via Assign Case Number or arrived on the scene with the case number.
- UTERM: Terminal which updated the event
- XTERM: Terminal which closed the event
- SUB_ENG: Textual description of sub-type(CAD, MDT,PAGER)
- SUB_TYCOD: The sub-type of the event type. If not sub-type is specified: Set to default
- TYCOD: Event type code
- TYP_ENG: AgencyEventTypeDescription-Verbose description of the event type
- EAREA: Area component of the event's location
- ECOMPL: Common place associated with the event location
- EDIRPRE: Direction prefix component of the event's location
- EDIRSUF: Direction suffix component of the event's location
- EFEANME: Feature name component (street name) of the event's location
- EFEATYO: Feature type component of the event's location
- X_CORD: X map coordinate for the event's location
- XSTREET1: Name and type of one street which intersects the event's location
- XSTREET2: Name and type of one street which intersects the event's location
- Y_CORD: Y map coordinate for the event's location

Incident Types

The following is a list of the common types of events recorded by TMC and reported to the State Patrol Dispatch. Records in the database with 1050-Property Damage Crash or TMC-Traffic Management Center (CRASH) as a type code selected as part of valid data for the purpose of this study.

- DEBRIS- DEBRIS ON ROADWAY
- STALL – STALLED VEHICLE NOT BLOCKING
- ***1050- PROPERTY DAMAGE CRASH***
- 1049- PEDESTRIAN ON FREEWAY
- 1052- PERSONAL INJURY CRASH
- ***TMC- TRAFFIC MANAGEMENT CENTER***
- MA- MOTORIST ASSIST
- MED- MEDICAL
- WW- WRONWAY DRIVER
- VOR- VEHICLE OFF ROAD
- TOWA- TOW ASSIST
- LL- LEAKING LOAD
- UE- UNIT EMERGENCY
- STALLB- STALLED VEHICLE BLOCKING
- ANIMAL- ANIMAL ON ROADWAY
- FIREV- FIRE VEHICLE
- DP- DAMAGE TO PROPERTY
- VSO- VEHICLE SPIN OUT
- 1073- UNATTENDED/ABANDODED VEHICLE
- NOMTR- NON-MOTORIZED VEHICLE IN ROADWAY