Evaluation of TxDOT Variable Speed Limit Pilot Projects

FINAL REPORT

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SwRI

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EVALUATION OF TXDOT VARIABLE SPEED LIMIT PILOT PROJECTS

FINAL REPORT

by

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Performed in cooperation with the
Texas Department of Transportation
and
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Disclaimer

This work was performed in cooperation with the Texas Department of Transportation (TxDOT). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Beverly Kuhn, P.E. #80308.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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Executive Summary

In May 2013, the regular session of the 83rd Texas State Legislature passed House Bill (HB) 2204 related to the establishment of a variable speed limits (VSL) pilot program by the Texas Transportation Commission. The bill was signed into law by the governor in June 2013. In December 2013, the Texas Transportation Commission established Rule §25.27 of the Texas Administrative Code authorizing and requiring the Texas Department of Transportation (TxDOT) to implement a variable speed limit pilot program to "study the effectiveness of temporarily lowering prima facie speed limits to address inclement weather, congestion, road construction, or any other condition that affects the safe and orderly movement of traffic on a roadway."

The goal of the pilot program was to deploy VSL in up to three locations to test the concept under three operational conditions and to determine the impacts of VSL on facility operations and safety. The specific objectives of the pilot project evaluation were to determine how much congestion was reduced in the area impacted by the implementation of VSL, to understand the users' perceptions of the VSL systems, to assess the safety impacts of VSL, and to determine the overall costs and benefits of VSLs. This report serves as the final updated report for TxDOT to provide the most comprehensive information and analysis about the pilot program and the results of the VSL evaluation.

TxDOT worked with the Texas A&M Transportation Institute (TTI) in selecting pilot project sites for the development, implementation, and evaluation of VSL. The VSL systems were to be used for the purpose of controlling speeds at sites that have (a) construction work zones, (b) weather-related events, and (c) urban congestion. Using a list of potential candidate sites provided by TxDOT along with other sites added for consideration, the team established the criteria for selection and gathered detailed information on each candidate site. Based on the information gathered in the initial stages of the project and local conditions, the project team recommended and TxDOT agreed to deploy VSL at the following sites for the purposes of the pilot study program:

- *Urban Congestion Site*: Westbound (WB) State Loop (SL) 1604 between US 281 and IH-10, San Antonio—The site on SL 1604 in the San Antonio District experiences recurring congestion that can benefit from VSL with no planned construction during the pilot study timeframe.
- *Construction Work Zone Site*: IH-35 northbound (NB), MM 297 – MM 301, Temple—The construction work zone site on IH-35 in Temple has recurring congestion as a result of the work zone that was expected to generate queues that can be managed by VSL.
- *Weather-Related Site*: Eastbound (EB) and WB IH-20 at Ranger Hill, Eastland County—The Ranger Hill site on IH-20 in the Brownwood District offered the best opportunity to assess the impacts of VSL for a variety of weather-related events.

A photo of the installation on SL 1604 in San Antonio is shown in Figure ES-1. Those in Temple and Ranger Hill, Eastland County were similar in design and layout.

Figure ES-1. VSL Sign Installation, San Antonio District.

A summary of the three locations, activation and deactivation dates of the VSL operation, and the dates for which data was analyzed for this report are provided in Table ES-1.

Table ES-1. VSL Activation Dates, and Data Analysis Dates by Location.

VSL Site	Direction / Facility	Activation Date	Deactivation Date	Data Analysis Start Date	Data Analysis End Date
San Antonio	WB SL 1604	June 30, 2014	December 31, 2014	June 30, 2014	December 31, 2014
Temple	NB IH-35	June 23, 2014	November 30, 2014	June 23, 2014	November 30, 2014
Ranger Hill, Eastland County	WB IH-20 EB IH-20	July 21, 2014	January 30, 2015	July 21, 2014	January 30, 2015

VSL Activations

As shown in Figure ES-2, San Antonio experienced the greatest number of system activations, while Ranger Hill, Eastland County experienced the fewest. Overall, the VSL system activated more frequently on Fridays than any other day of the week, particularly in San Antonio and Temple. San Antonio activations routinely occurred in the morning and evening peak periods, while the Temple activations were routinely a result of congestion from a lane closure and/or work activity during heavy traffic conditions. A relatively high number of activations also occurred on the weekends at these sites. With respect to triggering events cited for activating the VSL, Ranger Hill, Eastland County had the majority of the VSL activations caused by weather events, primarily reductions in pavement friction caused by rain events. In both San Antonio and Temple, the presence of congestion was the primary reason for activating the VSL system, although both locations also experienced activations due to weather events. The combination of congestion and weather was cited as the triggering event once in both the Temple, and Ranger Hill, Eastland County deployments.

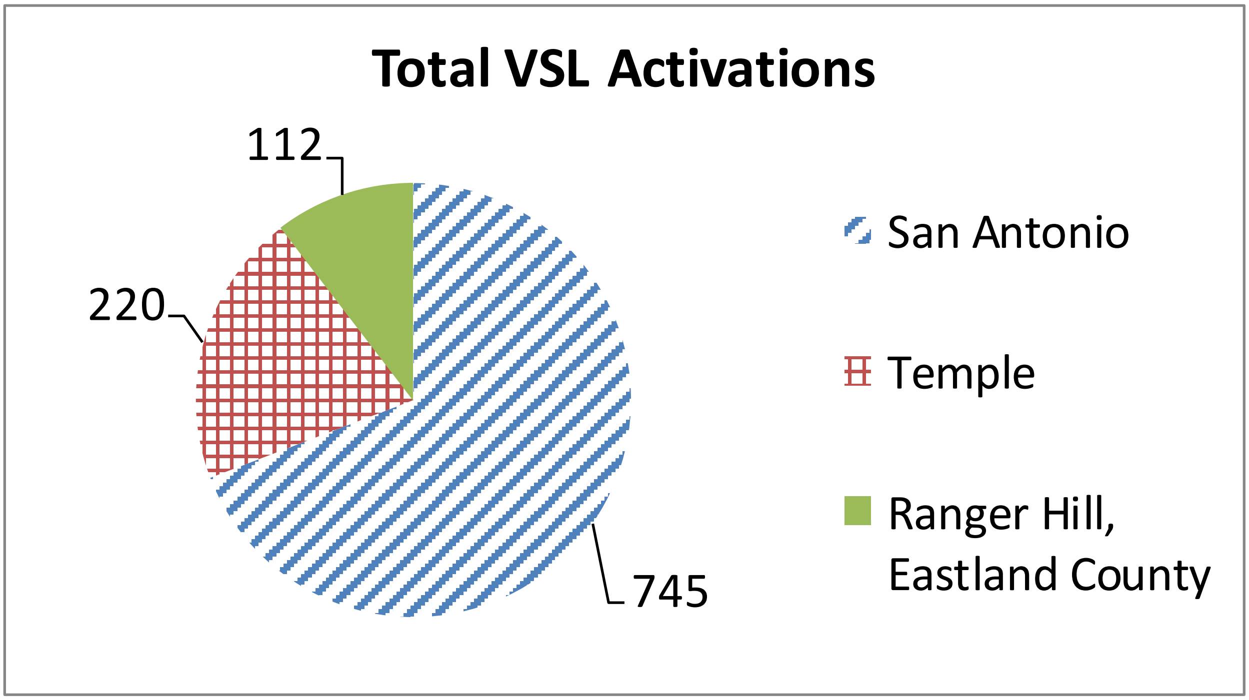

Figure ES-2. Total VSL Activations by Deployment Site.

Congestion

The three sites were analyzed in terms of the impact of VSL on congestion. For San Antonio, the team examined the impact of the VSL on average speeds at each sign location. Speed data in the evening peak period were used in the analysis as it represents the time period when the VSL was most active at this deployment. The analysis only examined data from Tuesdays and Thursdays as these days were determined to best represent typical weekday traffic. Representative results are presented in Figure ES-3.

These results indicate that when comparing the "With VSL" and "Without VSL" average speeds for Thursdays, average speeds from the "With VSL" in July showed a drop in average speeds across all VSL sign locations, while the data from September showed an increase in average speeds. A statistical analysis of the average speeds confirms that the results of the VSL system performance in the San Antonio corridor changed throughout the course of the study. Performance in July generated statistically significant reductions in speeds with performance in September resulted in statistically significant increases in speeds.

When analyzing the speed differentials (i.e., the difference between the travel speed and the posted speed limit) for San Antonio, at all VSL locations, measured average travel speeds are within $\pm$ 10 mph of the posted speed limit. This suggests that the process of stepping down speed limits in advance of the congestion points does not create substantial speed differential between posted and actual speeds. A statistical comparison of the average per lane flow rate with and without VSL active at the San Antonio deployment shows that average per lane flow rate remained relatively constant when the VSL was active compared to when the VSL was not active, suggesting that implementing VSL did not have a negative impact on vehicle throughput at this site and comparison of average speed is possible due to similar traffic conditions.

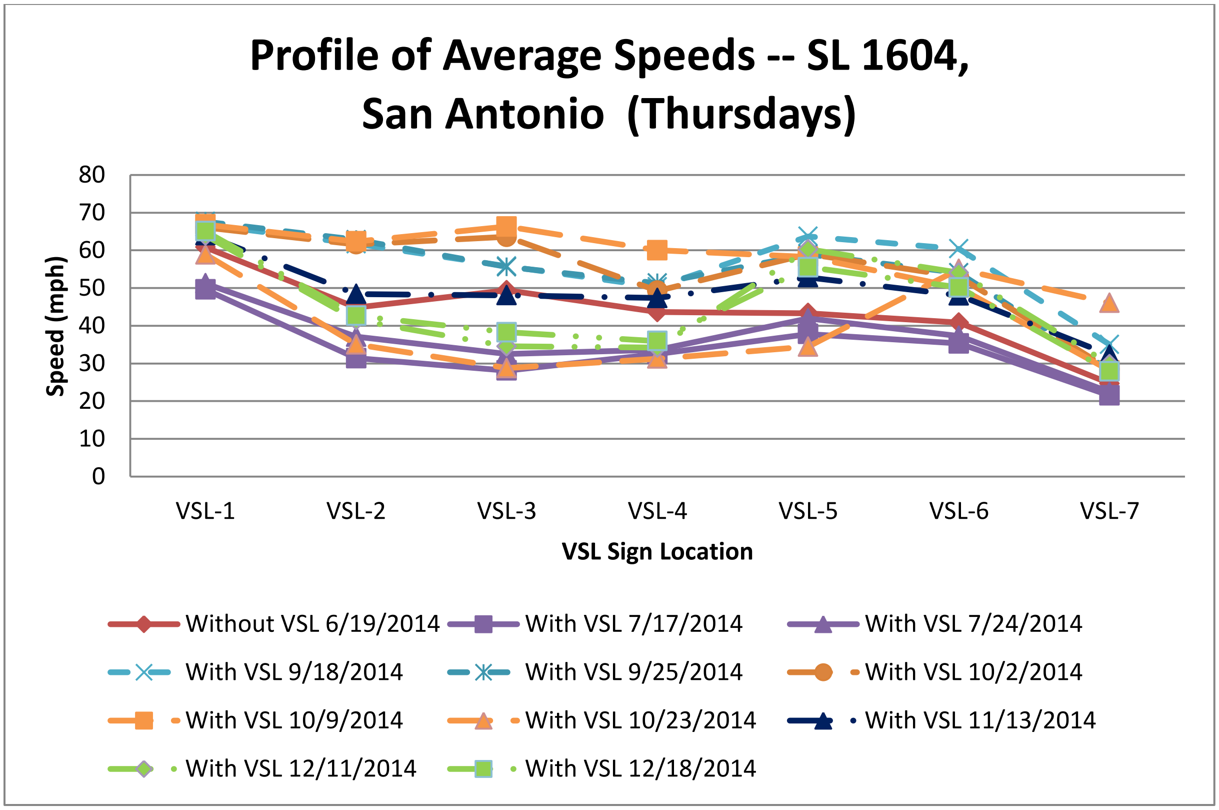

Figure ES-3. Comparison of Thursday's Average Speeds (mph) at Each VSL Sign Location, San Antonio.

For Temple, the VSL system was most active on Fridays. Analysis of speed data showed that average speeds at each of the sign locations had a tendency to be higher immediately following the initiation of VSL when compared to speeds late in the VSL operation. Additionally, the average speed at each of the sign locations had a tendency to be higher in July and then declined in both August and September. A statistical comparison of the average speeds measured at each sign location showed that average speeds were statistically higher during the two days evaluated in July at this location; while average speeds were statistically lower at all the stations in the last two days in September. For those activations studied in August, average speeds where similar to the before conditions at each of the study locations.

An analysis of the average per lane flow rate at each sign location for the Temple deployment indicate that beginning with the activations in August, the average per lane flow rate had increased over that generated before the VSL was active. These increases in average per lane flow rate were determined to be statistically significant at a 95 percentile confidence level.

For Ranger Hill, Eastland County, the data showed that reduced speed limits were actually posted on signs in the field on only four days though there were more potential activations.

Three days that saw activations were for weather events (8/29; 9/12; 9/17), and one was a congestion event (8/7). For the weather events, the VSL had very little impact with the VSL posted speed of 55 mph. Average travel speeds were between 60 and 65 mph. For the congestion event, the data suggests that an incident occurred where the freeway may have actually been blocked.

Safety

TxDOT's Crash Records Information System (CRIS) was used to analyze the safety of the study sites. Approximately six months within the three years of Before data (2011, 2012, and 2013) and one year of After data (2014) start and end dates (shown in Table ES-1) were used in the analysis. The crash frequency and crash rates are illustrated in Figure ES-4. In general, crashes decreased except on SL 1604 in San Antonio.

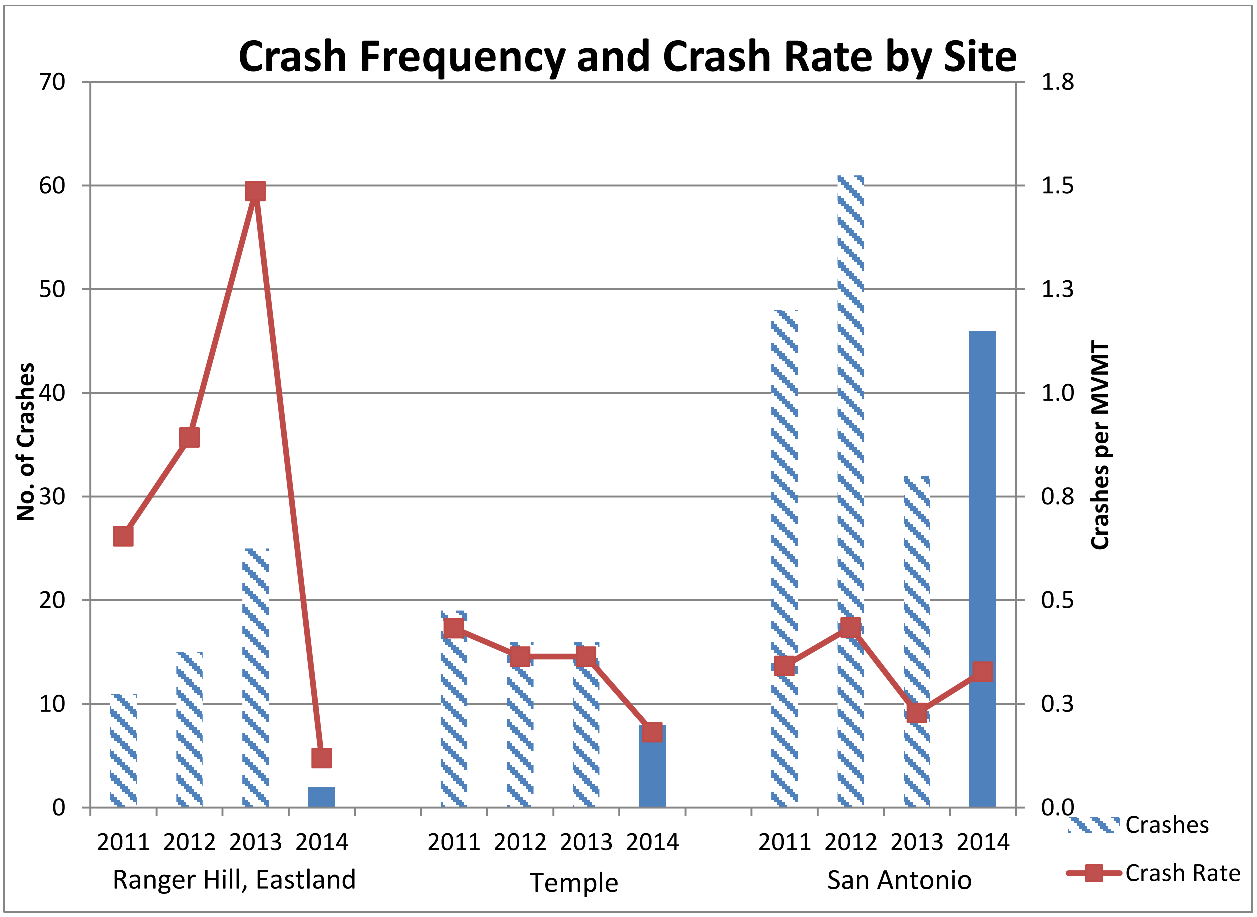

Figure ES-4. Crashes and Crash Rates for VSL Sites, Before and After Activation.

The crash severity is illustrated in Figure ES-5. In general, crash severity decreased after VSL with the exception of possible injury crashes. The Before and After crashes by "adverse" surface conditions are illustrated in Figure ES-6. In general, the number of crashes with 'adverse' surface conditions (e.g. wet, ice, snow, muddy, etc.) decreased after VSL activation.

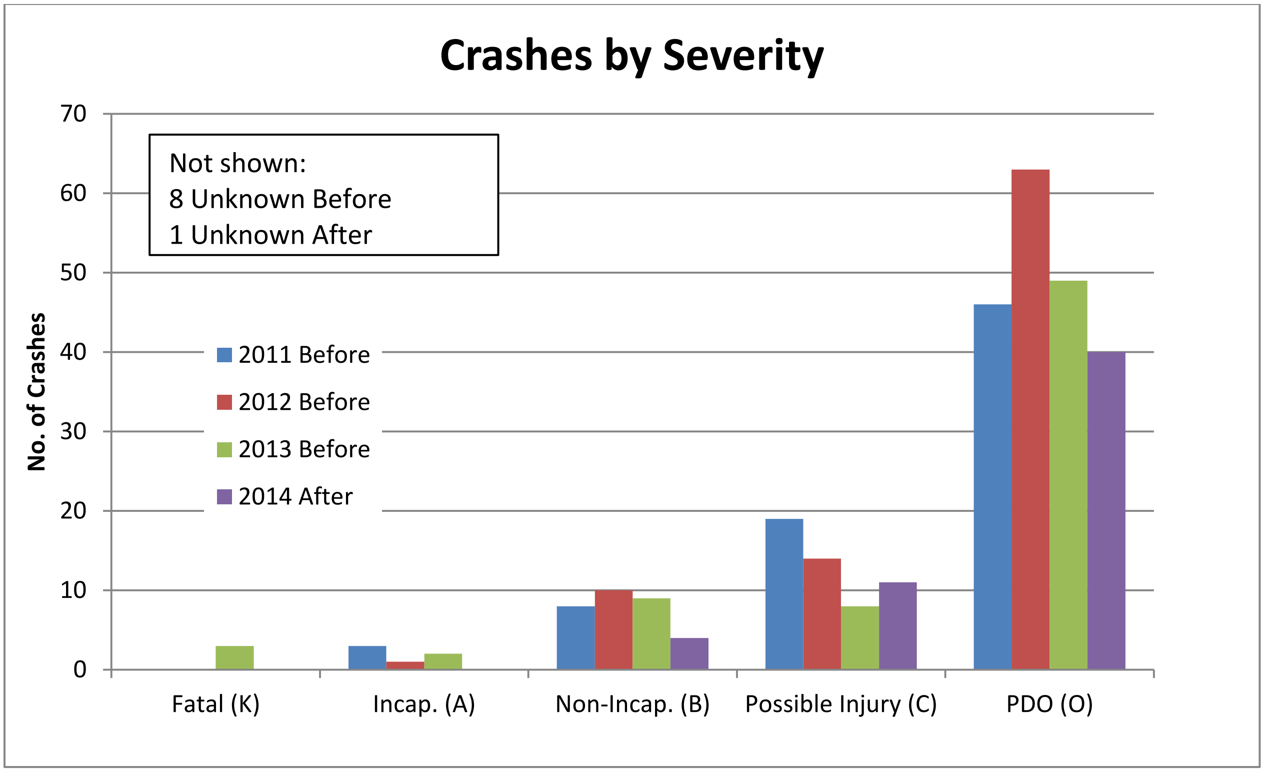

Figure ES-5. Crash Severity for VSL Sites, Before and After Activation.

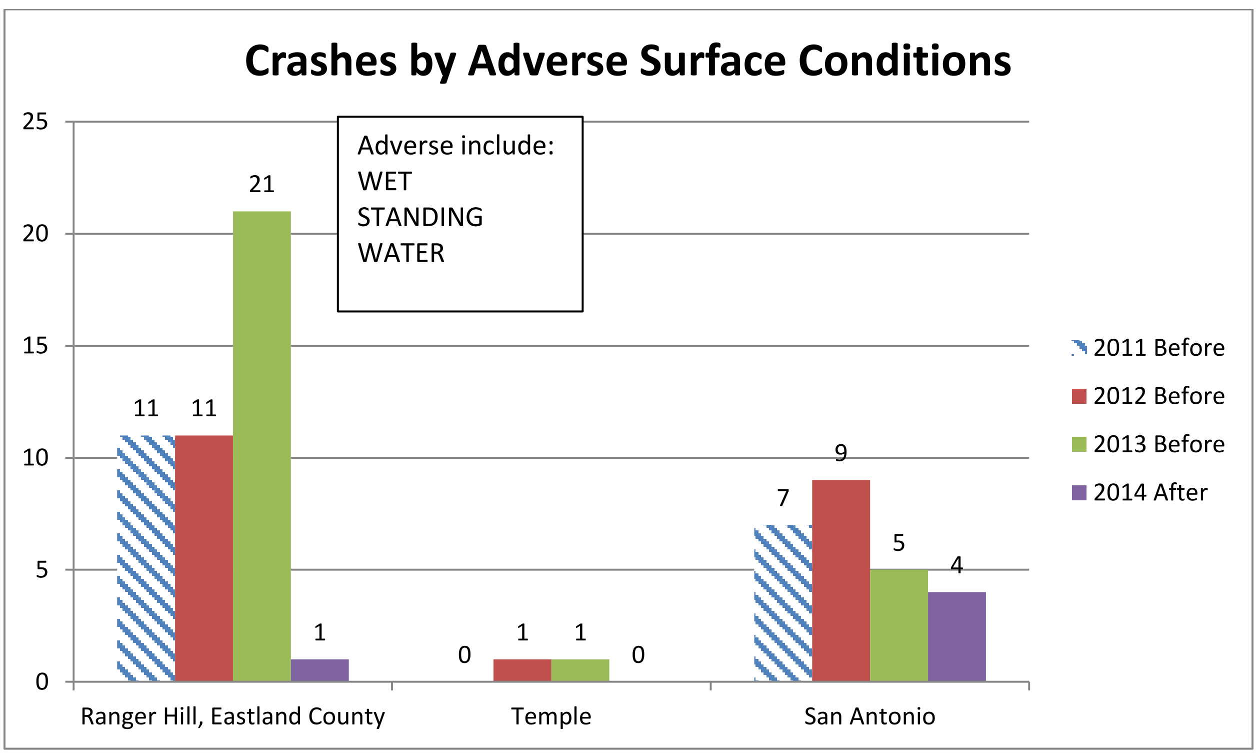

Figure ES-6. Crashes by Adverse Surface Conditions for VSL Sites, Before and After Activation.

No statistical significance test was completed given the short duration of the analysis period. Robust safety analyses involve multiple years of before and after data, and this analysis period was only a few months. The project team recommends that future assessments utilize at least three years of after data for each site.

Users' Perceptions

Users' perceptions of the VSL project were a key factor in overall success. To assess user understanding of the VSL sign systems, the project team conducted 300 surveys during the VSL deployment period in the San Antonio and Ranger Hill, Eastland County. The survey consisted of two sets of questions aimed at assessing the respondents' awareness and understanding of the VSL system, along with their opinions of the signs themselves. The project team focused on questions that would help ascertain public understanding of the VSL system. The survey results (provided in Figure ES-5) showed that the majority of respondents understood that the signs displayed a legal, enforceable speed limit. In addition, most respondents at each location were aware of the reasons for activation of the VSL system, (i.e., primarily congestion in San Antonio and weather in Ranger Hill, Eastland County).

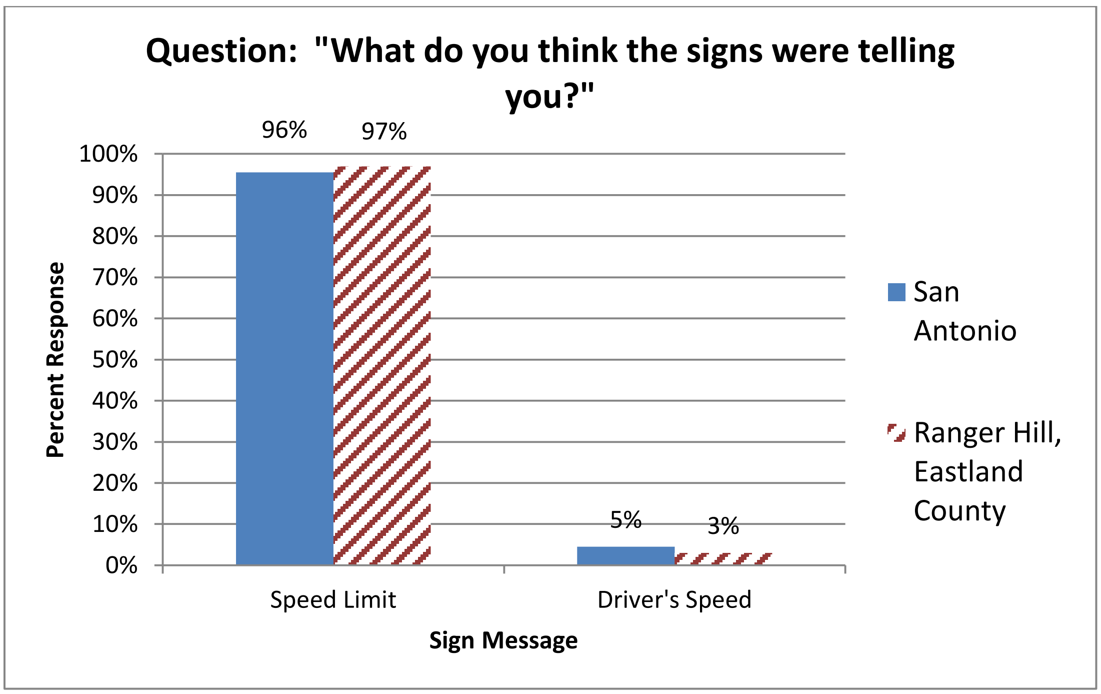

Figure ES-5. Users' Perception of VSL Message.

Violations

To determine the impacts of enforcement on VSL speed compliance, the project team performed an enforcement study at the VSL deployment in San Antonio. The study consisted of a comparison of recorded speed data taken from an advance warning portable changeable message sign (PCMS) and the first VSL trailer (VSL#1) in the series. In this upstream area, motorists often could not physically see any apparent need to reduce their speed, despite the "Reduced Speed Ahead" display on the advance warning PCMS and a reduced speed limit on VSL#1. The analysis of violation data, presented in Figure ES-6, indicate that the VSL system alone without enforcement had an impact on the percentage of time that average speeds exceed specific speed thresholds, more at higher speeds than at lower speeds. When a patrol officer was present, the impact increased, most likely because motorists perceived a need to slow down, albeit to avoid the penalty of receiving a speeding ticket. Thus, VSL compliance increases in the presence of law enforcement.

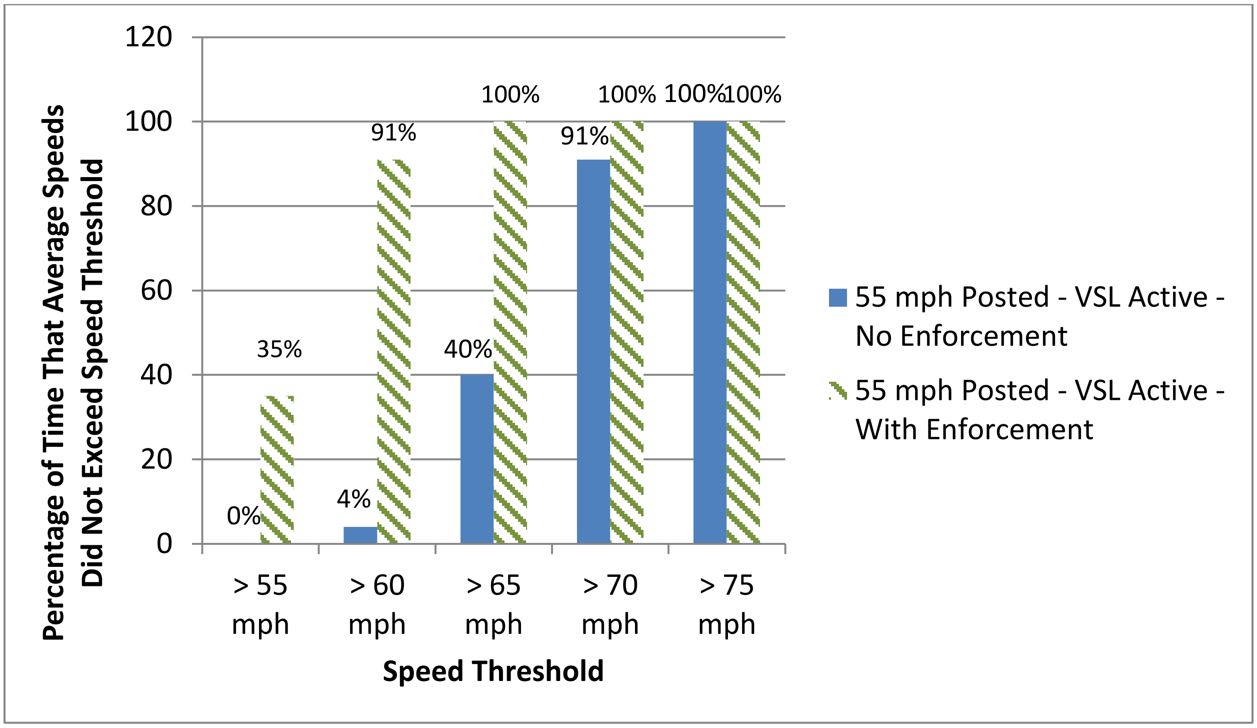

Figure ES-6. Impacts of VSL on Average Speeds, With and Without Enforcement.

Benefit-Cost

The project team conducted a high-level benefit-cost (B/C) analysis on potential VSL deployments in Texas as part of this project using a tool developed by Federal Highway Administration (FHWA) for planning-related analyses of operational strategies. Each individual deployment was analyzed separately assuming the VSL installation would be a full permanent installation. Included in the analysis is the value of capital equipment (basic infrastructure equipment and incremental deployment equipment) and operational and maintenance costs annualized over a 20-25 year useful life of the equipment. The potential B/C ratios are shown in Table ES-2. The benefits predicted in these deployments are based on a 7% reduction in crashes.

Table ES-2. Benefit-Cost Estimate.

Deployment Site	Annual Benefits	Annual Costs*	Net Benefit	B/C Ratio
San Antonio	$2,112,983	$300,370	$1,812,613	7.03
Temple	$2,358,976	$238,075	$2,120,901	9.91
Ranger Hill, Eastland County	$4,216,950	$300,370	$3,916,580	14.04

*Assumes full permanent installation.

Lessons Learned

In summary, the primary lessons learned from the pilot tests were as follows:

1. Use permanent equipment preferably mounted over the travel lanes. Temporary equipment was not suitable for long-term operations.
2. A wider separation of the sensors and signs would be necessary for permanent installations.
3. Utilize a more comprehensive and rigorous site selection process that incorporates pertinent information beyond the need for VSL and basic field layout information. This includes longitudinal and horizontal spacing considerations in addition to a thorough understanding of how traffic operates with respect to ingress/egress locations along the variable speed corridor. Understanding the existing speed profile on any proposed corridors and significant data collection before implementation is highly recommended.
4. The operational situation planning needs to be enhanced to account for more failure conditions in both equipment and communications. With additional time and consideration on potential failure conditions, the algorithm can be enhanced to address these issues and increase the public confidence in the messages posted by ensuring that they are correct and consistent.
5. Additional efforts to improve the overall algorithm are warranted, with multiple avenues being identified to enhance future operations, such as adjustments to sensor inputs, analysis, and spacing.
6. Consideration needs to be given to real-time data exchange to other agencies, such as the Department of Public Safety.
7. Significant and on-going public outreach is necessary to assist drivers in both understanding and complying with variable speed limits.

Conclusion

Based upon the limited data available for the VSL pilot project, VSLs would be beneficial if implemented to address inclement weather, congestion or road construction. VSLs had a safety benefit at each location and motorists had a clear understanding of the purpose of the VSLs. Therefore, it is recommended to allow the operation of VSLs in Texas.

Impetus of the Pilot Projects

In April 2013, the regular session of the 83rd Texas State Legislature passed House Bill (HB) 2204 related to the establishment of a variable speed limit (VSL) pilot program by the Texas Transportation Commission.[1] The bill was signed into law by the governor in June 2013. In December 2013, the Texas Transportation Commission established Rule §25.27 of the Texas Administrative Code authorizing and requiring the Texas Department of Transportation (TxDOT) to implement a variable speed limit pilot program to "study the effectiveness of temporarily lowering prima facie speed limits to address inclement weather, congestion, road construction, or any other condition that affects the safe and orderly movement of traffic on a roadway."[2]

Specific provisions in the code governing the program include the following:

- The prima facie speed limits on a portion of the state highway system may be lowered, and the reduced speed limits must be based on engineering and traffic investigation and lowered in multiples of 5 mph.
- The engineering or traffic study required to establish the variable speed limit may include several methods, such as a spot speed in the affected area, speed-over-distance readings or traffic flow obtained from field technology, or sight distance during inclement weather.
- Required signage includes a sign indicating the change in the speed limit placed between 500 and 1,000 feet before the point at which the speed limit takes effect, as well as a sign posted at the point where the speed limit takes effect. Electronic signs capable of displaying more than one message may be used.
- TxDOT is required to keep an official record of all changes made to the prima facie speed limit, which includes date, time, and duration of the lowered speed limit.
- TxDOT is required to coordinate closely with state and local law enforcement agencies regarding the locations of the pilot projects and make all records maintained as part of the pilot projects available to those law enforcement agencies to support enforcement.[2]

The goal of the pilot program was to deploy VSL in up to three locations to test the concept under three operational conditions and to determine the impacts of VSL on facility operations and safety. The specific objectives of the pilot project evaluation were to determine how much congestion was reduced in the area impacted by the implementation of VSL, to understand the users' perceptions of the VSL systems, to assess the safety impacts of VSL, and to determine the

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[1] Variable Speed Limit Pilot Program, HB 2204, Texas 83rd State Legislature, 2013 [Online], Available: http://www.capitol.state.tx.us/tlodocs/83R/billtext/pdf/HB02204F.pdf#navpanes=0 [accessed October 2014].

[2] Texas Transportation Code ch. 25(b), § 25.27, Texas Transportation Code, 12 December 2013 [Online], Available: http://info.sos.state.tx.us/pls/pub/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=43&pt=1&ch=25&rl=27 [accessed October 2014].

overall costs and benefits of VSL. This report serves as the report required by HB 2204 for TxDOT to provide information to the legislature about the pilot program and the results of the VSL evaluation.

Site Selection

TxDOT worked with the Texas A&M Transportation Institute (TTI) in selecting pilot project sites for the development, implementation, and evaluation of VSL. The VSL systems were to be used for the purpose of controlling speeds at sites that have (a) urban congestion, (b) construction work zones, and (c) weather-related events. Using a list of potential candidate sites provided by TxDOT, TTI added other sites that were considered by the project team and TxDOT. The team established the criteria for selection, gathered detailed information on each candidate site, and identified the most promising sites for discussion and decision making.

Urban Congestion VSL

The purpose of using VSL in corridors with recurring congestion is to foster better uniformity in speeds, sustain stable traffic flow, and delay the onset of traffic flow breakdown. VSL systems used in this application must include the ability to detect increases in traffic volumes. The best candidates for this type of situation typically have recurring congestion.

Construction Work Zone VSL

The purpose of using VSL in work zones is to control speeds upstream of developing queues. VSL systems used in this application must include the ability to detect queue development and propagation to reduce speeds upstream of the event. The best candidate sites for this type of situation typically have long-term lane closures, which may result in periodic congestion when traffic volumes increase.

Weather-Responsive VSL

The purpose of using VSL in corridors with weather-related issues is to reduce the likelihood of incidents. VSL systems used in this application must include the ability to detect fog, ice, rain, smoke, or other conditions that deteriorate driver visibility and vehicle control. The best candidates for this type of situation typically have above-average crash rates and are known to experience weather events that contribute to these crashes.

TxDOT VSL Pilot Study Sites

Based on the information gathered in the initial stages of the project and local conditions, the project team recommended and TxDOT agreed to deploy VSL at the following sites for the purposes of the pilot study program:

- *Urban Congestion Site*: WB State Loop (SL) 1604 between US 281 and IH-10, San Antonio – The site on SL 1604 in the San Antonio District experiences recurring congestion that can benefit from VSL with no planned construction during the pilot study timeframe.

- *Construction Work Zone Site*: IH-35 NB, MM 297 – MM 301, Temple – The construction work zone site on IH-35 in Temple has recurring congestion as a result of the work zone that was expected to generate queues that can be managed by VSL.
- *Weather-Related Site*: EB & WB IH-20 at Ranger Hill, Eastland County – The Ranger Hill site on IH-20 in the Brownwood District offered the best opportunity to assess the impacts of VSL for a variety of weather-related events.

A summary of the individual locations, activation and deactivation dates of the VSL operation, and the dates for which data was analyzed for this report are provided in Table 1.

Table 1. VSL Locations, Activation Dates, and Data Analysis Dates.

VSL Site	Direction / Facility	Activation Date	Deactivation Date	Data Analysis Start Date	Data Analysis End Date
San Antonio	WB SL 1604	June 30, 2014	December 31, 2014	June 30, 2014	December 31, 2014
Temple	NB IH-35	June 23, 2014	November 30, 2014	June 23, 2014	November 30, 2014
Ranger Hill, Eastland County	WB IH-20 EB IH-20	July 21, 2014	January 30, 2015	July 21, 2014	January 30, 3015

Implementation

The implementation of the VSL pilot projects provided a concept of operations and requirements for the development and deployment of VSL at the selected locations. Project implementation included various components to ensure success, including the data needs, equipment needs, software modification needs, and integration requirements for successful deployment. The sites for the VSL pilot studies, as noted previously, had a specific combination of VSL operational approaches that individually met the requirements of the legislative document while offering the project team the opportunity to analyze the impacts of VSL for the intended purposes. In all cases, the VSL system developed and deployed issued an alert to the operator when a VSL needed to be initiated. The operator then confirmed the alert to begin operating the signs in a VSL mode. The following sections provide a brief overview of the specific aspects of the VSL implementation. Appendix B provides additional details.

Urban Congestion VSL

The TxDOT pilot deployment also included a process for providing speed harmonization upstream of a known bottleneck location for the congestion-based VSL application. The process was patterned after the approach used in Seattle by the Washington State Department of Transportation (WSDOT) to provide speed harmonization on I-405, SR 522, and I-90. The goal of the TxDOT Congestion VSL was to gradually drop speeds of vehicles approaching a bottleneck location as congestion occurred in an attempt to: 1) delay (and possibly prevent) congestion from forming at the bottleneck, and 2) reduce the speed differential between congested and uncongested traffic flow at the back of the queue. The idea was to dynamically adjust the speeds limits upstream of the bottleneck as congestion formed and dissipated. When no congestion was present in the corridor, the speed limit in each segment was set to the maximum speed. However, as congestion began to form at the bottleneck, the speed limit at the bottleneck location became the controlling factor for speeds in the corridor, and all other speeds were adjusted so as to provide a gradual step down of speeds between the congested and uncongested sections of the freeway. In concept, the stepping down of speeds upstream of a bottleneck allows drivers to gradually adjust their speeds as they approach the congestion, thereby reducing the potential for rear-end collisions due to drivers unexpectedly encountering the back of the congestion.

Construction Work Zone VSL

The purpose of the construction work zone VSL application is to display work zone speed limits within a specified work zone. For many construction zones, TxDOT implements reduced speed zones to improve traveler and worker safety. This work zone contained a lane closure, which sometimes created congestion. During periods of congestion, the goal of the TxDOT construction-related VSL was to gradually drop speeds of vehicles approaching the lane closure in an attempt to (a) delay (and possibly prevent) congestion from forming at the lane closure, and (b) reduce the speed differential between congested and uncongested traffic flow at the back of the queue.

Weather-Responsive VSL

The weather-responsive VSL application uses a table look-up method to determine recommended safe travel speeds during inclement weather conditions. The table look-up method uses visibility and pavement conditions to determine the cell in the table representing the prevailing conditions in the corridor. Each cell in the table corresponds to a particular recommended travel speed for the prevailing conditions. The cells in the table are bound by a minimum and maximum recommended travel speed. The maximum recommended travel speed corresponds to the most favorable condition—high coefficients of friction with high visibility. The minimum recommended travel speed corresponds to the least favorable condition—limited visibility with poor coefficients of friction.

While multiple levels of visibility and pavement friction conditions are supported through this method, the pilot deployment consisted of only two visibility levels (defined by one visibility threshold) and three pavement surface conditions (defined by two coefficient of friction thresholds). For implementation, users needed to define the recommended maximum and minimum travel speeds for the specific corridor as well as the recommended travel speed for the different levels of visibility and pavement conditions. Recommended speed levels needed to correspond to agency-defined recommended speed criteria for various visibility and pavement surface conditions. As implemented, the algorithm used six recommended speed levels.

Each district was responsible for determining the recommended safe travel speeds for each visibility and pavement surface condition depending on the equipment installed. This approval was based on the contents of the implementation plan, the evaluation plan, and the software change documentation provided by the Southwest Research Institute® (SwRI®). The weather-related VSL application was operational at all three pilot study sites, one with visibility and pavement friction sensors (Ranger Hill, Eastland County) and two with only pavement friction sensors (Temple and San Antonio).

Field Display of VSL Speeds

The TxDOT Lonestar™ software was modified by SwRI to contain new algorithms corresponding to the three VSL criteria detailed above. The project team evaluated the algorithms simultaneously using all available input data, and the resulting output was the lowest prevailing speed condition warranted.

Once the appropriate VSL speeds were determined by the algorithm, the field display of the signs was activated through the existing dynamic message sign (DMS) module. In determining which signs to use to display the changes in speeds, the research team sought to minimize the step down between any two VSLs, subject to the following two constraints:

- The maximum change between two signs could be no more than 15 mph.
- The minimum change between two signs could not be less than 5 mph.

Any triggered speed (S_t) was evaluated, and for the pilot project, the lowest generated speed for a VSL was used. The general rules that were used to govern the speed displays were as follows:

- Speed step downs needed to be between 5 and 15 mph, with 5 mph being the preferred step down.
- Where a step down of greater than 15 mph was needed or there were an insufficient number of signs over which the speeds could be reduced following the rule above, then the speed that was displayed on the VSL needed to be higher than the recommended speed.
- If a large drop in speed was required over multiple VSL, the largest drop in speed had to occur at the farther upstream speed. For example, a drop in speed of 15 mph needed to be distributed over two signs, with the first sign displaying a drop of 10 mph and the second sign displaying a drop of 5 mph.
- Speeds were NOT stepped up to normal speeds after a reduced speed. Step ups in speed could occur between two low target speeds if there was a sufficient number of signs over which the speed changes could occur.

Deployment Schematics

The following figures and tables provide detailed deployment design and locations for the various portable changeable message signs (PCMSs) allocated for each VSL pilot study location. Figure 1, Figure 2, and Figure 3 show the VSL signs installed in San Antonio, Temple, and Ranger Hill, Eastland County, respectively. Each sign consisted of a solar-powered PCMS equipped with a cellular modem, a road condition sensor, a roadway visibility sensor (Ranger Hill, Eastland County only), and a vehicle detection system and was installed with a minimum of four safety drums for protection, per the *Manual on Uniform Traffic Control Devices* (MUTCD). Additional information on the field equipment is included in Appendix D.

Figure 1. VSL Sign Installation, San Antonio.

Figure 2. VSL Sign Installation, Temple.

Figure 3. VSL Sign Installation, Ranger Hill, Eastland County.

Table 2 provides a list of the individual sign locations for the San Antonio deployment, including their description, latitude, and longitude for reference purposes. Figure 4 displays the VSL sign locations along WB SL 1604 in San Antonio.

Table 2. Sign Location Coordinates, WB SL 1604 VSL Site, San Antonio.

Sign	Description	Latitude	Longitude
RSA	San Antonio "Reduced Speed Ahead"	29.610230°	-98.473170°
VSL-1	San Antonio WB VSL #1	29.610030°	-98.481640°
VSL-2	San Antonio WB VSL #2	29.609340°	-98.489350°
VSL-3	San Antonio WB VSL #3	29.608660°	-98.498030°
VSL-4	San Antonio WB VSL #4	29.608830°	-98.510660°
VSL-5	San Antonio WB VSL #5	29.606770°	-98.527860°
VSL-6	San Antonio WB VSL #6	29.602350°	-98.539380°
VSL-7	San Antonio WB VSL #7	29.601640°	-98.551660°

Table 3 provides a list of the individual sign locations along with their description for the Temple deployment. Figure 5 shows the sign locations along NB IH-35 in Temple.

Table 3. Sign Location Coordinates, NB IH-35 VSL Site, Temple.

Sign	Description	Latitude	Longitude
RSA	Temple "Reduced Speed Ahead"	31.071306°	-97.422710°
VSL 1	Temple NB VSL #1	31.075085°	-97.418193°
VSL 2	Temple NB VSL #2	31.078476°	-97.414176°
VSL 3	Temple NB VSL #3	31.083097°	-97.408577°
VSL 4	Temple NB VSL #4	31.085604°	-97.402642°

Table 4 provides a list of the individual sign locations along with their description for the Ranger Hill, Eastland County deployment, and Figure 6 displays the sign locations along IH-20 in the eastbound and westbound directions.

Table 4. Sign Location Coordinates, EB and WB IH-20 VSL Site, Ranger Hill, Eastland County.

Sign	Description	Latitude	Longitude
EB RSA	Ranger Hill EB "Reduced Speed Ahead"	32.483378°	-98.582741°
EB VSL 1	Ranger Hill EB VSL #1	32.484725°	-98.575118°
EB VSL 2	Ranger Hill EB VSL #2	32.486301°	-98.565960°
EB VSL 3	Ranger Hill EB VSL #3	32.487427°	-98.559653°
WB RSA	Ranger Hill WB "Reduced Speed Ahead"	32.500193°	-98.501216°
WB VSL 1	Ranger Hill WB VSL #1	32.499846°	-98.509188°
WB VSL 2	Ranger Hill WB VSL #2	32.499263°	-98.520088°
WB VSL 3	Ranger Hill WB VSL #3	32.498698°	-98.532566°

Software and Integration

The deployment of the VSL pilot study projects required the modification of the TxDOT Lonestar Advanced Traffic Management System (ATMS) in use by traffic management centers (TMCs) covering each deployment area. SwRI was responsible for this software modification. With the assistance of TTI staff, SwRI developed an integration plan and provided it to TxDOT. All software modification and integration details are provided in Appendix H.

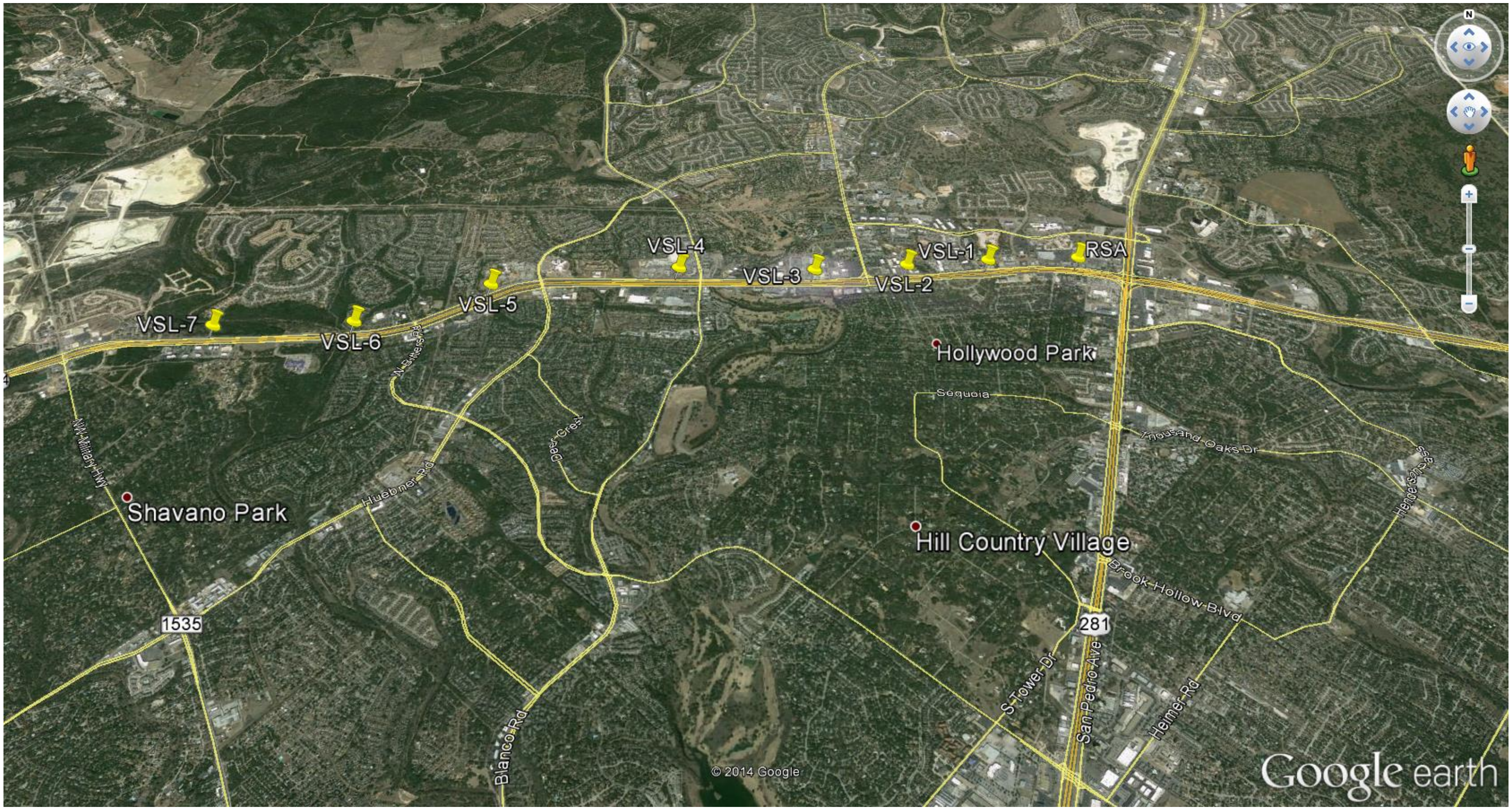


Figure 4. Sign Locations, WB SL 1604 VSL Site, San Antonio.

Figure 5. Sign Locations, NB IH-35 VSL Site, Temple.

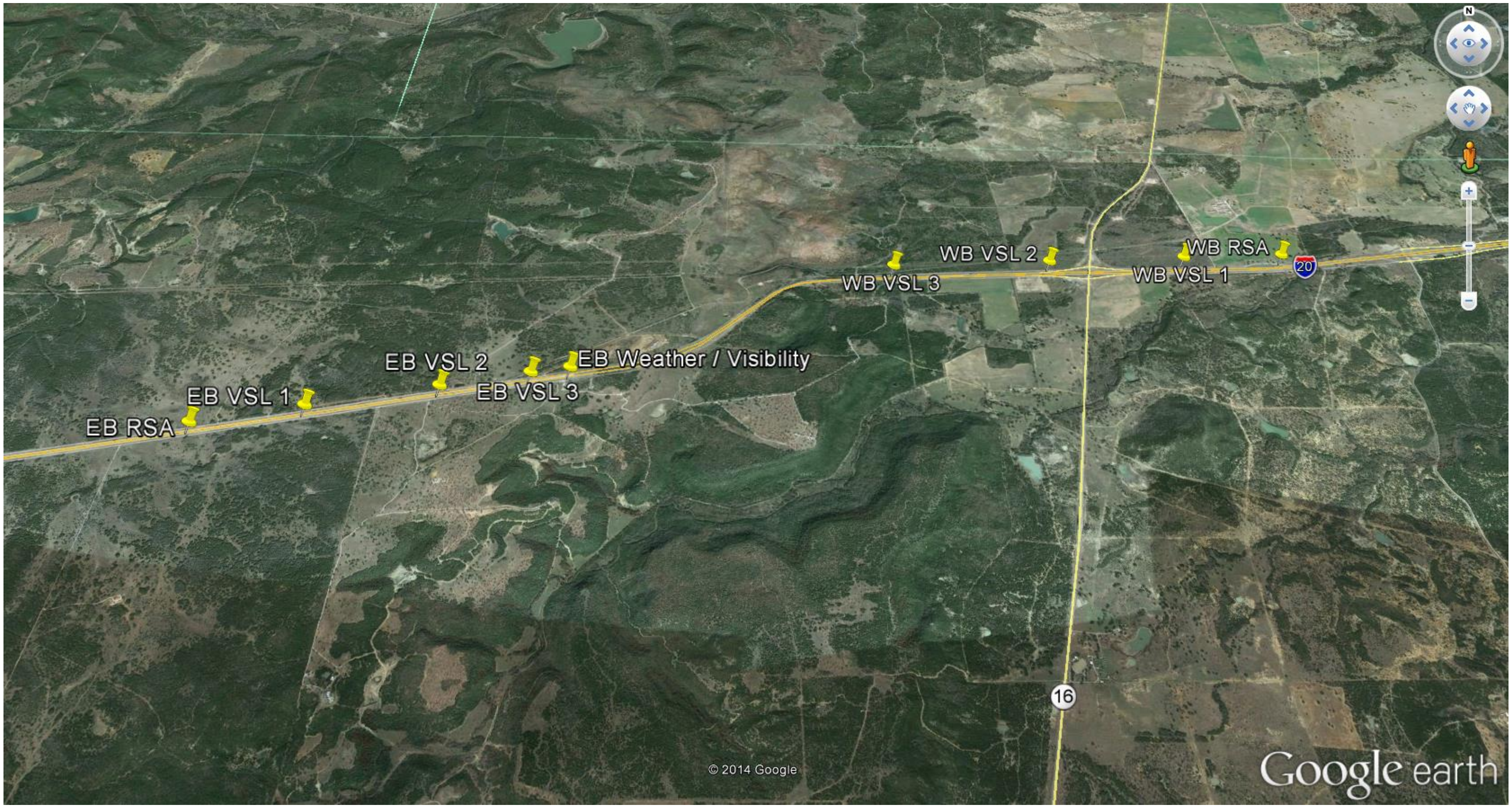


Figure 6. Sign Locations, EB and WB IH-20 VSL Site, Ranger Hill, Eastland County.

Evaluation

The following sections provide a summary of the operational analyses conducted as part of the VSL pilot studies.

VSL Activations

Table 5 shows the number of requests and the number of approved activations of the VSL system in each deployment location for each month of the evaluation period. By far, the San Antonio deployment experienced the greatest number of system activations, while the Ranger Hill, Eastland County deployment experienced the fewest activations during the evaluation period. As mentioned previously, the San Antonio system was targeted primarily to address congestion related to queuing, while the Ranger Hill, Eastland County system was targeted primarily to address weather events on Ranger Hill.

Table 5. Number of Recommended and Operator-Approved VSL Activations.

Month	San Antonio		Temple		Ranger Hill, Eastland County	
	Activations Requested by System	Activations Approved by Operator	Activations Requested by System	Activations Approved by Operator	Activations Requested by System	Activations Approved by Operator
July	82	74	84	44	-	-
August	165	133	81	44	6	5
September	218	136	42	33	19	11
October	115	127	43	31	20	0
November	242	145	165	52	105	73
December	179	130	-	-	30	23
TOTAL	**1069**	**745**	**490**	**220**	**180**	**112**

Table 6 shows the number of operator-approved activations by day of the week for each pilot deployment site. The table shows that the system activated more frequently on Fridays than any other day of the week, particularly at both the San Antonio and Temple pilot sites. A relatively high number of activations also occurred on the weekends at both the San Antonio and Temple deployment sites.

Table 6. Number of Approved VSL Activations by Day of Week.

Day of Week	San Antonio	Temple	Ranger Hill, Eastland County
Sunday	44	30	5
Monday	97	15	5
Tuesday	132	29	39
Wednesday	121	16	38
Thursday	109	28	4
Friday	152	80	10
Saturday	90	22	11
TOTAL	**745**	**220**	**112**

Table 7 shows the triggering events cited for activating the VSL at each of the deployment locations. At the Ranger Hill, Eastland County site, the majority of the VSL activations were caused by weather events, primarily reductions in pavement friction caused by rain events. In both the San Antonio and Temple deployments, the presence of congestion was cited as the primary reason for activating the VSL system, although both the San Antonio and Temple deployments experienced activations due to weather events as well. The combination of congestion and weather was cited as the triggering event once in both the Ranger Hill, Eastland County and Temple deployments.

Table 7. Reasons for Activating VSL at Each Deployment Location.

Reason for Activation	San Antonio	Temple	Ranger Hill, Eastland County
Congestion/Queuing	766	236	9
Weather	76	54	136
Combination	0	1	4
TOTAL	**842**	**291**	**149**

As shown in Table 5, not all requests for activations were approved by operators. The initial set of speed limits was not displayed on the variable message signs in the field until the request was approved by the operator. A common reason for not approving the plan was "conditions returned to normal before plan was accepted", which indicated that either the triggering conditions recovered before the operator approved activation of the VSL system. The reason "plan replaced by new plan" implies that the initial triggering conditions were superseded by a new activation request before the operator had a chance to approve the plan. In some cases, the new request was accepted and the VSL was eventually implemented. In other cases, the new request was not acted upon by the operator, and the VSL was not activated before conditions returned to normal. No requests for activations were rejected at any of the three deployment sites.

Congestion Analysis

The following sections provide a summary of the analyses conducted to assess the effectiveness of the VSL pilot projects at the three sites. Each section addresses the three metrics of average speeds, speed profiles, and vehicle throughput within the study locations.

San Antonio

The project team examined the impact of the VSL deployment on average speeds at each of the deployment locations. Speed data from 4:00 p.m. to 6:15 p.m. were used in the analysis, as this time period represented the period when the VSL was most active at this deployment. The analysis also only examined data from Tuesdays and Thursdays, as these days were deemed by the TTI team to best represent typical weekday traffic. Because of communication issues, data from August and early September were not used in this comparison from this deployment site.

Figure 7 and Figure 8 show the profile of average speeds collected at each of the VSL sign locations during the p.m. peak period (4:00 p.m. through 6:15 p.m.). Figure 7 shows the average speed measured at each VSL location for five Tuesdays (one without VSL active and four with VSL active), while Figure 8 shows the average speed at each VSL location for five Thursdays.

The figures show that at this particular deployment site in San Antonio, speeds had a tendency to decline, beginning at approximately 65 mph at VSL Location #1 and declining throughout the corridor to VSL Location #7. At this particular location, VSL Location #7 was located closest to the point where congestion formed in the corridor (i.e., closest to IH 10).

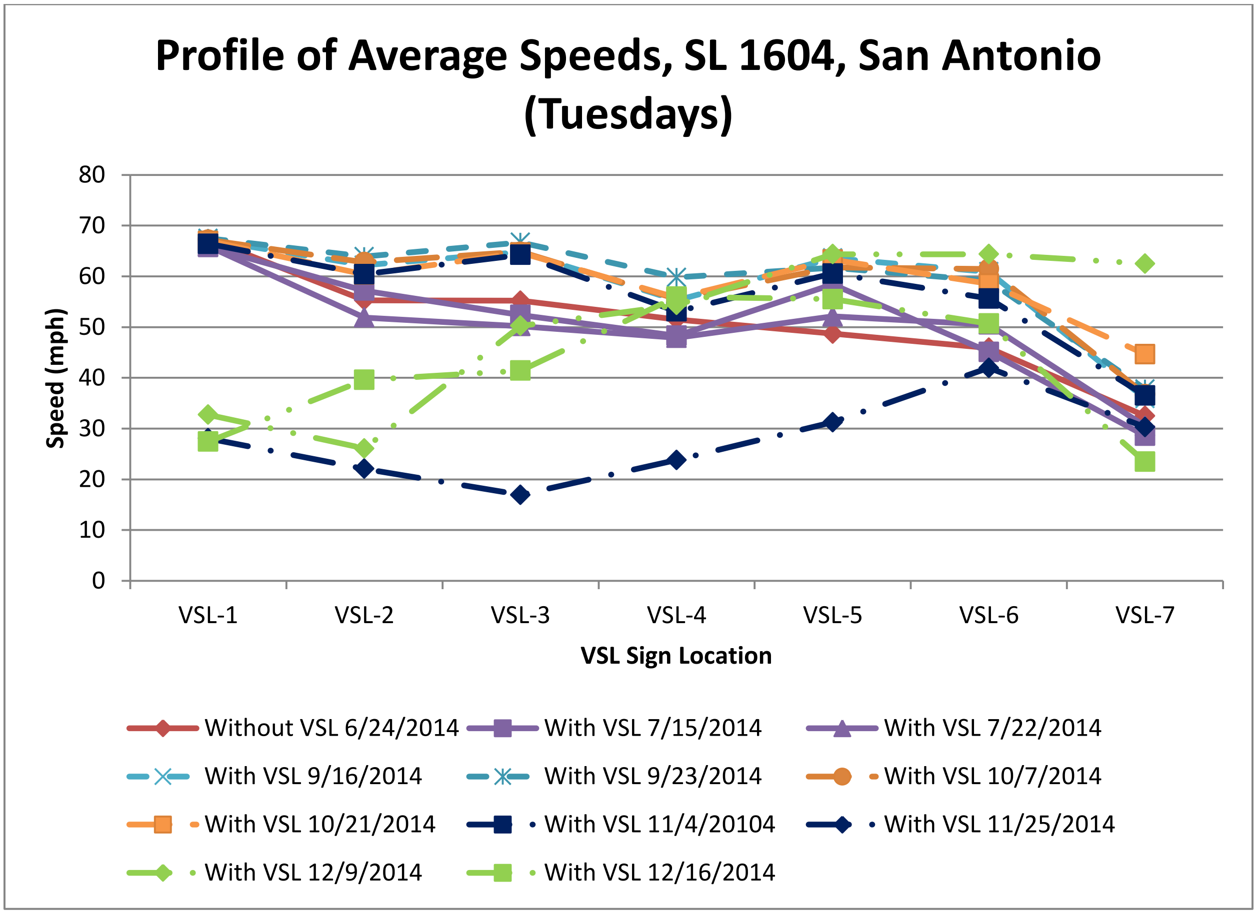


Figure 7. Comparison of Tuesday's Average Speeds (mph) at Each VSL Sign Location, San Antonio.

Based on a comparison of the with VSL and without VSL average speeds for each individual day, the figures show that on Tuesdays, average speeds from the locations with VSL in July were slightly less than the average speeds without VSL at VSL Locations #2 through #4 but were slightly higher at VSL Locations #5 and #6 leading up to the primary congestion point (VSL Location #7). For the days in September, the average speeds were higher across all sites with VSL leading up to the primary congestion point. A similar trend was observed from the comparison of average speeds on Thursdays—with the data from July showing a drop in average speeds and the data from September showing an increase in average speeds across all the VSL locations.

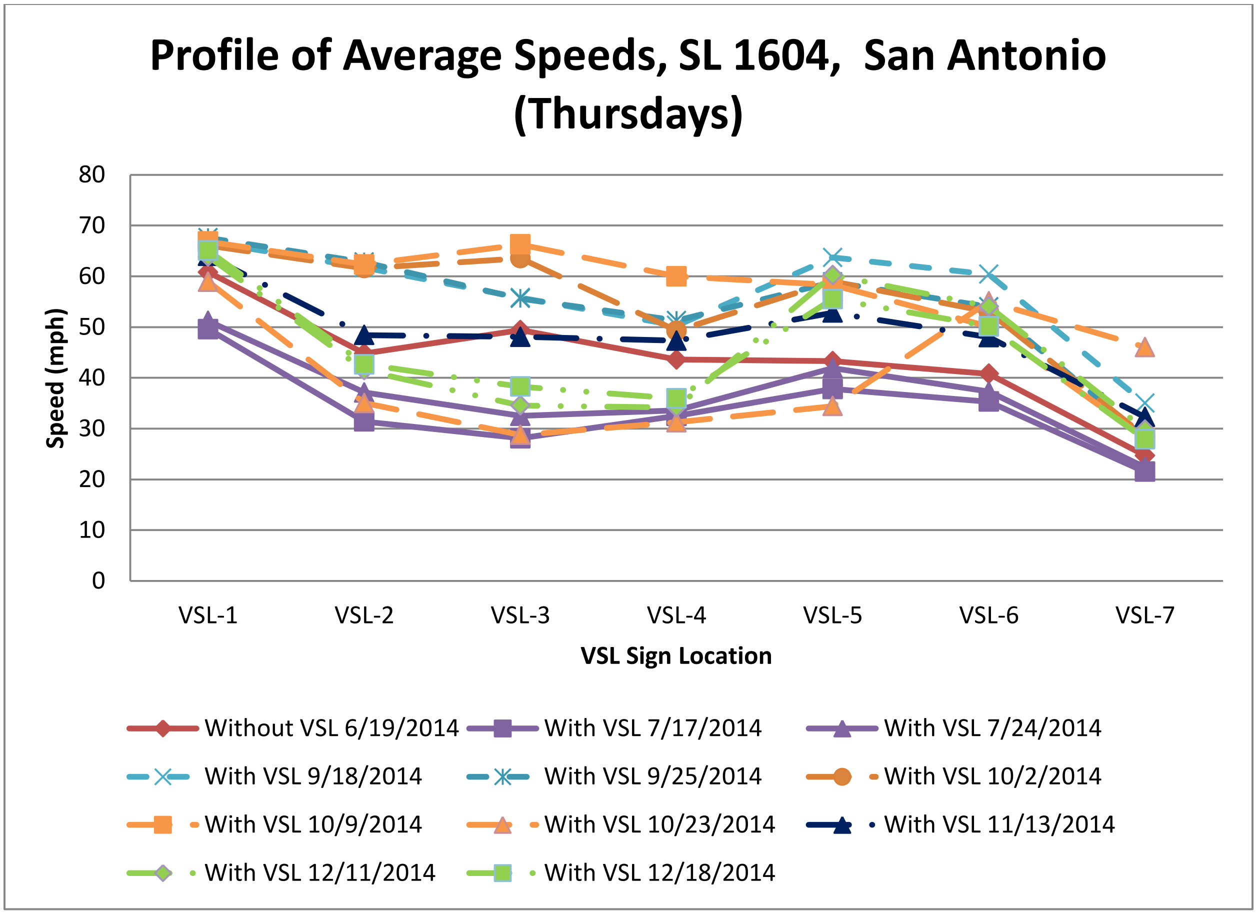


Figure 8. Comparison of Thursday's Average Speeds (mph) at Each VSL Sign Location, San Antonio.

Table 8 (Tuesdays) and Table 9 (Thursdays) provide a statistical comparison of the difference between the observed average speeds at each VSL sign location for each individual day. The statistical comparison involved using comparison of means techniques with unequal variance performed at a 95 percentile confidence level. The values shown in bold indicate statistically significant differences. Negative values indicate speeds with VSL being less than speeds without VSL. Positive values in the table indicate speeds being higher with VSL compared to speeds without VSL. The tables confirm that the results of the VSL system performance in the San Antonio corridor changed throughout the course of the study. Performance of the VSL in July generated statistically significant reductions in speeds, while performance of the VSL in September resulted in statistically significant increases in speeds.

Two potential reasons are hypothesized to explain the increase in September average speeds:

- The without VSL data were collected during the summer months when area-wide schools were not in session. September's speed data came from days after area-wide schools were back in session. The with VSL data from July exhibited similar characteristics to the without VSL data collected in June, which suggests that there was a fundamental difference in driver behavior in the corridor when school was back in session.

- Over the course of the evaluation period, the novelty effect of seeing speed limits posted on the VSL had worn off, and drivers were returning to their normal driving behavior when no signs were present in the corridor.

Table 8. Statistical Comparison of Difference in Average Speeds with and without VSL—Tuesdays, San Antonio.

Evaluation Date	Difference in Speeds with VSL Compared to Withou VSL (mph)						
	VSL-1	VSL-2	VSL-3	VSL-4	VSL-5	VSL-6	VSL-7
7/15/2014	**-1.5**	1.9	-2.8	-3.2	**9.7**	-0.8	-3.9
7/22/2014	**-1.4**	-3.4	**-5.0**	**-3.6**	3.4	**4.6**	-2.0
9/16/2014	-0.1	**6.9**	**9.6**	**3.8**	**14.9**	**15.0**	3.4
9/23/2014	0.2	**8.6**	**11.5**	**8.3**	**13.0**	**13.2**	**5.3**
10/7/2014	**6.4**	**18.0**	**15.4**	**12.0**	**18.5**	**20.7**	**12.0**
10/21/2014	**6.2**	**15.6**	**15.2**	**12.2**	**20.0**	**17.9**	**20.0**
11/4/20104	**5.6**	**15.6**	**14.8**	**9.6**	**17.2**	**14.8**	**11.4**
11/25/2014	**-32.9**	**-22.6**	**-32.5**	**-19.8**	**-12.1**	1.2	**5.6**
12/9/2014	**-28.2**	**-18.6**	1.2	**10.7**	**21.0**	**21.7**	**30.9**
12/16/2014	**-22.6**	**-17.4**	**-9.9**	-2.2	**12.5**	**9.9**	-1.2

Note: Values shown in bold are statistically significant at a 95 percent confidence level and imply a reduction in speeds compared to the without VSL condition. Positive values imply an increase in speeds compared to the without VSL condition.

Table 9. Statistical Comparison of Difference in Average Speeds with and without VSL—Thursdays, San Antonio.

Evaluation Date	Difference in Speeds with VSL Compared to Withou VSL (mph)						
	VSL-1	VSL-2	VSL-3	VSL-4	VSL-5	VSL-6	VSL-7
7/17/2014	**-11.2**	**-13.4**	**-21.3**	**-11.1**	**-5.5**	**-5.5**	**-3.2**
7/24/2014	**-9.6**	**-7.7**	**-16.9**	**-10.0**	-1.4	**-3.5**	**-2.3**
9/18/2014	**6.0**	**16.9**	**6.4**	**6.7**	**20.4**	**19.6**	**10.3**
9/25/2014	**6.8**	**18.0**	**6.2**	**7.7**	**15.6**	**13.2**	**3.5**
10/2/2014	**5.2**	**16.8**	**14.1**	**5.9**	**15.7**	**12.3**	**4.0**
10/9/2014	**6.0**	**17.5**	**16.8**	**16.4**	**15.0**	**9.3**	**3.5**
10/23/2014	**6.2**	**15.5**	**15.2**	**12.2**	**20.0**	**17.8**	**20.0**
11/13/2014	**3.2**	**3.1**	-1.3	**3.7**	**9.5**	**7.2**	**7.5**
12/11/2014	**3.3**	**-4.5**	**-16.7**	**-10.6**	**11.9**	**7.9**	**4.1**
12/18/2014	**4.3**	-2.2	**-11.2**	**-7.7**	**10.0**	**9.4**	**3.6**

Note: Values shown in bold are statistically significant at a 95 percent confidence level. Negative values imply a reduction in speeds compared to the without VSL condition. Positive values imply an increase in speeds compared to the without VSL condition.

Figure 10 show the relative differences between the measured average travel speeds and the posted speed limits. This differential was computed by subtracting the posted speed limit from the average measured speed limit. A positive value indicated that the actual average travel speeds were higher than the posted speed limit, while a negative value indicated that average travel speeds were lower than the posted speed limit. Again, separate analyses were performed for Tuesdays and Thursdays with and without VSL.

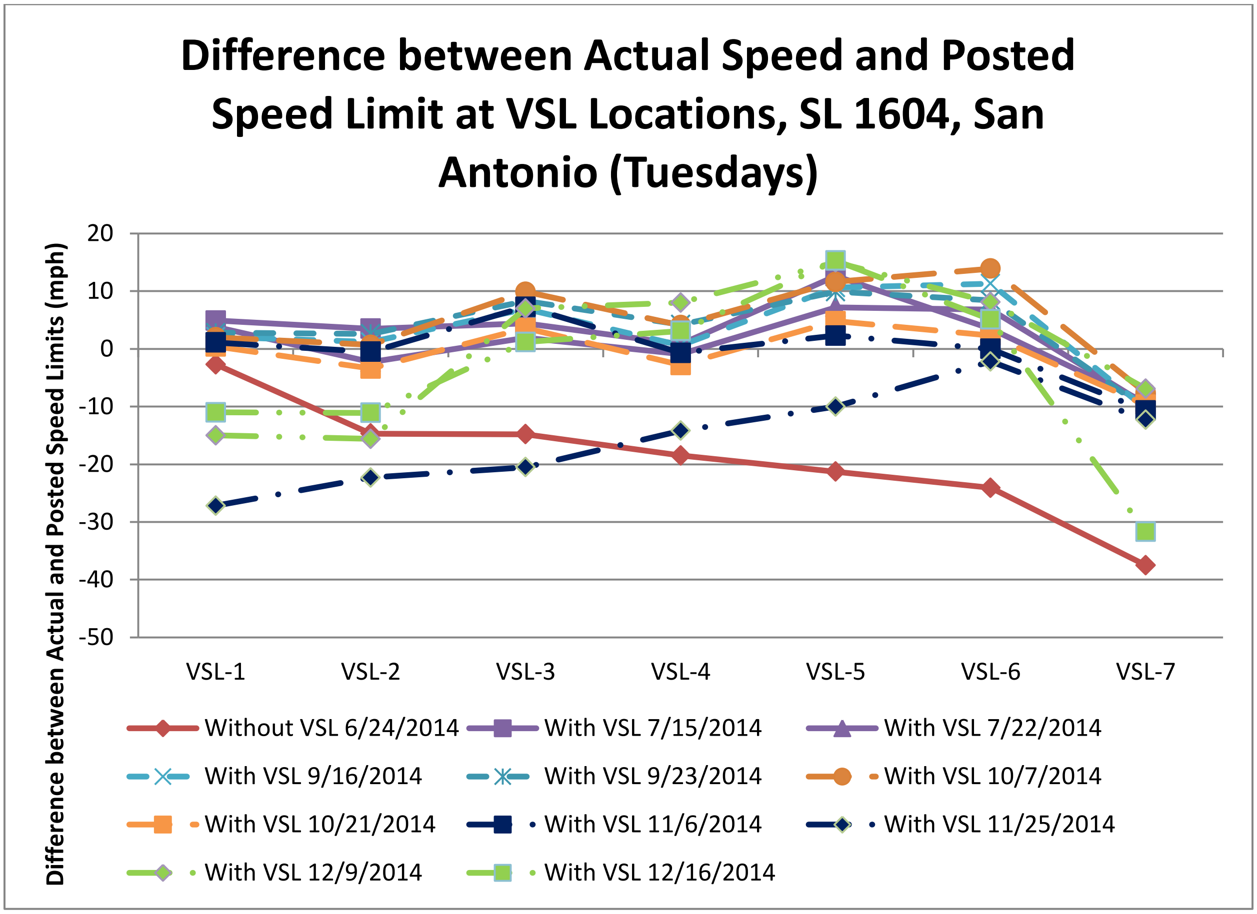


Figure 9. Difference between Actual and Posted Speeds with and without VSL Active—Tuesdays, San Antonio.

These figures show that at all VSL locations, measured average travel speeds were within ±10 mph of the posted speed limit. This suggests that the process of stepping down speed limits in advance of the congestion points does not create substantial speed differentials between posted and actual speeds. On the contrary, not reducing speeds in advance of congestion locations can create much greater differentials between posted and actual travel speeds.

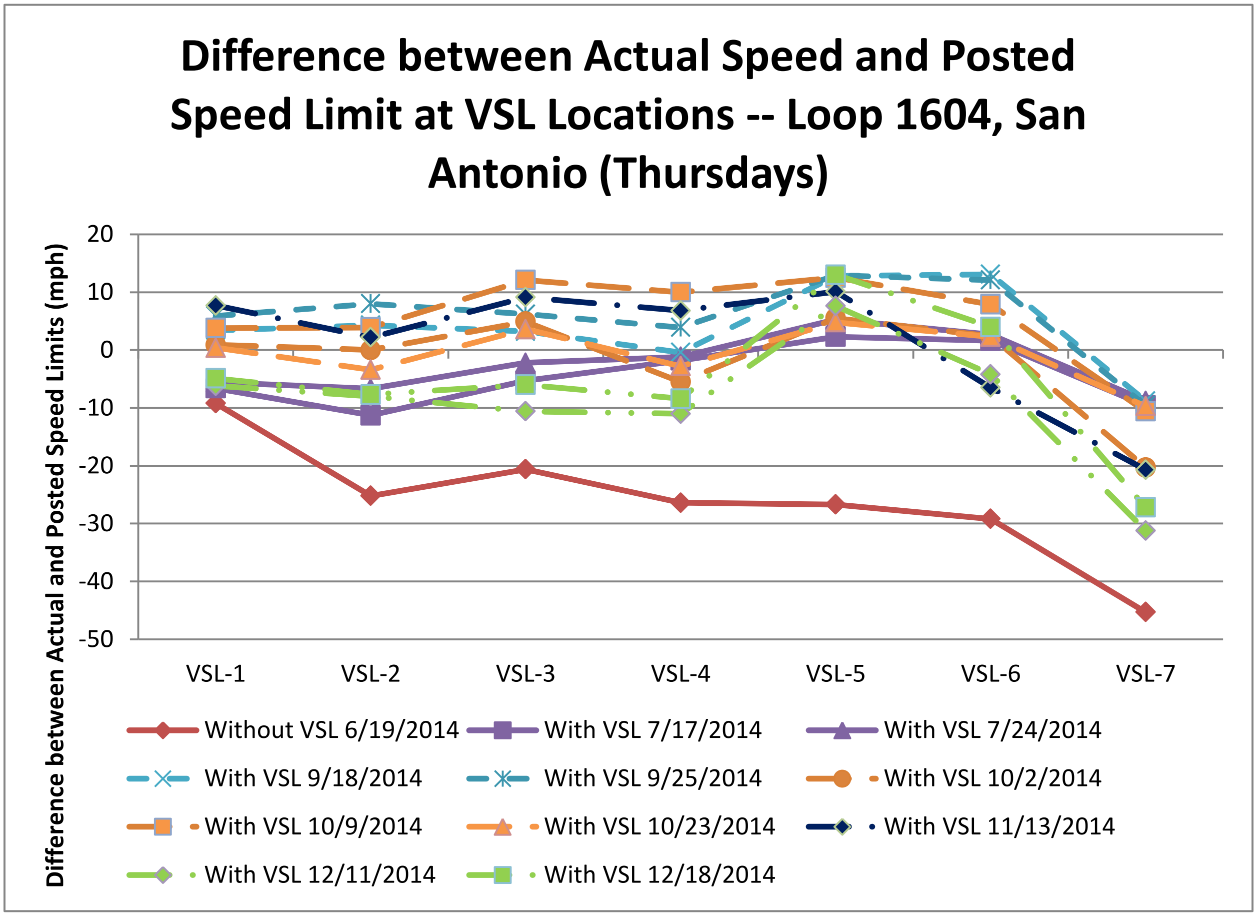


Figure 10. Difference between Actual and Posted Speeds with and without VSL Active—Thursdays, San Antonio.

Table 10 shows a comparison of the average per lane flow rate with and without VSL active at the San Antonio deployment. The table shows that average per lane flow rate remained relatively constant between with VSL was active compared to when VSL was not active. The table suggests that implementing VSL did not have a negative impact on vehicle throughput at this site at this site. Per lane vehicle flow rate were statistically equal with and without VSL.

Table 10. Comparison of Average per Lane Flow Rate with and without VSL Active – San Antonio.

Day	Date	Date	Difference in Speeds with VSL Compared to Withou VSL (mph)						
		Date	VSL-1	VSL-2	VSL-3	VSL-4	VSL-5	VSL-6	VSL-7
Tuesday	w/o VLS	6/24	1147	1407	1408	1733	1816	1800	1418
	w/ VLS	7/15	**715**	**857**	**850**	**1044**	**1081**	**1066**	**770**
		7/22	**745**	**854**	**882**	**1057**	**1033**	**1055**	**782**
		9/16	1111	**1347**	**1343**	1678	**1700**	1730	1257
		9/23	1119	1362	**1341**	1683	**1731**	**1706**	**1282**
		10/7	1108	**1341**	1374	1718	1769	1747	**1304**
		10/21	1114	**1339**	**1339**	1683	1749	**1729**	**1319**
		11/4	1101	1402	1380	1730	1706	1657	1225
		11/25	**978**	**1058**	**954**	**1485**	**1412**	**1401**	**1053**
		12/9	**1026**	**1104**	**1160**	**1636**	**1697**	**1655**	1354
		12/16	**1011**	**1045**	**1125**	**1507**	**1511**	**1466**	**994**
Thursday	w/o VLS	6/19	1203	1358	1361	1737	1746	1709	1252
	w/ VLS	7/17	**720**	**777**	**810**	**1021**	**977**	**973**	**691**
		7/24	**737**	**818**	**803**	**985**	**961**	**986**	**703**
		9/18	1169	1405	1392	1737	1791	**1789**	1292
		9/25	1184	1416	1406	1767	**1817**	**1785**	1244
		10/2	1171	1413	1386	1718	1759	1754	1270
		10/9	**1128**	1380	1411	1756	1773	1746	1228
		10/23	**1200**	**1284**	**1286**	**1669**	**1653**	**1633**	**1277**
		11/13	1210	1390	1344	1704	1735	1682	1246
		12/11	**1099**	**1214**	1374	1787	1636	1326	1311
		12/18	**1063**	**1165**	**1186**	1721	1708	1753	1242

Note: Values shown in bold are statistically significant at a 95 percent confidence level.

Temple

For the IH 35 deployment in Temple, the VSL system was most active on Friday. Traffic conditions on IH 35 caused the system to activate almost every Friday afternoon during the evaluation period. The project team used the time periods shown in Table 11 for evaluating the Temple VSL deployment.

Table 11. VSL Activations Used in Evaluating Temple VSL Deployments.

Evaluation Condition	Date of Activation	Start Time of Activation	End Time of Activation
Without VSL Active	6/20/2014	2:34 p.m.	5:20 p.m.
With VSL Active	7/11/2014	2:00 p.m.	5:44 p.m.
	7/25/2014	1:17 p.m.	6:31 p.m.
	8/8/2014	1:20 p.m.	5:59 p.m.
	8/15/2014	2:00 p.m.	6:17 p.m.
	8/22/2014	2:00 p.m.	6:46 p.m.
	9/12/2014	3:43 p.m.	6:17 p.m.
	9/19/2014	3:50 p.m.	6:07 p.m.
	9/26/2014	3:23 p.m.	6:49 p.m.
	10/3/2014	3:56 p.m.	7:21 p.m.
	10/10/2014	3:56 p.m.	6:23 p.m.
	10/17/2014	2:58 p.m.	9:47 p.m.
	10/24/2014	2:50 p.m.	5:42 p.m.

Figure 11 shows the average speed at each of the VSL signs and the RSA sign averaged over the duration when the sign was active. The figure shows that average speed at each of the sign locations had a tendency to be higher immediately following the deployment when compared to speeds late in the deployment. The figure also shows that average speed at each of the sign locations had a tendency to be higher in July and then declined in both August and September.

Table 12 shows a statistical comparison of the average speeds measured at each sign location in the VSL deployment. The values shown in bold in the table represent speeds that were judged to be statistically significant with the VSL active compared to the speeds measured at the same location without the VSL active. These statistical comparisons were performed using a standard t-test with unequal variance. A 95 percent confidence interval was used in the statistical comparisons. As shown, average speeds at each sign location were statistically higher during the two days evaluated in July at this location, while average speeds were statistically lower at all the stations in the last two days in September. For those activations studied in August, average speed where similar to the before conditions at each of the study locations.

Table 13 and Figure 12 show a comparison of the average difference between the speed limit and the measured travel speeds at each of the sign locations (including the RSA sign). As expected, the speed differential is greatest and continues to worsen as travelers traverse through the congestion when no VSL is active. With the exception of the activations on 9/19 and 9/26, actual travel speeds and posted speeds are within 10 mph at each of the sign locations when VSL is active. On 9/19 and 9/26, the difference between posted and measured speeds is greatest further upstream of the congestion point. This suggests that traffic is spilling back past the beginning of the VSL signs.

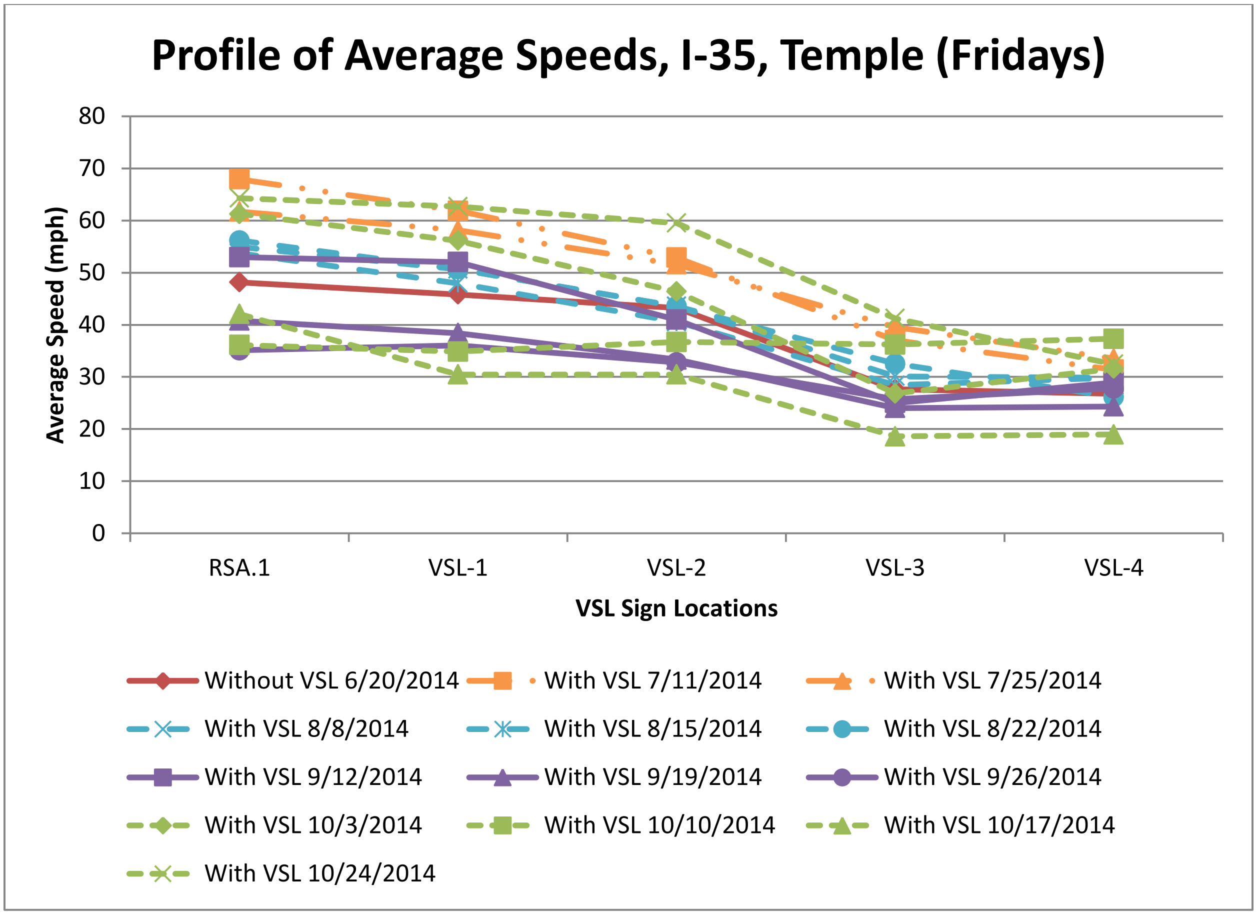


Figure 11. Profile of Average Speeds, Fridays, Temple.

Table 12. Statistical Comparison of Average Speeds With and Without VSL Active, Temple.

VSL Status	Average Measured Speed (mph) at Each Sign Location					
	Date	RSA-1	VSL-1	VSL-2	VSL-3	VSL-4
Without VSL	6/20	48.1	45.8	43.2	27.7	26.8
With VSL-	7/11	**67.9**	**61.9**	**52.9**	**37.0**	**31.4**
	7/25	**61.7**	**58.1**	**51.6**	**39.6**	**33.5**
	8/8	**54.9**	**50.7**	43.6	**30.1**	**29.9**
	8/15	**53.7**	**48.0**	40.6	28.4	**29.9**
	8/22	**56.2**	**50.7**	43.5	**32.5**	26.2
	9/12	**53.0**	**52.0**	41.0	**25.0**	**28.9**
	9/19	**40.8**	**38.4**	**33.3**	**24.0**	**24.3**
	9/26	**35.1**	**36.0**	**32.8**	**25.8**	**27.8**
	10/3	**61.3**	**56.1**	**46.4**	26.8	**31.6**
	10/10	**36.1**	**34.9**	**36.7**	**36.2**	**37.3**
	10/17	**42.1**	**30.5**	**30.5**	**18.6**	**19.0**
	10/24	**64.3**	**62.7**	**59.5**	**41.2**	**32.4**

Note: values shown in bold red are statistically significant at a 95 percent confidence interval. These values are compared to the average speed without VSL active observed on 6/20.

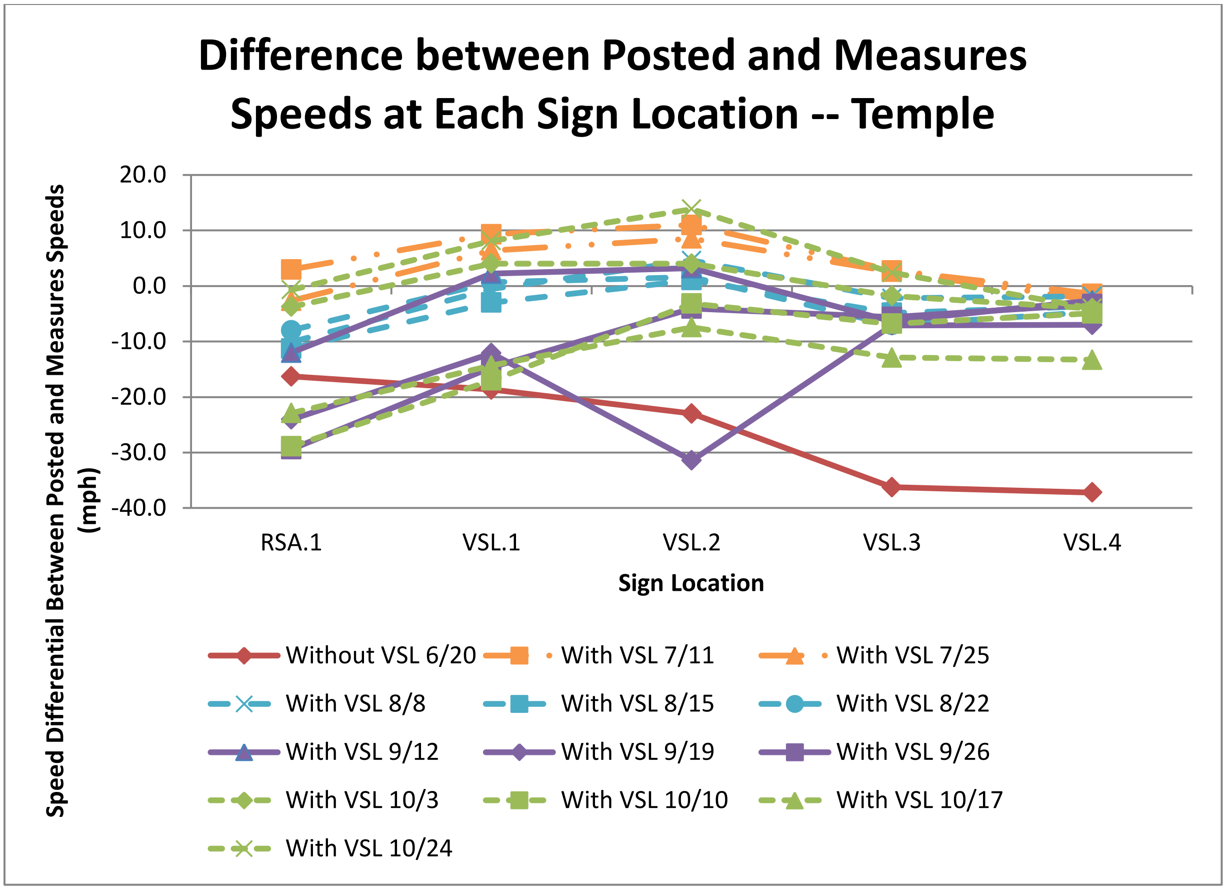


Figure 12. Difference between Posted and Measured Speeds, Temple.

Table 13. Statistical Analysis of Speed Differential, Temple.

VSL Status	Average Differential between Measured and PostedSpeed (mph) at Each Sign Location					
	Date	**RSA-1**	**VSL-1**	**VSL-2**	**VSL-3**	**VSL-4**
Without VSL	6/20	-16.3	-18.6	-23.0	-36.2	-37.2
With VSL-	7/11	**3.0**	**9.3**	**11.0**	**2.8**	**-1.4**
	7/25	**-2.7**	**6.4**	**8.5**	**2.6**	**-2.5**
	8/8	**-10.1**	**-0.6**	**4.6**	**-2.2**	**-1.8**
	8/15	**-11.3**	**-3.0**	**1.0**	**-4.8**	**-3.7**
	8/22	**-8.0**	**0.7**	**1.6**	**-7.1**	**-4.7**
	9/12	**-12.0**	**2.2**	**3.2**	**-6.4**	**-2.6**
	9/19	**-24.0**	**-12.1**	**-31.4***	**-7.1**	**-7.0**
	9/26	**-29.4**	**-14.7**	**-4.1**	**-5.6**	**-3.3**
	10/3	**-3.7**	**4.0**	**4.0**	**-1.8**	**-4.0**
	10/10	**-28.9**	**-17.0**	**-3.2**	**-6.8**	**-4.9**
	10/17	**-22.9**	**-14.3**	**-7.4**	**-12.9**	**-13.3**
	10/24	**-0.7**	**8.1**	**13.8**	**2.4**	**-4.0**

Note: values shown in bold are statistically significant at a 95 percent confidence interval. These values are compared to the average speed without VSL active observed on 6/20. Negative values imply that measured speed were lower than posted speed limits, while positive values imply that measured speeds were higher than posted speed limits.

* Error in communicating with sign. Sign posted at 65 mph during activation.

Table 14 shows the average per lane flow rate at each sign location for the Temple deployment. The data show that beginning with the activations in August, the average per lane flow rate has increased over that generated before the VSL was active. These increases in average per lane flow rate were determined to be statistically significant at a 95 percentile confidence level. The increase in flow rate may be a result of increased efficiencies generated by the VSL deployment or signify an increase in traffic demands toward the end of summer.

Table 14. Average Per Lane Flow Rate at Each Sign Location, Temple.

VSL Status	Average Per Lane Flow Rate (VPHPL) at Each Sign Location					
	Date	**RSA-1**	**VSL-1**	**VSL-2**	**VSL-3**	**VSL-4**
Without VSL	6/20	716.6	732.8	643.7	634.5	763.3
With VSL-	7/11	719.8	712.3	611.7	612.3	732.3
	7/25	723.5	725.3	628.3	642.2	726.2
	8/8	**1168.5**	**1153.6**	**988.0**	**1012.7**	**1191.0**
	8/15	**1167.6**	**1160.9**	**999.7**	**1067.8**	**1188.7**
	8/22	**1102.6**	**1093.2**	**924.7**	**958.2**	**1057.5**
	9/12	**1145.5**	**1112.9**	**1013.9**	**1015.5**	**1206.8**
	9/19	**1106.4**	**1101.2**	**922.3**	**968.3**	**1055.3**
	9/26	**1098.3**	**1067.4**	**955.5**	**972.8**	**1150.6**
	10/3	**1227.6**	**1211.6**	**1029.6**	**1055.4**	**846.0**
	10/10	**1091.9**	**1133.2**	**984.1**	**976.4**	**821.7**
	10/17	**1018.3**	**1012.6**	**792.9**	**810.1**	**593.1**
	10/24	**1234.5**	**1243.9**	**1106.3**	**1123.7**	**846.4**

Note: values shown in bold are statistically significant at a 95 percent confidence interval. These values are compared to the average speed without VSL active observed on 6/20.

Ranger Hill, Eastland County

The project team reviewed the data from the Ranger Hill, Eastland County site to determine the best approach to analyze the operational performance of the VSL. Once the VSL system in Ranger Hill, Eastland County was operational, reduced speed limits were actually posted on signs in the field on only four days though were more potential activations. Three days that saw activations were for weather events (8/29; 9/12; 9/17), and one was a congestion event (8/7). For the weather events, the VSL had very little impact with the VSL posted speed of 55 mph. Average travel speeds were between 60 and 65 mph. For the congestion event, the data suggests that an incident occurred where the freeway may have actually been blocked. For this event, the posted speeds were initially close to measured speeds. Once the freeway stopped moving altogether, the system registered that no cars were passing in front of the sensor and displayed 65 mph when in fact, no vehicles were moving. The system did not recover until vehicles started moving again. No routine congestion forms along the facility, offering no true baseline data for comparison. Furthermore, the weather events that did occur were fairly minor. More significant weather events may yield more telling results.

Safety Analysis

TxDOT's Crash Records Information System (CRIS) was used to analyze the safety of the study sites. The specific crash data assessed, based on the project's scope of work, is shown in Table

15. Approximately six months within the three years of Before data (2011, 2012, and 2013) and one year of After data (2014) for start and end dates (shown in Table 1) were used in the analysis.

Table 15. Safety Analysis Approach.

Hypothesis/Question	Measures of Effectiveness	Data
The deployment of VSL will improve safety within the study site.	• Change in the number of crashes within the VSL site. • Change in the number of crashes during peak/congested periods in the VSL site. • Change in the distribution of severity of all crashes. • Change in the distribution of severity of crashes during peak/congested periods.	• Total number of all crashes. • Total number of crashes during VSL activation. • Severity of all crashes. • Severity of all crashes during VSL activation.

Note: The project team used data during the same period in previous years. The limited timeframe of the evaluation limited the statistical significance of the safety data.

Because the intent of the VSL project was to slow down traffic as drivers approached the end of a queue, the limits for each study site generally started at the first RSA sign to 1 mi downstream of the last VSL sign. However, the IH-20 sections were extended to the RSA signs in the opposite direction. This extension ensured that crashes related to the horizontal and vertical curves were included in the analysis.

The safety analysis showed that all test sites saw a decrease in the number of crashes and in the crash rate, as presented in Figure 13. In general, crashes decreased except on SL 1604 in San Antonio. Combined, there were 243 Before crashes and 56 After crashes.

The crash severity and crashes by time-of-day are illustrated in Figure 14 and Figure 15, respectively. In general, crash severity decreased after VSL activation with the largest decrease in fatal and in incapacitating crashes followed by non-incapacitating crashes. Likewise, the largest decrease in crashes occurred in AM peak followed by midday crashes.

The Before and After crashes by 'adverse' surface conditions are illustrated in Figure 16. In general, the number of crashes with 'adverse' surface conditions (e.g. wet, ice, snow, muddy, etc.) decreased after VSL activation.

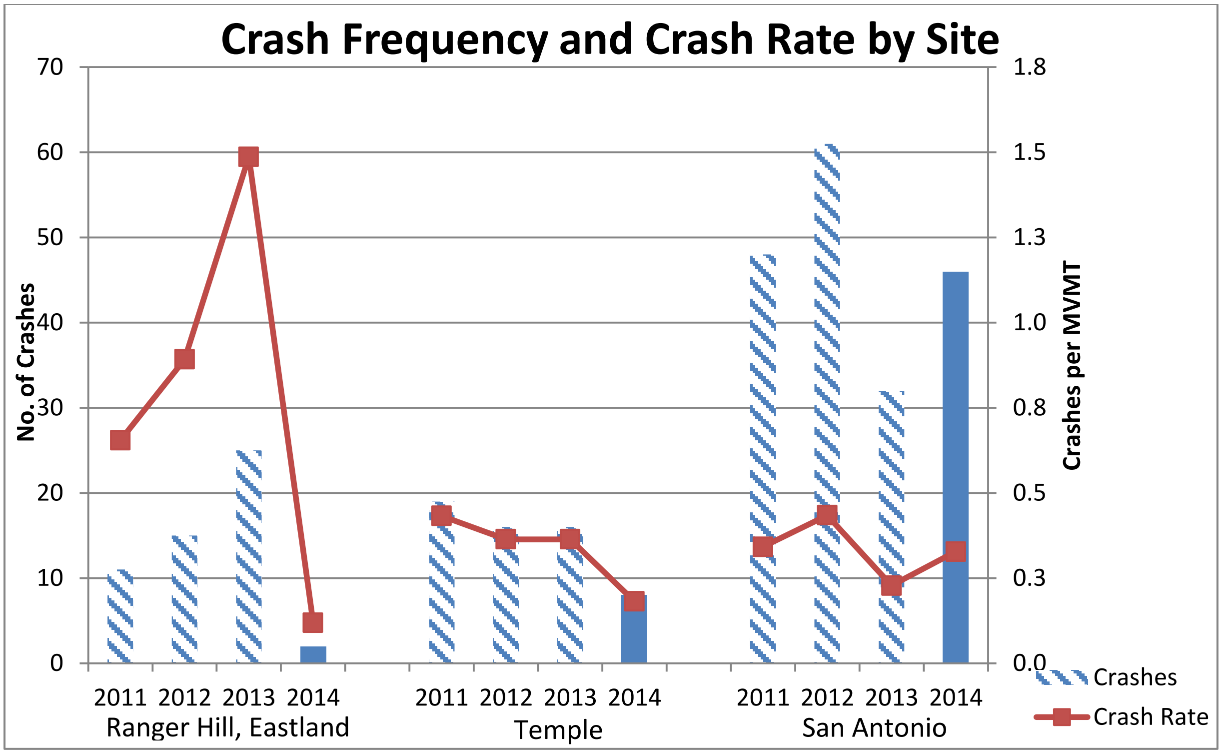


Figure 13. Crashes and Crash Rates for VSL Sites, Before and After Activation.

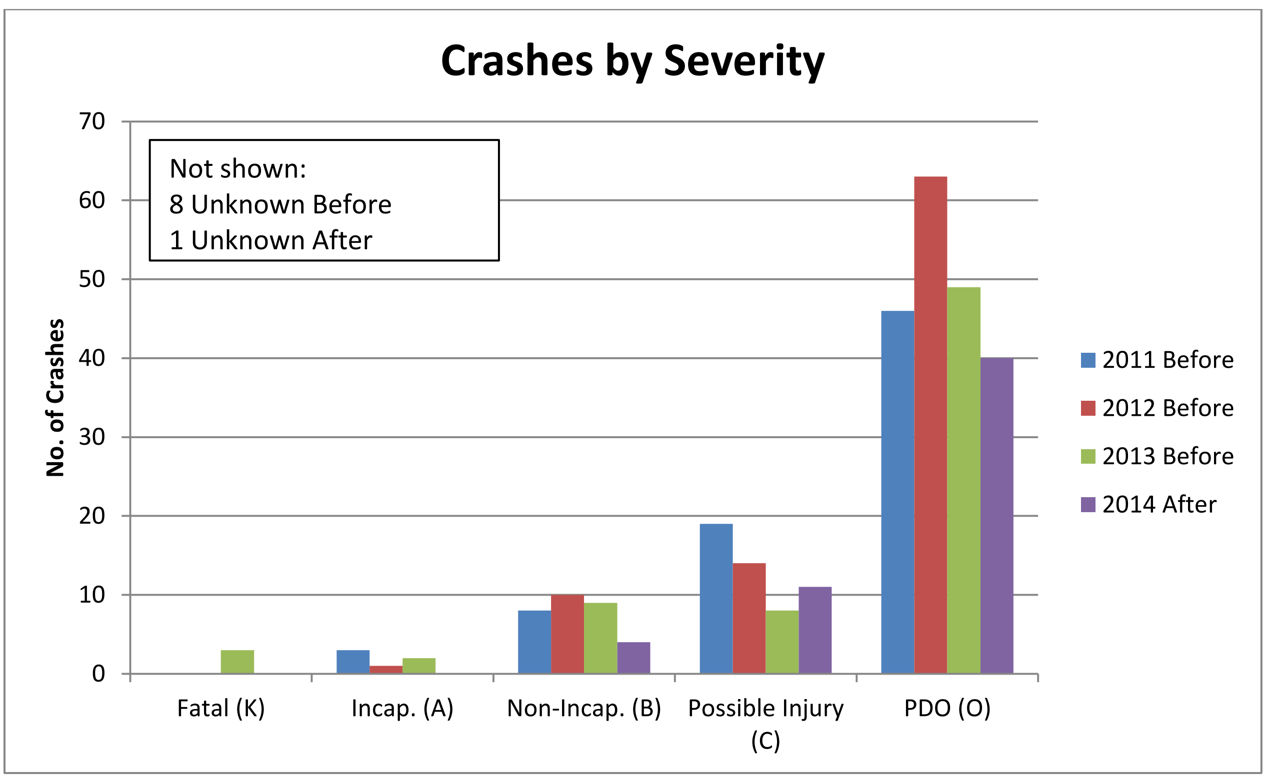


Figure 14. Crash Severity for VSL Sites, Before and After Activation.

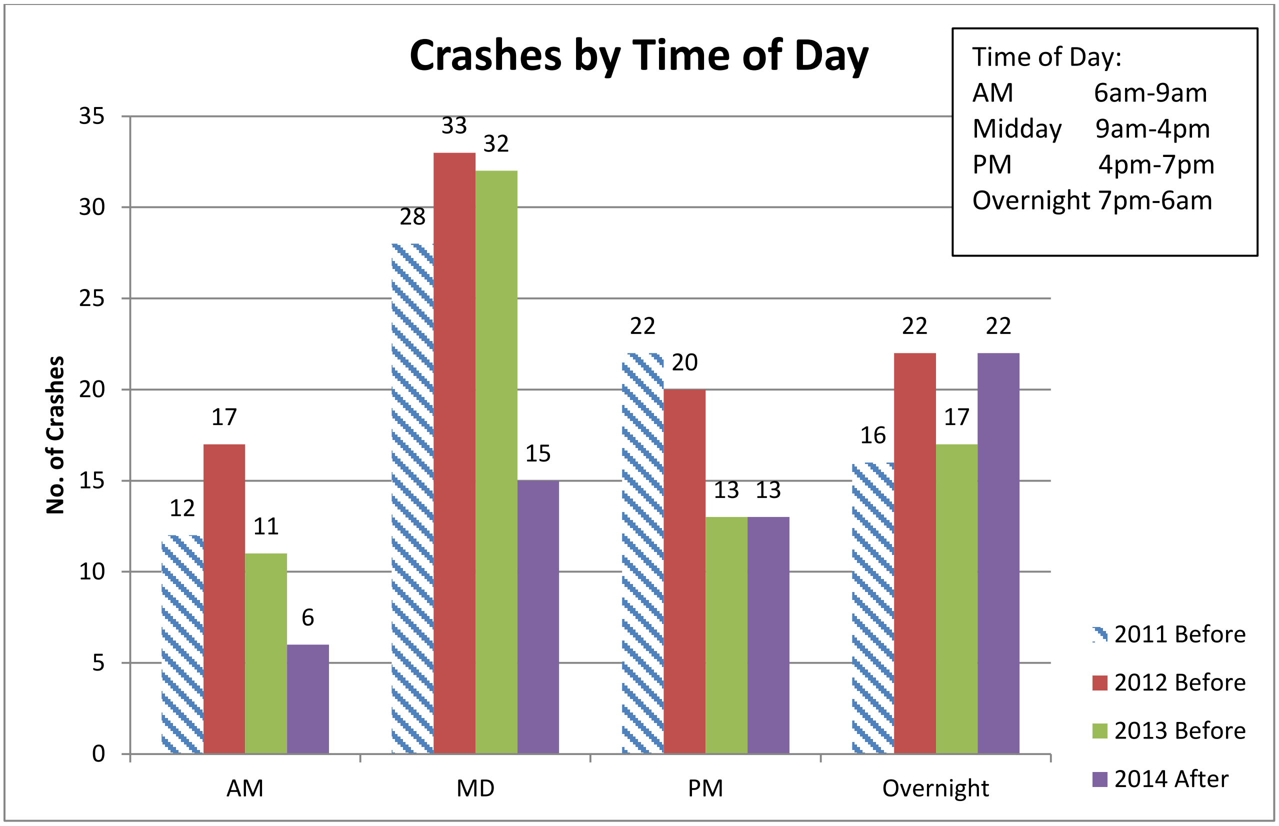


Figure 15. Crashes by Time of Day for VSL Sites, Before and After Activation.

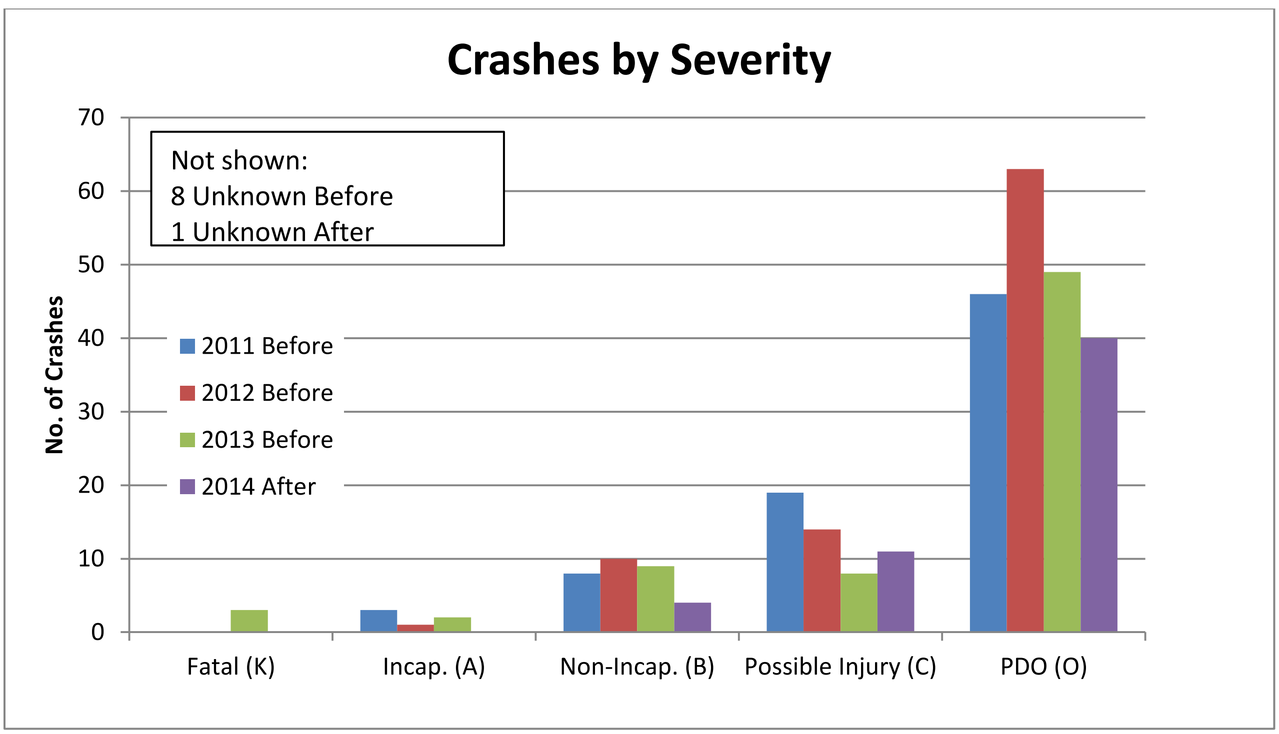


Figure 16. Crashes by Adverse Surface Conditions for VSL Sites, Before and After Activation.

No statistical significance test was completed given the short duration of the analysis period. Robust safety analyses involve multiple years of before and after data, and this analysis period was only a few months. Researchers recommend that future assessments utilize at least three years of after data for each site.

Users' Perception

Users' perceptions of the VSL project were a key factor in overall success. To assess user understanding of the VSL sign systems, the project team conducted 300 surveys during the VSL deployment period in San Antonio and Ranger Hill, Eastland County.

In the San Antonio District, 200 surveys were conducted during the month of August at the Leon Valley Driver License Office located at 7410 Huebner Road, approximately 7 mi from the VSL deployment site. This site was the closest public venue for which the project team was able to obtain consent to conduct the surveys. At the Ranger Hill, Eastland County site, 100 surveys were conducted at the Red Star Truck Terminal in Eastland, which was located on rural IH-20 approximately 17 mi west of the VSL deployment site. Consent to conduct surveys closer to the VSL deployment site could not be obtained. The same survey questions were used at each location. No surveys were conducted in Temple because consent to conduct them within a reasonable distance from the VSL deployment site was unattainable.

The survey consisted of two sets of questions aimed at assessing the respondents' awareness and understanding of the VSL system, along with their opinions of the signs themselves. The first group of questions included:

- When was the last time you traveled through [the study area]?
- How often do you travel through that area?
- Can you describe the speed limit signs that you saw while driving through that area? If so, what did you notice about them?
- What do you think the signs were telling you?
- How many signs did you see?
- Was the speed limit the same on all of those signs?

The results of the awareness questions were recorded, tabulated, and analyzed. In San Antonio, between 40 and 45 percent of the survey respondents had exposure to the signs on a regular basis. Similar results were seen at the Ranger Hill, Eastland County site, with about 40 to 45 percent of the survey respondents having recent exposure to the signs. However, they did not have the same frequency of exposure to the VSL signs on a regular basis.

When asked if they could describe the speed limit signs, 79 of the 200 respondents (about 40 percent) in San Antonio said they could and proceeded to explain the speed limit sign attributes that they recalled. The descriptions included terms such as *digital*, *electronic*, *adjustable*, or *changeable*. About 90 percent of these affirmative responses came from the more frequent travelers in the corridor (i.e., traveled within the last week or claimed to make routine trips in the corridor). There were 121 respondents (about 60 percent) who were not able to describe the speed limit signs.

At the Ranger Hill, Eastland County site, 42 of the 100 respondents (42 percent) said they could describe the speed limit signs, with descriptions including terms such as *digital*, *LED*, *electronic*, *lighted*, *flashing*, or *changeable*. There were 58 respondents (58 percent) who were not able to describe the speed limit signs because they said they did not remember or were not paying attention.

The subsequent question asked what the sign was telling the respondent. In the San Antonio District, all 79 respondents who described the signs said that the signs revealed the posted speed limit. Twenty-four percent volunteered additional information, indicating that the speed limit was for a certain traffic condition, while another 16 percent added that it was for a certain time period. Several of these respondents mentioned that they had seen or heard something on the local news about the purpose of the signs. Over one-half (54 percent) did not indicate that they knew the reason that the posted speed limit would change, but this question was not directly asked at this point. Four percent thought that the speed limit was for a work zone, although no work zone was present, but it is likely that the safety drums surrounding the VSL trailers might have influenced these responses. One respondent, who was an infrequent traveler in the corridor, thought that the signs were not working.

When asked how many signs each respondent saw, answers varied from one, two, three, or four or more. This is likely due to the fact that many respondents may have entered and exited the corridor within the VSL area and not seen all of the signs.

At the Ranger Hill, Eastland County site, 41 of the 42 respondents who described the signs said that the signs showed the posted speed limit. Three of these 41 thought that the speed limit was related to the work zone that was located within the VSL system (where new rest area ramps were under construction). One person thought the signs were displaying his/her speed (like a "My Speed" sign). The 42 respondents who recalled the signs were also asked if the posted speed limit was the same on all of the signs. Sixty percent said yes and recalled that the posted speed was 65 mph on all of the signs. Thirty-eight percent said no and recalled seeing speeds of 65, 55, and 25 mph on the signs. These results were not surprising given the infrequency with which the Ranger Hill, Eastland County VSL system deployed due to weather or crashes. The remaining 2 percent were not sure if all the signs were the same.

The second group of questions was related to assessing driver understanding of the VSL signs. The questions were aimed at getting more information from those respondents who did not initially recall the speed limit signs. These questions were the following:

- Is this the sign that you saw?
- Do you think the speed limit shown on the sign changes?
- When do you think there would be a need to change the speed limit?
- Do you think you could get a speeding ticket for going over the speed limits shown on the signs?

The project team showed all respondents a photo of an actual VSL sign taken at the deployment site. When asked if it was the sign that they recalled, 88 (73 percent) of the 121 respondents in San Antonio who initially did not recall the signs then responded affirmatively. The remaining 33 respondents still did not recall the signs but continued to answer the survey questions based on the photo image of the VSL sign. At the Ranger Hill, Eastland County site, 80 percent of respondents said yes. The remaining 20 respondents still did not recall the signs but continued to answer the survey questions based on the photo image of the VSL sign.

At this point in the survey, 191 out of 200 San Antonio District respondents understood that the sign was telling them that the speed limit was 70 mph. Nine respondents, all of whom had not seen the sign until shown the photo, thought that the sign was telling them their speed (like a "My Speed" sign). At the Ranger Hill, Eastland County site, 97 out of 100 respondents understood that the sign was telling them that the speed limit was 65 mph. Of this group, five indicated that the posted speed was due to a nearby work zone. Three respondents thought that the sign was telling them their speed (like a "My Speed" sign).

The San Antonio respondents were asked when they thought there would be a need to change the speed limit. Many of the respondents gave more than one answer. The most common answer was congestion or peak-hour traffic, followed by accident, work zone or construction, weather, and nighttime conditions. These results are shown in Figure 17.

When asked if they thought they could get a speeding ticket for exceeding the posted speed, 198 of the 200 respondents said yes. The two dissenters thought that the sign was not legal because it was lighted or represented a suggested speed.

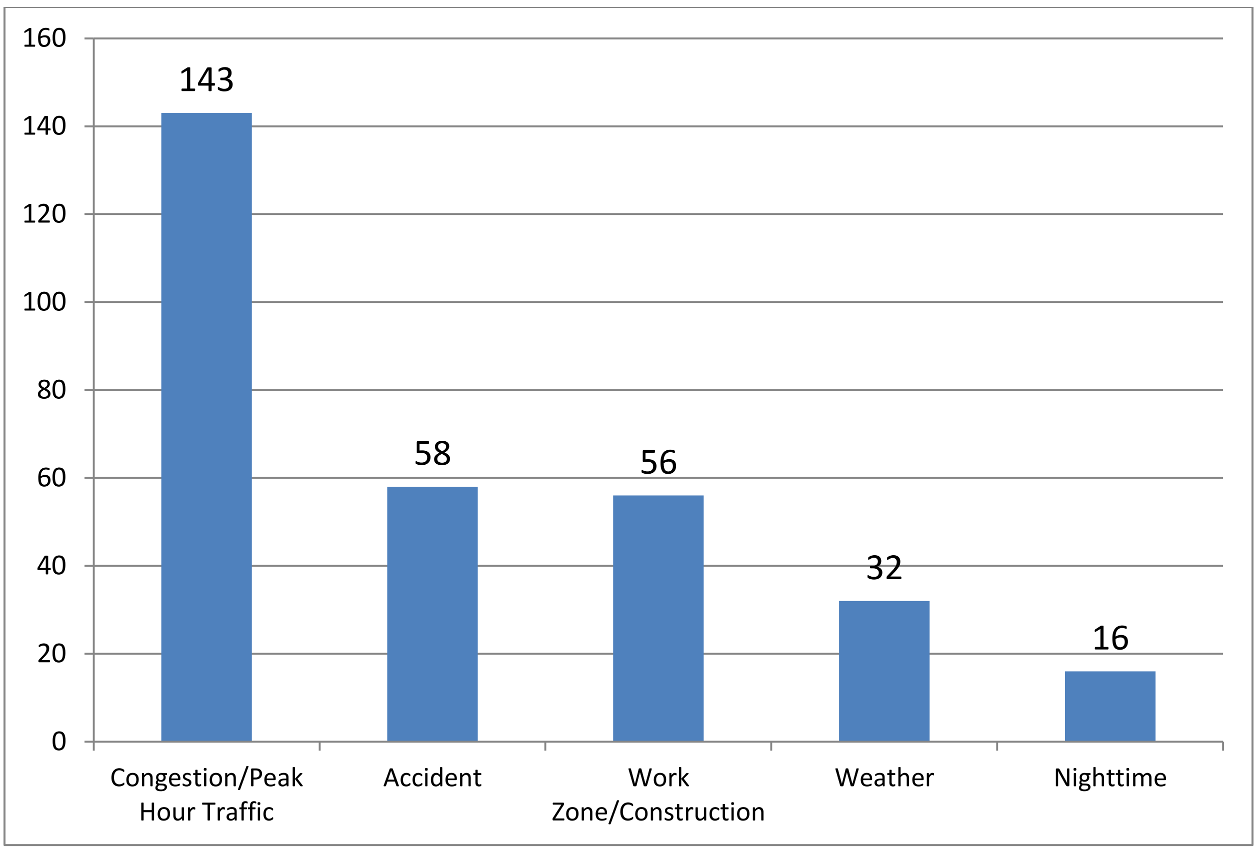


Figure 17. Conditions under which San Antonio Respondents Thought a Speed Limit Change May Occur.

At the Ranger Hill, Eastland County site, the most common answer given for conditions under which a speed limit change may occur was weather, followed by work zone or construction, accident, road conditions, traffic, and nighttime conditions. These results are shown in Figure 18. When asked if they thought they could get a speeding ticket for exceeding the posted speed, 98 of the 100 respondents said yes. The two dissenters thought that the sign was not legal because it was a temporary sign or a warning sign.

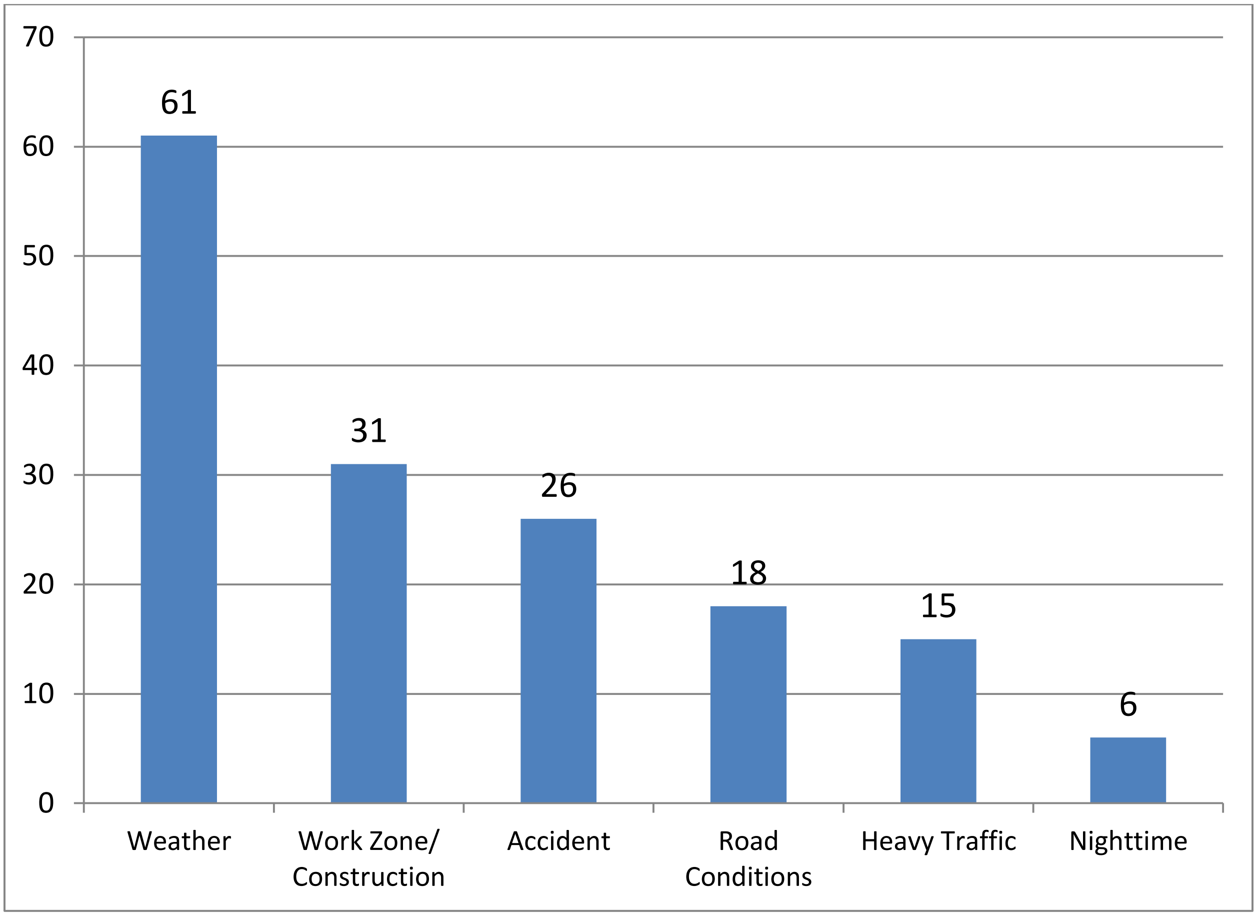


Figure 18. Conditions under which Ranger Hill, Eastland County Respondents Thought a Speed Limit Change May Occur.

Because consent to conduct the surveys closer to the VSL deployment sites could not be obtained, the project team did not expect respondents to be able to recall or accurately compare their speeds with and without the VSL system activated. Thus, the project team focused on other questions that would better ascertain public understanding of the VSL system. The survey results indicate that the respondents understood that the signs displayed a legal, enforceable speed limit. In addition, most respondents at each location were aware of the reasons for activation of the VSL system (i.e., primarily congestion in San Antonio and weather in Ranger Hill, Eastland County).

As noted previously, Figure 19 shows that the majority of respondents understood that the signs display a legal, enforceable speed limit VSL sign was displaying a speed limit.

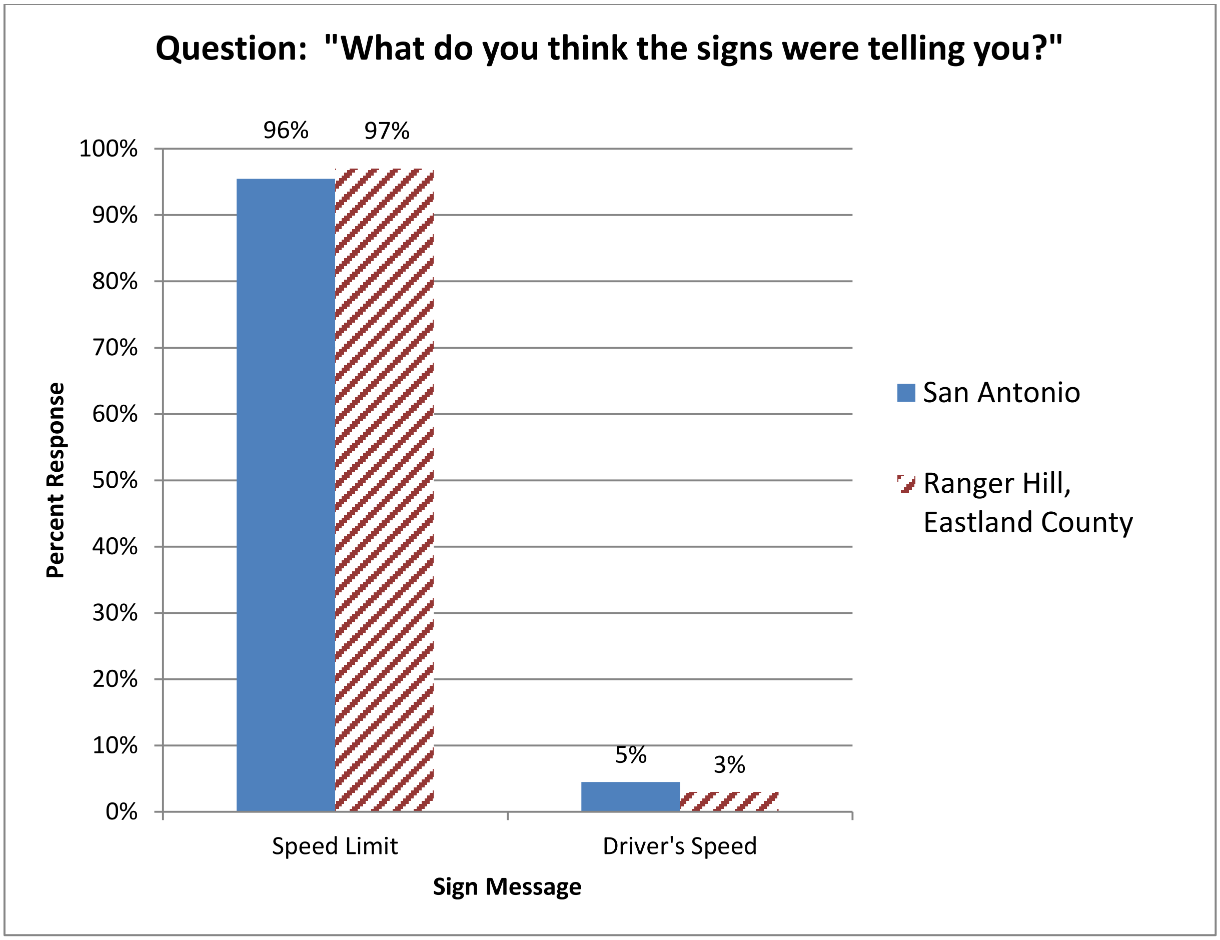


Figure 19. Users' Perceptions of VSL Message.

Violation Analysis

Past research shows that motorists typically drive at a speed they deem comfortable for the given conditions. Thus, posted speed limits that do not appear to be appropriate for the prevailing conditions are less likely to have good compliance rates. Speed limit compliance is a function of many different factors, including road and traffic conditions, weather, and various driver characteristics. In order to determine the impacts of enforcement on VSL speed compliance, the project team performed an enforcement study at the VSL deployment located on SL 1604 in San Antonio.

This analysis consisted of a comparison of recorded speed data taken from the advance warning PCMS and VSL#1 in the series. These locations were selected because a review of the San Antonio data revealed that congestion at downstream VSLs (such as #5 and #6) often triggered the system to deploy speed limits of 55 or 60 mph farther upstream. In the upstream area, motorists often could not physically see any apparent need to reduce their speed, despite the "Reduced Speed Ahead" display on the advance warning PCMS and a reduced speed limit on VSL#1.

On September 30 and October 1, 2014, a patrol car was positioned near VSL#1 during the a.m. and p.m. peak periods. At this location, the VSL routinely displayed lowered speed limits during peak periods. For comparison, the project team used data collected on September 23, 24, and October 7 with the reduced speed limit of 55 mph without the officer present. Control data were collected at the advance warning PCMS while it was displaying "Reduced Speed Ahead" and while the VSL#1 display was 55 mph.

The analysis of violation data, presented in Figure 20, indicate that the VSL system alone without enforcement had an impact on the percentage of time that average speeds exceed specific speed thresholds, more at higher speeds than at lower speeds. When a patrol officer was present, the impact increased, most likely because motorists perceived a need to slow down, albeit to avoid the penalty of receiving a speeding ticket. Thus, VSL compliance increases in the presence of law enforcement.

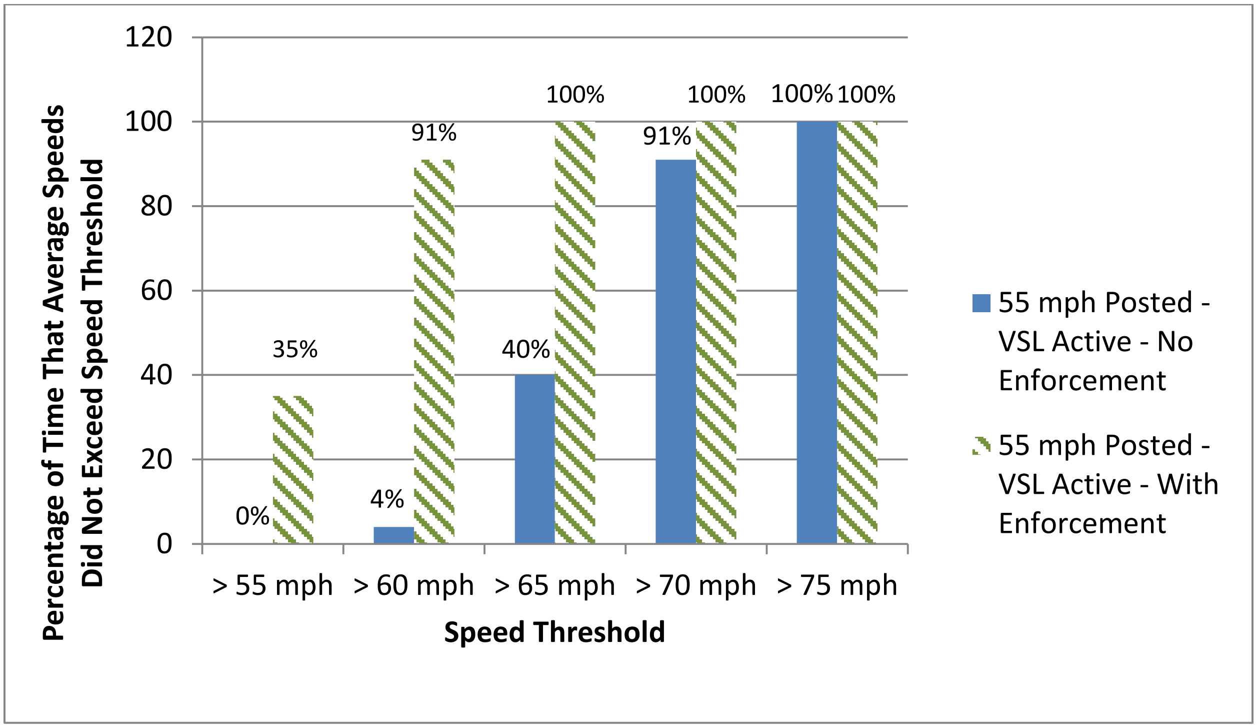


Figure 20. Impacts of VSL on Average Speeds, With and Without Enforcement.

In summary, there are cases where downstream congestion creates a need to reduce speeds in upstream areas to avoid sudden braking and other erratic maneuvers when vehicles reach the congested area. These data show that the effectiveness of the VSL system was very limited in upstream locations where motorists may not have realized there was a legitimate need to reduce their speed. When a patrol officer was present, motorists perceived a need to slow down, albeit to avoid the penalty of receiving a speeding ticket. Thus, VSL compliance increased in the presence of law enforcement.

Benefit-Cost Analysis

The project team conducted a high-level benefit-cost analysis on potential VSL deployments in Texas as part of this project. Given the short duration of the evaluation period for the pilot deployments and the temporary nature of the installed equipment, the project team determined that an analysis using the specific project costs and benefits may not provide useful information. Thus, the team utilized the Federal Highway Administration (FHWA) *Operations Benefit/Cost Analysis Desk Reference* to conduct the analysis.[3] As presented by FHWA, speed harmonization—also known as VSL—involves the implementation of VSL to help lessen stop-and-go conditions and lower the speeds of vehicles as they approach downstream bottlenecks. These bottlenecks, as considered throughout the TxDOT VSL pilot deployments, include recurring congestion, work zones, and weather conditions causing slowdowns. The anticipated primary benefit of VSL is improved safety.

The high-level results of the B/C analysis are provided in Table 16. Each individual deployment (Ranger Hill, Eastland County EB and WB, Temple, and San Antonio) was analyzed separately. Data included in the analysis contained the length of the deployment site, cross-section of the facility, free-flow speed on the facility, and historical crash data. The crash data used were the same data used in the safety analysis discussed previously. In all instances, the analysis assumed the speed harmonization installation was a full, permanent installation on the selected facility. Included in the analysis was the value of capital equipment (basic infrastructure equipment and incremental deployment equipment) and operational and maintenance costs annualized over a 20–25 year useful life of the equipment. The B/C ratio estimated for installing future VSL in the four locations as a permanent operational strategy was positive. All of the benefits predicted to be realized in these deployments were based on a 7 percent reduction in crashes.

Table 16. Benefit-Cost Estimate.

Deployment Site	Annual Benefits	Annual Costs*	Net Benefit	B/C Ratio
San Antonio	$2,112,983	$300,370	$1,812,613	7.03
Temple	$2,358,976	$238,075	$2,120,901	9.91
Ranger Hill, Eastland County	$4,216,950	$300,370	$3,916,580	14.04

*Assumes full permanent installation.

[3] Sallman, D., E. Flanigan, K. Jeannotte, C. Hedden, and D. Morallos, *Operations Benefit/Cost Analysis Desk Reference*, Report FHWA-HOP-12-028, Cambridge Systematics for Federal Highway Administration, Washington, D.C., 2012.

Appendix A: Site Selection

Objective

The objective of the site selection task was to provide assistance to TxDOT in selecting pilot project sites for the development, implementation, and evaluation of VSL. The VSL systems were to be used for the purpose of controlling speeds at sites that have (a) construction work zones, (b) weather-related events, and (c) urban congestion.

Methodology

Using the list of potential candidate sites provided by TxDOT, the project team added other sites that were considered by the project team and TxDOT. The team established the criteria for selection, gathered detailed information on each candidate site, and identified the most promising sites for discussion and decision making. This appendix provides a high-level summary of the potential sites investigated and those selected for the pilot sites.

Urban Congestion Sites

The purpose of using VSL in corridors with recurring congestion is to foster better uniformity in speeds, sustain stable traffic flow, and delay the onset of traffic flow breakdown. VSL systems used in this application must include the ability to detect increases in traffic volumes. The best candidates for this type of situation typically have recurring congestion. Table A-1 presents viable sites identified by the project team.

Table A-1. Candidate Urban Congestion Sites.

Facility	Limits	Mile Markers	Length (mi)	AADT (vpd)
IH-10	Loop 410 to Downtown (San Antonio)	564–570	6.3	203,500
IH-35	FM 1604 to New Braunfels (New Braunfels)	172–185	13.1	134,500
Loop 410	Bandera Rd to Perrin Beitel Rd.	13–26	12.4	228,000
US 281	Airport (Loop 410) to Downtown (IH-35)	532–536	6.3	150,500
US 281	SL 1604 to Bitters Rd.	524–530	3.4	167,500

Initially, the team considered IH-10 in El Paso and US 290 in Houston as potential sites for the project. After the kick-off meeting with TxDOT, it was decided that El Paso was too remote for the short duration of the project, and ongoing construction on US 290 in Houston precluded its use for the urban congestion site. Consequently, the research team selected potential sites in San Antonio that met the general criteria for an urban congestion installation. After review of the various sites, the project team determined that none of them were feasible for the purpose of the pilot study. Thus, alternate sites were considered for implementation.

Construction Work Zone Sites

The purpose of using VSL in work zones is to control speeds upstream of developing queues. VSL systems used in this application must include the ability to detect queue development and propagation to reduce speeds upstream of the event. The best candidate sites for this type of situation typically have long-term lane closures that may result in periodic congestion when traffic volumes increase.

The primary corridor of interest for this type of VSL implementation was the IH-35 corridor near Temple, Texas. Table A-2 shows the candidate sites located along this corridor. For each of these locations, recurring congestion as a function of the work zone is predictable. Furthermore, the potential for lane closures within these segments presents an opportunity to work to meet the purpose of the VSL to control speeds upstream of developing queues within the work zone. Additionally, TTI's current involvement within the corridor provides a strong familiarity with the challenges of the corridor.

Table A-2. Candidate Construction Work Zone Sites.

Facility and Direction	Limits	Mile Markers (Start–End)	Length (mi)	Number of Lanes
IH-35 NB	E. 6th Ave. to Loop 363 (Temple)	294–299	5	3
IH-35 SB	N. FM 2837 to Callan Ranch Rd. (Lorena/Hewitt)	325–322	3	2
IH-35 SB	Moonlight Dr. to S. FM 2837 (Lorena/Hewitt)	328–323	5	2
IH-35 NB	Callan Rand Rd. to N. FM 2837 (Lorena/Hewitt)	322–325	3	2
IH-35 NB	S. FM 2837 to Moonlight Dr. (Lorena/Hewitt)	323–328	5	2
IH-35 SB	FM 1342 to East County Line Rd. (Abbott)	357–356	1	2
IH-35 NB	East County Line Rd. to FM 1243 (Abbott)	356–357	1	2

Weather-Related Sites

The purpose of using VSL in corridors with weather-related issues is to reduce the likelihood of incidents. VSL systems used in this application must include the ability to detect fog, ice, rain, smoke, high wind, or other conditions that deteriorate driver visibility and vehicle control. The best candidates for this type of situation typically have above-average crash rates and are known to experience weather events that contribute to these crashes. The sole candidate for this type of VSL implementation was IH-20 in Eastland County. This area is known locally as Ranger Hill. Ranger Hill is known to have a 6 percent grade, heavy truck traffic, limited right of way (ROW), and weather-related incidents.

A site visit was conducted by the project team on January 14–15, 2014. The site visit was conducted with members of the TxDOT Traffic Operations Division. Site visit activities included examination of the Brownwood District Lonestar system and the infrastructure located at or near Ranger Hill, an investigation of the physical characteristics of the site and site approaches, and wide-ranging discussions related to anticipated deployment needs. It was anticipated that the Ranger Hill deployment would be bi-directional. The following list provides a brief overview of the site visit findings.

Physical Characteristics

While the available ROW within the hill area was severely constrained, the tangent lead-in for both the eastbound and westbound approaches was long and flat with no significant impediments to deployment of PCMSs or other sensors required for the operation of the deployment. The district had available communications, and the commercial cell coverage in the area was excellent. Infrastructure locations for mounting some equipment were available at the top, middle, and bottom of the hill.

Operating Characteristics

Operationally, the VSL deployment at this site was expected to be reactive to weather conditions such as wind, rain, ice, and snow, and visibility issues such as fog or smoke.

Support Characteristics

District personnel were highly interested in the potential deployment, offered local examples of weather trigger events, and participated in the discussions pertaining to locating infrastructure. The district communications and Lonestar deployment were available for use to support this deployment. The project team concurred with TxDOT that the Ranger Hill location had the potential of benefitting from VSL, particularly during weather events, and that the deployment was feasible given the above characteristics.

Recommendations

Based on the information gathered in the initial stages of the project and local conditions, the project team recommended the following sites for the VSL pilot studies:

- *Urban Congestion Site*: SL 1604SL 1604 WB, US 281 to IH-10, San Antonio.
- *Construction Work Zone Site*: IH-35 NB, MM 297 to MM 301, Temple.
- *Weather-Related Site*: IH-20 EB and WB at Ranger Hill, Eastland County.

These three sites individually met the requirements of the project and offered the opportunity to analyze the impacts of VSL for the intended purposes. The site on SL 1604 in San Antonio had recurring congestion that could benefit from VSL with no planned construction during the pilot study timeframe. The construction work zone site on IH-35 in Temple had recurring congestion as a function of the work zone as well as frequent lane closures that generated queues that could potentially benefit from VSL. Finally, the Ranger Hill site on IH-20 in Eastland County offered the opportunity to assess the impacts of VSL for a variety of weather-related events.

Appendix B: Implementation Plan

Objective

The objective of the implementation plan task was to develop an overall implementation plan for the VSL pilot projects. The implementation plan was intended to provide a concept of operations and requirements for the development and deployment of the VSL pilot projects. This plan included various components to ensure success, including the data needs, equipment needs, software modification needs, and integration requirements for successful deployment. The sites for the VSL pilot studies, which are listed below, had a specific combination of VSL operational approaches that individually met the requirements of the legislative document while offering the opportunity to analyze the impacts of VSL for the intended purposes.

- *Urban Congestion Site*: WB State Loop (SL) 1604 between US 281 and IH-10, San Antonio – The site on SL 1604 in the San Antonio District experiences recurring congestion that can benefit from VSL with no planned construction during the pilot study timeframe.
- *Construction Work Zone Site*: IH-35 NB, MM 297 – MM 301, Temple – The construction work zone site on IH-35 in Temple has recurring congestion as a result of the work zone that was expected to generate queues that can be managed by VSL.
- *Weather-Related Site*: EB & WB IH-20 at Ranger Hill, Eastland County – The Ranger Hill site on IH-20 in the Brownwood District offered the best opportunity to assess the impacts of VSL for a variety of weather-related events.

Implementation Plan

The following sections outline the specific concepts of operations and algorithm logic for the three VSL pilot deployment projects. In all cases, the VSL system issued an alert to the operator when a VSL needed to be initiated. The operator then had to confirm the alert to begin operating the signs in a VSL mode.

Congestion-Based VSL

The TxDOT pilot deployment also included a process for providing speed harmonization upstream of a known bottleneck location for the congestion-based VSL application. The process was patterned after the approach used in Seattle by WSDOT to provide speed harmonization on IH-405, SR 522, and IH-90. The goal of the TxDOT congestion VSL was to gradually drop speeds of vehicles approaching a bottleneck location as congestion occurred in an attempt to (a) delay (and possibly prevent) congestion from forming at the bottleneck, and (b) reduce the speed differential between congested and uncongested traffic flow at the back of the queue. The idea was to dynamically adjust the speed limits upstream of the bottleneck as congestion formed and dissipated. As illustrated in Figure B-1, when no congestion was present in the corridor, the speed limit in each segment was set to the maximum speed. However, as congestion began to form at the bottleneck, the speed limit at the bottleneck location became the controlling factor for speeds in the corridor, and all other speeds were adjusted to provide a gradual step down of speeds between the congested and uncongested sections of the freeway. In concept, the stepping down of speeds upstream of a bottleneck allows drivers to gradually adjust their speeds as they approach the congestion, thereby reducing the potential for rear-end collisions due to drivers unexpectedly encountering the back of the congestion. Figure B-1 provides an illustration of the congestion-based VSL process.

For the TxDOT pilot deployment, a 5-mi section of freeway upstream of a known bottleneck was used to demonstrate the concept. The section of freeway was divided into segments, generally between 0.5 and 1 mi in length. Each freeway segment represented a zone over which speed limits were varied approaching the bottleneck location. A variable speed limit sign was used to establish the recommended speed limit for travelers along the segment of freeway. Traffic sensors that measured speeds, volumes, and occupancies across all lanes were used to establish the speed limit to be displayed within the segment. The speeds were then displayed dynamically with VSL signs also associated with each segment.

The approach began by determining the local speed at each detector station. The VSL system monitored the volumes and occupancies being reported by the detector stations once a minute and compared them to thresholds that were defined by the operator. If both the volume and occupancy readings were below the thresholds, the local speed was set to the maximum speed. If both volume and occupancy were above the thresholds, the local speed was set to the speeds recorded by infrastructure speed detectors determined by the sensor. Under very low volume conditions (when no vehicles were detected in an interval of at least one minute), the local speed was set to a maximum speed value. If the measured speed at a station was greater than the maximum allowed speed for the segment, the measured speed was set to the maximum allowable speed.

After the local speed for each detector station was established, the next step in the process was to determine the smoothed speed. The average speed read from each sensor was rounded up to the next highest 5 mph to determine the associated VSL sign's target speed. Target speeds were then stepped in 5, 10, and 15 mph increments, as described later in this document.

The system was designed to automatically alert the operator of when to activate the VSL. To do this, the algorithm performed a persistency check. The purpose of this persistency check was to ensure that conditions had stabilized over time before activating and deactivating the variable speed limits. The process involved updating two counters each minute: an ON counter and an OFF counter. The ON counter was used to determine when to begin displaying variable speed limits on the sign. The ON counter counted the number of intervals in which the smoothed speed was less than or equal to a designated speed (in Seattle, WSDOT uses 50 mph). If the smoothed speed at a sign was greater than the activation speed, the ON counter was reset to zero and the process began again. Each time the speed in a segment was less than or equal to the activation speed, the ON counter was increased. When the ON counter was 1 or 2, the segment speed was set to maximum speed; however, once the ON counter reached 3, the segment speed was set to equal to the smoothed speed, causing the signs to display the new speed.

Once the signs were activated, the displayed speeds were updated every minute automatically without operator intervention. The algorithm automatically determined the speed and displayed it without an alert being issued to the operator every time the speed limit changed.

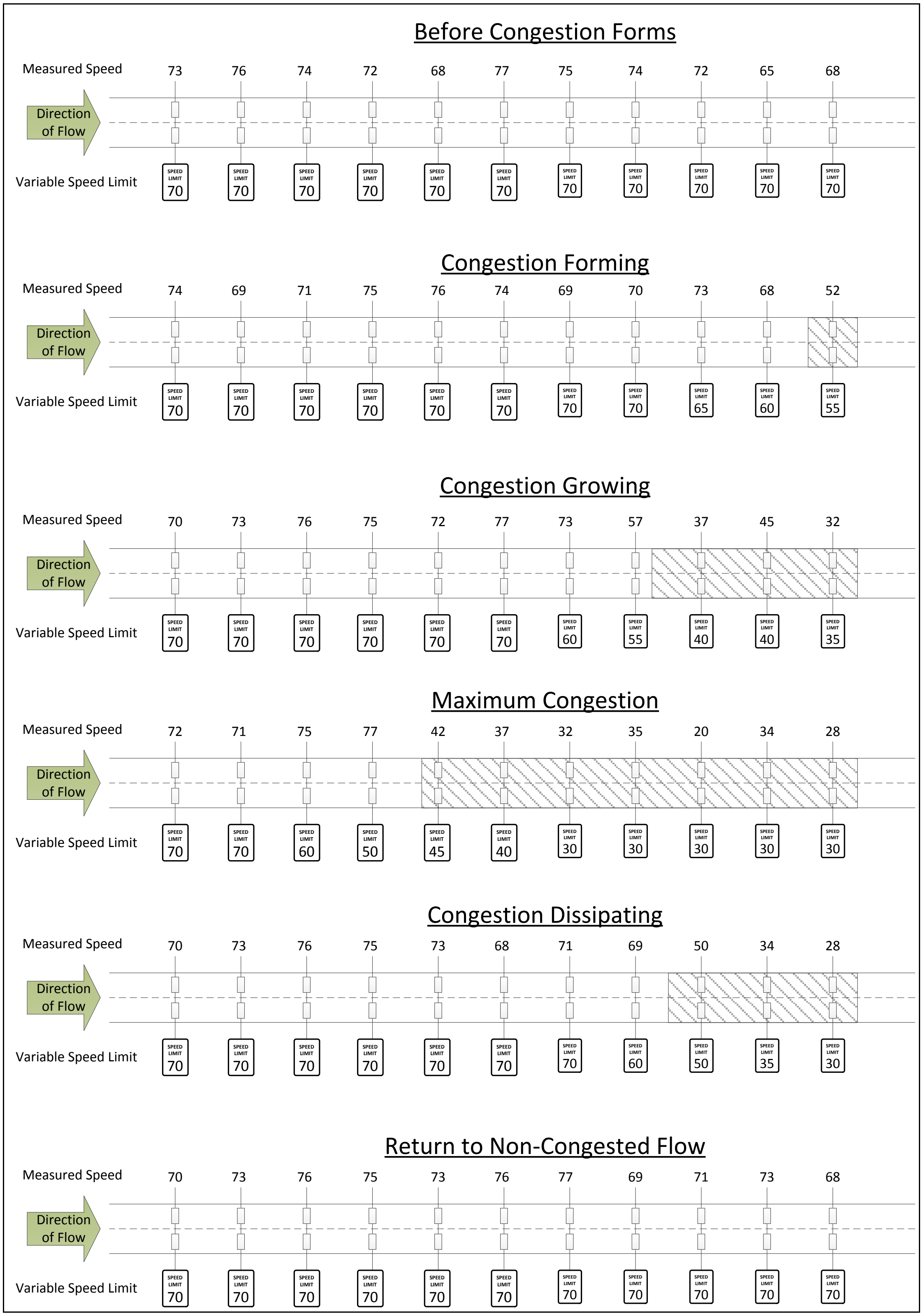


Figure B-1. Illustration of TxDOT Congestion-Based VSL Process.

To deactivate the VSL signs, an OFF counter was used. The OFF counter was incremented every time the smoothed speed for the segment was greater than the activation speed. If the OFF counter was 1 or 2, the speed displayed on the sign was calculated normally until the deactivation counter was reached. Once the OFF count was 3, the operator was alerted that the VSL operation was deactivated. The VSL signs should have displayed the normal speed limit used for uncongested operations. The congestion VSL application was operational at all three pilot study sites.

Construction-Related VSL

The purpose of the construction-related VSL application is to display work zone speed limits within a specified work zone. For many construction zones, TxDOT implements reduced speed zones to improve traveler and worker safety. In this pilot deployment, the VSL was deployed in a long-term construction zone displaying the recommended work zone speed limit as outlined in the related minute order. This work zone contained a lane closure, which sometimes created congestion. During periods of congestion, the goal of the TxDOT construction-related VSL was to gradually drop speeds of vehicles approaching the lane closure in an attempt to (a) delay (and possibly prevent) congestion from forming at the lane closure, and (b) reduce the speed differential between congested and uncongested traffic flow at the back of the queue.

Weather-Responsive VSL

The weather-responsive VSL application uses a table look-up method to determine recommended safe travel speeds during inclement weather conditions. The table look-up method uses visibility and pavement conditions to determine the cell in the table representing the prevailing conditions in the corridor. Each cell in the table corresponds to a particular recommended travel speed for the prevailing conditions. The cells in the table are bound by a minimum and maximum recommended travel speed. The maximum recommended travel speed corresponds to the most favorable condition—high coefficients of friction with high visibility. The minimum recommended travel speed corresponds to the least favorable condition—limited visibility with poor coefficients of friction.

While multiple levels of visibility and pavement friction conditions are supported through this method, the pilot deployment consisted of only two visibility levels (defined by one visibility threshold) and three pavement surface conditions (defined by two coefficient of friction thresholds). Table B-1 shows an example of how the table of recommended speeds was configured for this deployment. For implementation, a user needed to define the recommended maximum and minimum travel speeds for the specific corridor as well as the recommended travel speed for the different levels of visibility and pavement conditions. Recommended speed levels needed to correspond to agency-defined recommended speed criteria for various visibility and pavement surface conditions. As implemented, the algorithm used six recommended speed levels. Recommended travel speeds needed to conform to the following criteria:

- Maximum Recommended Speed > Recommend Speed Level 1 > Recommended Speed Level 2 > Minimum Recommended Speed.
- Minimum Recommended Speed < Recommended Speed Level 4 < Recommended Speed Level 3 < Maximum Recommended Speed.

Table B-1. General Structure of Look-Up Table for Determining Recommended Speed Based on Prevailing Road Weather Conditions (Source: TTI).

Visibility Conditions		Observed Pavement Surface State		
		Dry	Wet	Ice/Snow
		Measured Coefficient of Friction		
Measured Visibility	**Measured Visibility State**	**> Upper Coefficient of Friction Threshold**	**Between Upper and Lower Coefficient of Friction Threshold**	**< Lower Coefficient of Friction Threshold**
> Visibility Threshold	**Good**	Maximum Recommended Speed	Recommended Speed Level 1	Recommended Speed Level 2
< Visibility Threshold	**Poor**	Recommended Speed Level 3	Recommended Speed Level 4	Minimum Recommended Speed

Recommended travel speeds for each segment were determined using the following logic:

- If the measured visibility was greater than the visibility threshold, then the following conditions applied:
  - If the measured surface friction factor of the roadway was greater than the friction factor upper threshold, then the recommended target speed for each segment was equal to the maximum speed defined for the segment.
  - If the measured surface friction factor of the roadway was between the upper and lower friction factor thresholds, then the recommended travel speed for each segment was equal to the recommended travel speed adopted by the agencies corresponding to visibility conditions but deteriorating pavement surface conditions.
  - If the measured surface friction factor of the roadway was less than the friction factor lower threshold, then the recommended target speed for each segment was equal to the recommended travel speed adopted by the agencies corresponding to visibility conditions but poor pavement surface conditions.
- If the measured visibility was less than the visibility threshold, then the following criteria were applied for determining the recommended target speed for each section of roadway:
  - If the surface friction factor of the roadway was greater than surface friction factor upper threshold, then the recommended target speed for each segment was equal to the recommended travel speed adopted by the agencies corresponding to reduced visibility conditions and deteriorating pavement surface conditions.
  - If the measured surface friction factor of the roadway was between the upper and lower surface friction factor thresholds, then the recommended target speed for each segment of roadway was equal to the recommended travel speed adopted by the agencies corresponding to reduced visibility conditions and poor pavement surface conditions.

- If the measured surface friction factor was less than the surface friction factor lower threshold, then the recommended target speed for each segment of roadway was equal to the minimum speed defined for each segment.

Each district was responsible for determining the recommended safe travel speeds for each visibility or pavement surface condition depending on the equipment installed. This approval was based on the contents of the implementation plan, the evaluation plan, and the software change documentation provided by SwRI. Weather inputs in the algorithms consist of visibility and the coefficient of friction. The weather algorithm is shown in Table B-2. Thresholds and resulting speeds are configured per location. One weather device can be assigned one or more VSL devices and thresholds configured which affect each VSL.

Table B-2. Weather Algorithm.

		$F \geq F^{UT}$	Good	$F^{LT} < F < F^{UT}$	Moderate	$F \leq F^{LT}$	Poor
$V > V^T$	Good	Normal speeds		*Speed1*		*Speed2*	
$V \leq V^T$	Poor	*Speed3*		*Speed4*		30 mph	

Note: Coefficient of friction (F) thresholds are upper, F^{UT}, and lower, F^{LT}; visibility threshold is V^T.

Settings in Table B-3are based upon the document (last table in “WRTM speed Limits.docx”) provided by TTI on April 1, 2014, and modifications to weather speeds sent in emails. The San Antonio and Temple deployments did not have visibility sensors, while the Ranger Hill, Eastland County site had a visibility sensor. Sites without visibility sensors ignore visibility for triggering calculations, as shown in the table. Figure B-2 shows the proposed logic for the weather-responsive speed limit.

Table B-3. Weather Settings per Site.

Configuration Value	San Antonio	Temple	Ranger Hill, Eastland County
V^T	n/a	n/a	500′
F^{LT}	0.25 (25%)	0.25 (25%)	0.25 (25%)
F^{UT}	0.45 (45%)	0.55 (55%)	0.45 (45%)
Speed1	60	45	55
Speed2	45	30	45
Speed3	n/a	n/a	50
Speed4	n/a	n/a	40

The weather-related VSL applications were operational at all three pilot study sites, one with visibility and pavement frictions sensors (Ranger Hill, Eastland County) and two with only pavement frictions sensors (Temple and San Antonio).

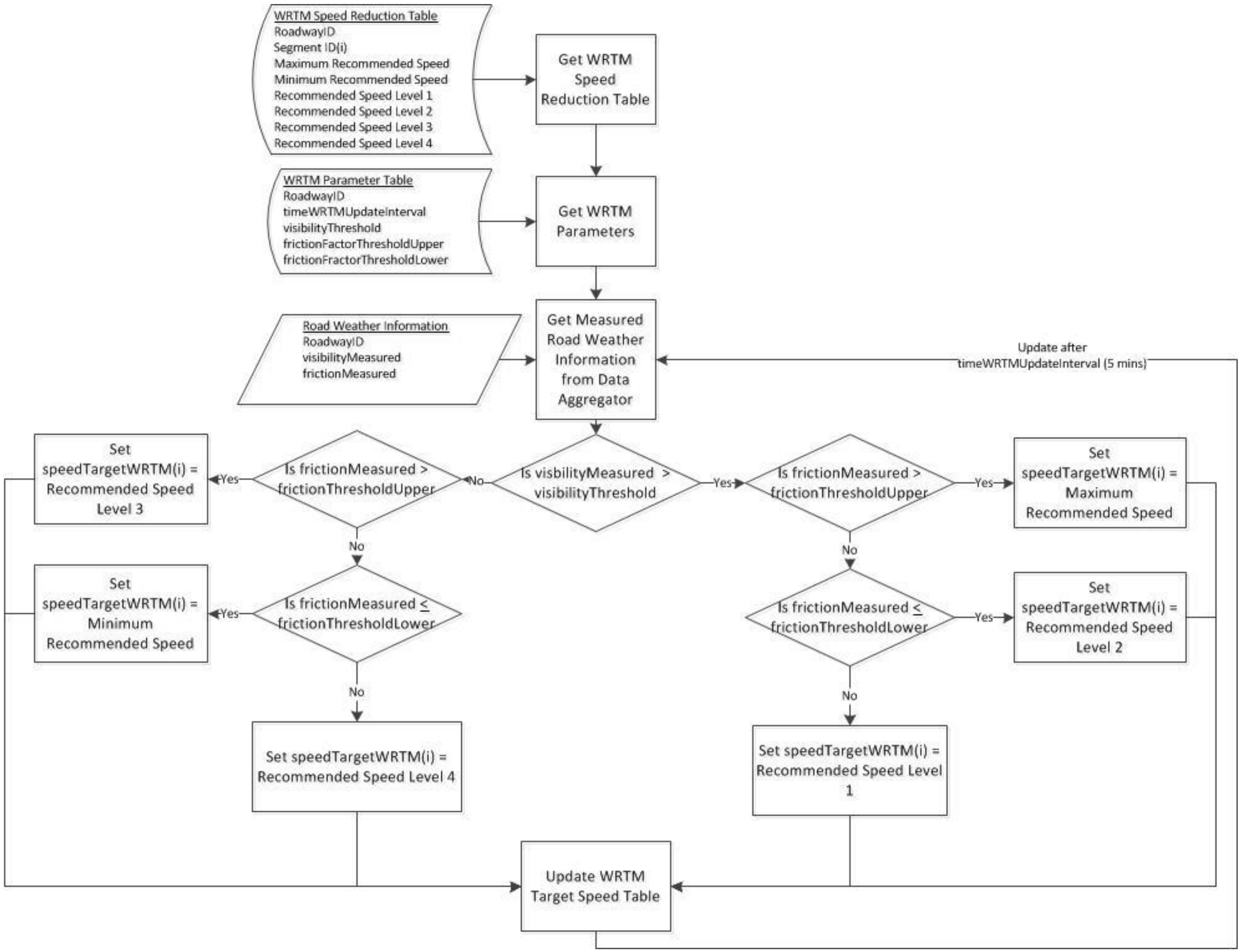


Figure B-2. Flowchart for Proposed Logic for TxDOT Weather-Responsive VSL.

Field Display of VSL Speeds

The TxDOT Lonestar software was modified by SwRI to contain new algorithms corresponding to the three VSL criteria detailed above. The software evaluated the algorithms simultaneously using all available input data, and the resulting output was the lowest prevailing speed condition warranted.

Once the appropriate VSL speeds were determined by the algorithm, the field display of the signs was activated through the existing DMS module. In determining which signs to use to display the changes in speeds, researchers sought to minimize the step down between any two VSLs, subject to the following two constraints:

- The maximum change between two signs could be no more than 15 mph.
- The minimum change between two signs could not be less than 5 mph.

Any triggered speed (S_t) was evaluated, and for the pilot project, the lowest generated speed for a VSL was used. The general rules that were used to govern the speed displays were as follows:

- Speed step downs were between 5 and 15 mph, with 5 mph being the preferred step down.
- Where a step down of greater than 15 mph was needed or there was an insufficient number of signs over which the speeds could be reduced following the rule above, then the speed that was displayed on the VSL had to be higher than the recommended speed.
- If a large drop in speed was required over multiple VSL, the largest drop in speed had to occur at a farther upstream speed. For example, a drop in speed of 15 mph needed to be distributed over two signs, with the first sign displaying a drop of 10 mph and the second sign displaying a drop of 5 mph.
- Speeds were NOT stepped up to normal speeds after a reduced speed. Step ups in speed occurred between two low target speeds if there was a sufficient number of signs over which the speed changes could occur.

Data Requirements

The following sections provide details on the specific data requirements for the operation and evaluation of the VSL pilot project.

Algorithm

The three algorithms for the VSL pilot projects required specific field-related data to function properly. Table B-3 provides a detailed compilation of each data element required for each of the three algorithms, a description of the element, and its source.

Table B-3. Data Requirements for Algorithm Functionality.

Data Element	Description
Weather-Responsive Variable Speed Limits	
ESS Sensor ID	The identification number associated with the environmental sensor station (ESS) that is the source of the weather data. This ESS is assumed to be associated with a roadway name, direction of travel, and beginning and end mile point.
Visibility	The measured visibility reported by a visibility sensor.
Pavement Friction Factor	The measured coefficient of friction reported by a pavement surface sensor.
Visibility Threshold	The threshold used to define the separation between adequate and poor visibility conditions.
Coefficient of Friction Upper Threshold	The value of the coefficient of friction defining good and moderate pavement conditions.
Coefficient of Friction Lower Threshold	The value of the coefficient of friction defining moderate and poor pavement conditions.
Maximum Weather Speed Limit	The recommended speed limit under adequate visibility and good pavement conditions.
Recommended Speed Level 1	The recommended speed limit under adequate visibility and moderate pavement conditions.
Recommended Speed Level 2	The recommended speed limit under adequate visibility and poor pavement conditions.
Recommended Speed Level 3	The recommended speed limit under poor visibility and good pavement conditions.
Recommended Speed Level 4	The recommended speed limit under poor visibility and moderate pavement conditions.
Minimum Weather Speed Limit	The recommended speed limit under poor visibility and poor pavement conditions.
Construction-Related Variable Speed Limits	
Roadway Name	The name of the roadway where the lane closure is to be implemented.
Direction	The direction of flow travel on the roadway.
Start Location of Lane Closure	The point on the roadway where the lane closure is expected to begin, expressed as latitude and longitude combined with a roadway, direction, and cross street.
Start Time of Lane Closure	The time of day in which the lane closure is expected to be installed in the roadway.
End Time of Lane Closure	The time of day in which the lane closure is expected to be removed from the roadway.
Start Date of Lane Closure	The date (mm/dd/yyyy) the lane closure is implemented in the roadway.
End Date of Lane Closure	The date (mm/dd/yyyy) that the lane closure is to be removed from the roadway.
End Location of Lane Closure	The point on the roadway where the lane closure is expected to end, expressed as a latitude, longitude, roadway, direction, and cross street.
Construction Speed Limit	The maximum permitted speed in the work zone. This is the starting point for the system.
Congestion-Related Variable Speed Limits	
Detector Station ID	
Averaging Interval	The time of which data from loop detectors are smoothed.
Station Average Speed	The rolling average of the speeds measured by all the sensors associated with a detector station.
Station Volume	The sum total of the volume measured by all the detectors associated with a detector station.
Station Smoothed Occupancy	The rolling average of the percent occupancy associated with the detectors measured at a detector station.

Evaluation

The project team identified the specific traffic-related data needs highlighted in Table B-4 for evaluation of the pilot projects.

Table B-4. VSL Evaluation Data Needs.

Data Element	Analysis Category			
	Congestion	User Perception	Safety	Benefit-Cost
Rolling average link speeds	X			
Rolling average link speeds during VSL activation	X			
85th percentile link speeds (manual collection)	X			
85th percentile link speeds during VSL activation (manual collection)	X			
Free-flow speeds	X			
Link length	X			
Traffic counts (by vehicle class/manual collection)	X			
Travelers' reported speeds		X		
Travelers' reported duration of congestion experienced		X		
Travelers' reported reasons for VSL speed reductions		X		
Total number of all crashes			X	
Total number of crashes during VSL activation			X	
Severity of all crashes			X	
Severity of all crashes during VSL activation			X	
Costs (capital, operations, maintenance)				X
Benefits (vehicle operating cost savings, safety cost savings)				X

As planned, Lonestar operated the VSL implementations, but equipment maintenance was the responsibility of TTI. As such, TTI required several items to help manage the scenario, as listed below:

- An email alert to a defined distribution when a VSL implementation recommendation was presented to an operator. Email needed to contain location, system parameters, and time of presentation to operator.
- An email alert to a defined distribution when a VSL implementation recommendation was initiated by an operator. Email needed to contain location, system parameters, and time of acceptance by operator.
- An email alert to a defined distribution list when any given item of equipment failed on X number of intervals, e.g., PCMS and posting, Wavetronix and polling, ESS and polling, etc. Email needed to include equipment type, name, location, latitude/longitude, last good communication, and timestamp when the device entered failed status.
- An email alert to a defined distribution list when any given item of equipment returned to service, e.g., PCMS, Wavetronix, ESS, etc. Email needed to include equipment type, name, location, latitude/longitude, return to service time, number of cycles off-line, and timestamp when the device entered active status.
- A 24-hour accounting of message posting success across each VSL implementation and each individual PCMS. Report needed to include the timestamp of the failed cycles as well as polls of the device.

Also, since Lonestar operated each VSL implementation, and the project team was comprised of individuals without Lonestar access, even within TxDOT, the entire project team needed the capability to view the implementation status and current information outside of Lonestar. The following is specific information that TTI needed for system monitoring to ensure operational conformance during shadow mode testing and the actual timeframe of the pilot tests. This information was to be in the form of a live web page showing at minimum:

- Location.
- Current system time.
- Online status of all equipment components in that particular VSL deployment.
- Data feeds from sensors (preferably current and past XX cycles).
- Current status of VSL system (in effect or not).
- Current speed limit displayed on each PCMS (preferably current and past XX cycles).
- Links to daily (or defined time range) historical logging for all equipment components—could be as simple as CSV or TXT file downloads.
- Last initiation time.
- Operator initiation information.
- TMC operator contact information.

Equipment and Schematics

Once the operational approaches and algorithms were established, the team identified the equipment necessary to successfully implement the VSL pilot studies within the approved equipment budget. The team then analyzed the study sites to determine the exact location of equipment for operational and evaluation purposes. The following sections outline the equipment costs and deployment schematics for the three sites.

Equipment Costs

The project team developed detailed cost estimates for each of the three pilot study sites. These costs included PCMS rental, modifications required for the PCMS to install additional equipment, radar sensors, visibility sensors, roadway condition sensors, modems, and other miscellaneous equipment needs that might arise. All of these costs were calculated with indirect costs applied where assumed. TTI administration approved waiving the inclusion of indirect costs (overhead) on the equipment rental, as it could prove detrimental to the project budget. The initial cost estimates for the various pilot study sites are included in Table B-5 through Table B-8, with an initial total cost estimate shown in Table B-9.

Table B-5. Initial Cost Estimates for WB SL 1604 VSL Site, San Antonio.

Equipment	Quantity	Payment Unit	Unit Cost ($)	Monthly Cost ($)	Cost ($)
Reduced Speed Ahead PCMS	1	Monthly	3,227	3,227	12,908
VSL PCMS—Base	8	Monthly	2,708	21,664	86,656
VSL PCMS—Modifications	8	Monthly	519	4,152	16,608
Wavetronix	8	Each	5,500	N/A	44,000
Roadway Visibility Sensor	0	Each	5,224	N/A	–
Roadway Condition Sensor	1	Each	11,315	N/A	11,315
Wavetronix Modems	8	Each	500	N/A	4,000
Miscellaneous	1	Each	5,000	N/A	5,000
Total Equipment Cost					**$180,487**

Table B-6. Initial Cost Estimates for NB IH-35 VSL Site, Temple.

Equipment	Quantity	Payment Unit	Unit Cost ($)	Monthly Cost ($)	Cost ($)
Reduced Speed Ahead PCMS	1	Monthly	2,708	2,708	10,832
VSL PCMS—Base	5	Monthly	2,708	13,540	54,160
VSL PCMS—Modifications	5	Monthly	519	2,595	10,380
Wavetronix	4	Each	5,500	N/A	22,000
Roadway Visibility Sensor	0	Each	5,224	N/A	–
Roadway Condition Sensor	1	Each	11,315	N/A	11,315
Wavetronix Modems	5	Each	500	N/A	2,500
Miscellaneous	1	Each	5,000	N/A	5,000
Total Equipment Cost					**$116,187**

Table B-7. Initial Cost Estimates for EB IH-20 VSL Site, Ranger Hill, Eastland County.

Equipment	Quantity	Payment Unit	Unit Cost ($)	Monthly Cost ($)	Cost ($)
Reduced Speed Ahead PCMS	1	Monthly	2,708	2,708	10,832
VSL PCMS—Base	4	Monthly	2,708	10,832	43,328
VSL PCMS—Modifications	4	Monthly	519	2,076	8,304
Wavetronix	4	Each	5,500	N/A	22,000
Roadway Visibility Sensor	1	Each	5,224	N/A	5,224
Roadway Condition Sensor	1	Each	11,315	N/A	11,315
Wavetronix Modems	5	Each	500	N/A	2,500
Miscellaneous	1	Each	5,000	N/A	5,000
Total Equipment Cost					**$108,503**

Table B-8. Initial Cost Estimates for WB IH-20 VSL Site, Ranger Hill, Eastland County.

Equipment	Quantity	Payment Unit	Unit Cost ($)	Monthly Cost ($)	Cost ($)
Reduced Speed Ahead PCMS	1	Monthly	2,708	2,708	10,832
VSL PCMS—Base	4	Monthly	2,708	10,832	43,328
VSL PCMS—Modifications	4	Monthly	519	2,076	8,304
Wavetronix	4	Each	5,500	N/A	22,000
Roadway Visibility Sensor	1	Each	5,224	N/A	–
Roadway Condition Sensor	1	Each	11,315	N/A	–
Wavetronix Modems	5	Each	500	N/A	2,000
Miscellaneous	1	Each	5,000	N/A	5,000
Total Equipment Cost					**$91,464**

Table B-9. Total Equipment Initial Cost Estimate.

Application	Direction	Site Cost ($)
San Antonio	WB	180,487
Temple	NB	116,187
Ranger Hill, Eastland County	EB	108,503
Ranger Hill, Eastland County	WB	91,464
Total Equipment Cost		**$496,641**

Deployment Schematics

The following figures and tables provide detailed deployment locations for the various PCMSs allocated for each VSL pilot study location. Table B-10 provides a list of the individual sign locations for the San Antonio deployment, including their description, latitude, and longitude for reference purposes. Figure B-3 displays the VSL sign locations along WB SL 1604 in San Antonio.

Table B-10. Sign Location Coordinates, WB SL 1604 VSL Site, San Antonio.

Sign	Description	Latitude	Longitude
RSA	San Antonio “Reduced Speed Ahead”	29.610230°	-98.473170°
VSL-1	San Antonio WB VSL #1	29.610030°	-98.481640°
VSL-2	San Antonio WB VSL #2	29.609340°	-98.489350°
VSL-3	San Antonio WB VSL #3	29.608660°	-98.498030°
VSL-4	San Antonio WB VSL #4	29.608830°	-98.510660°
VSL-5	San Antonio WB VSL #5	29.606770°	-98.527860°
VSL-6	San Antonio WB VSL #6	29.602350°	-98.539380°
VSL-7	San Antonio WB VSL #7	29.601640°	-98.551660°

Table B-11 provides a list of the individual sign locations along with their description for the Temple deployment. Figure B-4 shows the sign locations along NB IH-35 in Temple.

Table B-11. Sign Location Coordinates, NB IH-35 VSL Site, Temple.

Sign	Description	Latitude	Longitude
RSA	Temple “Reduced Speed Ahead”	31.071306°	-97.422710°
VSL 1	Temple NB VSL #1	31.075085°	-97.418193°
VSL 2	Temple NB VSL #2	31.078476°	-97.414176°
VSL 3	Temple NB VSL #3	31.083097°	-97.408577°
VSL 4	Temple NB VSL #4	31.085604°	-97.402642°

Table B-12 provides a list of the individual sign locations along with their description for the Ranger Hill, Eastland County deployment, and Figure B-5 displays the sign locations along IH-20 in the eastbound and westbound directions.

Table B-12. Sign Location Coordinates, EB and WB IH-20 VSL Site, Ranger Hill, Eastland County.

Sign	Description	Latitude	Longitude
EB RSA	Ranger Hill EB “Reduced Speed Ahead”	32.483378°	-98.582741°
EB VSL 1	Ranger Hill EB VSL #1	32.484725°	-98.575118°
EB VSL 2	Ranger Hill EB VSL #2	32.486301°	-98.565960°
EB VSL 3	Ranger Hill EB VSL #3	32.487427°	-98.559653°
WB RSA	Ranger Hill WB “Reduced Speed Ahead”	32.500193°	-98.501216°
WB VSL 1	Ranger Hill WB VSL #1	32.499846°	-98.509188°
WB VSL 2	Ranger Hill WB VSL #2	32.499263°	-98.520088°
WB VSL 3	Ranger Hill WB VSL #3	32.498698°	-98.532566°

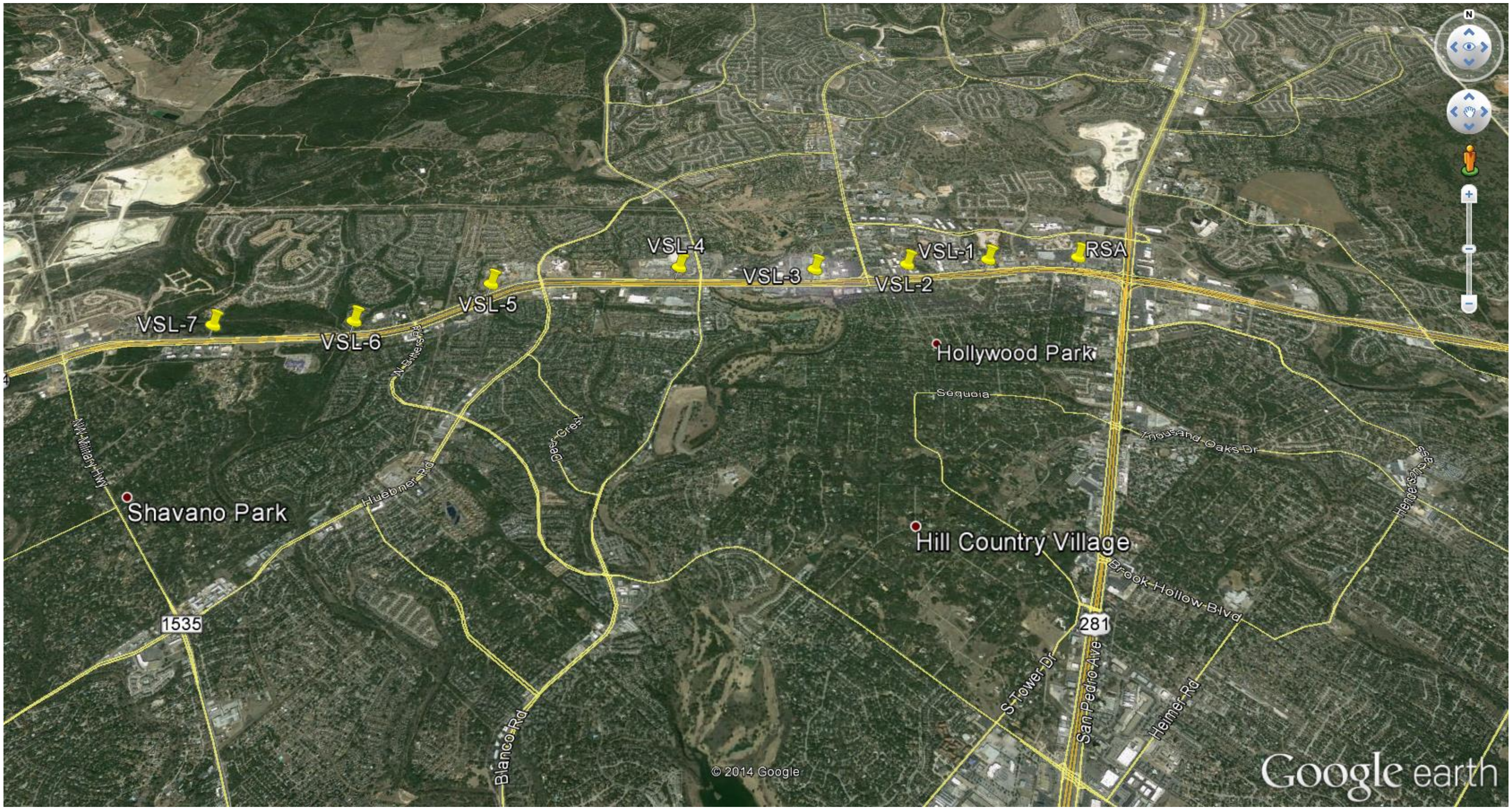


Figure B-3. Sign Locations, WB SL 1604 VSL Site, San Antonio.

Figure B-4. Sign Locations, NB IH-35 VSL Site, Temple.

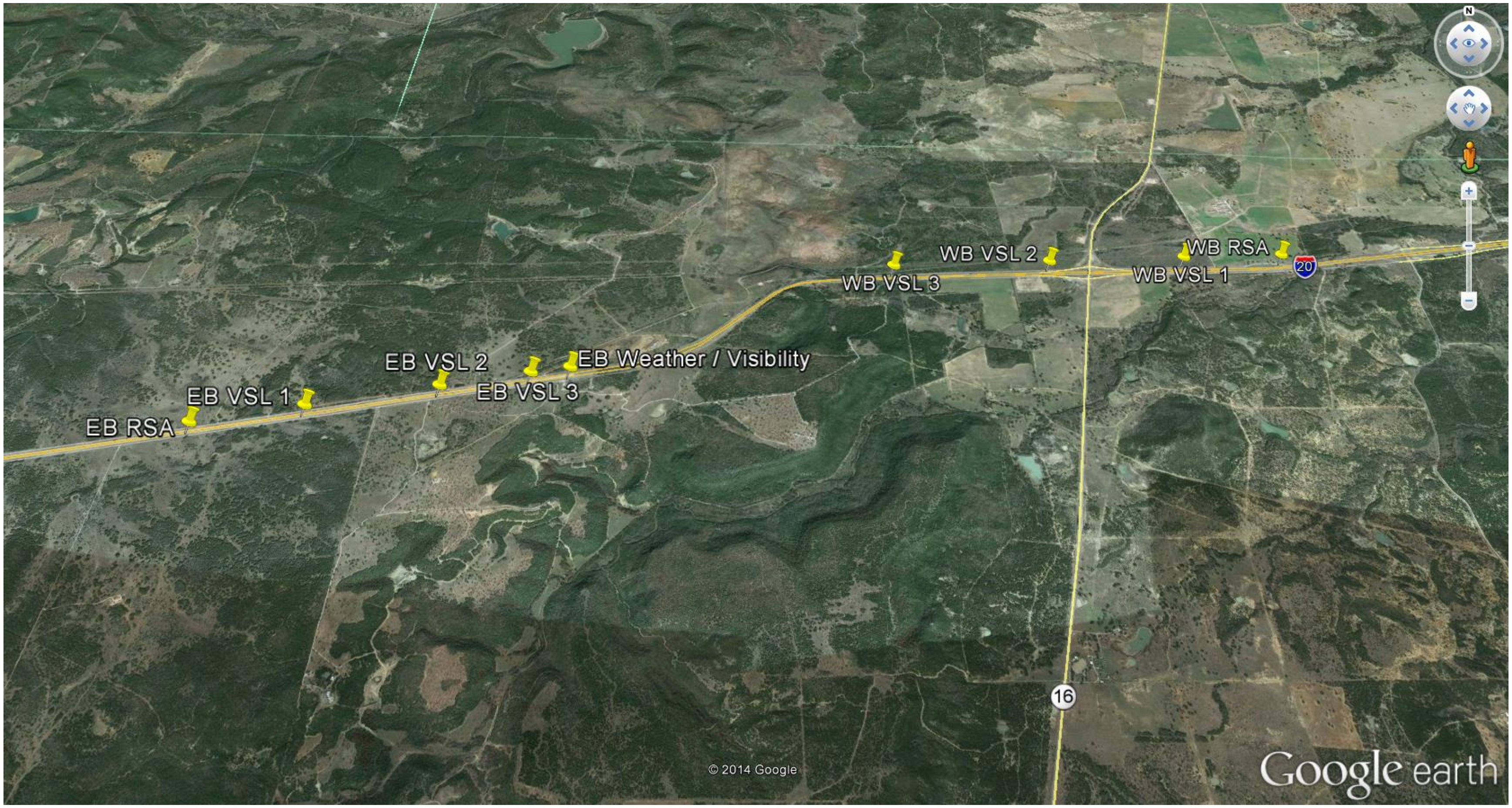


Figure B-5. Sign Locations, EB and WB IH-20 VSL Site, Ranger Hill, Eastland County.

Software and Integration

The deployment of the VSL pilot study projects required the modification of the TxDOT Lonestar ATMS in use by traffic management centers covering each deployment area. SwRI was responsible for this software modification. With the assistance of TTI staff, SwRI developed an integration plan and then provided it to TxDOT. All software modification and integration details are provided in Appendix H.

Appendix C: Evaluation Plan

Objective

The objective of the evaluation plan task was to develop an overall evaluation plan for the VSL pilot projects. The evaluation plan was intended to identify performance metrics for safety, mobility, user opinion, and benefit-cost. For each site, a data collection plan was identified, recognizing that each site may have slightly different data collection needs depending on the implementation. However, the evaluation used common performance measures typically used with active traffic management and other operational strategies that allowed for an overall assessment of the VSL program as well as the effectiveness of each of the emphasis areas.

Evaluation Plan

Table C-1 shows the four analyses that the project team utilized. The analyses presented what needed to be studied to answer questions related to congestion, user perception, safety, and benefit-cost. They highlighted the areas of inquiry, which varied by pilot study site as a result of data availability.

Table C-1. VSL Pilot Project Analyses.

Operational Congestion Analysis	How much was congestion reduced in the area impacted by the implementation of VSL and what were other associated impacts? It was anticipated that impacts could be assessed by one of the following measures and would vary by site: • Increases in travel speeds during peak/congested periods. • Increases in facility throughput during peak/congested periods.
Users' Perceptions Analysis	What were the users' perceptions of the VSL systems? • Did motorists understand the VSL system? • Were there perceived benefits of the VSL system?
Safety Analysis	What were the safety impacts of VSL? It was anticipated that impacts could be assessed by one of the following measures (compared to the same period during previous years) and would vary by site: • Reduction in overall crashes. • Reduction in crashes during peak/congested periods. • Reduction in crash severity.
Cost-Benefit Analysis	What were the overall costs and benefits of VSL?

The evaluation plan represented the project team's approach to measuring the effects of the VSL deployments, the kinds of data needed to perform the evaluation, and the planned analytic approach. Specific details were provided on data sources and analysis methods as a function of the measures of effectiveness being assessed.

For each evaluation analysis noted in Table C-1, the related measures of effectiveness and data elements are defined in Table C-2 (congestion), Table C-3 (users' perceptions), Table C-4 (safety), and Table C-5 (benefit-cost). The analysis questions describe the expected results of the

VSL pilot projects, including benefits such as congestion reduction, throughput improvement, improved mobility, safety, and related outcomes. Each specific analysis approach is discussed in the following sections.

Congestion Analysis Approach

The purpose of the congestion analysis was to assess the extent to which the VSL projects were able to achieve the related congestion objectives identified. Specifically, the congestion analysis was designed to assess the following impacts of the VSL:

- Travel speed.
- Speed profile.
- Vehicle throughput.

Table C-2. Congestion Analysis Approach.

Hypothesis/Question	Measures of Effectiveness	Data
Deploying VSL will increase speeds within the study location.	• Percent change in average, median, and 85th percentile travel speeds.	• Average link speeds. • Average link speeds during VSL activation. • 85th percentile link speeds. • 85th percentile link speeds during VSL activation. • Free-flow speeds. • Link length.
Deploying VSL will smooth the speed profile within the study location.	• Change in slope of speed profile between data collection sites.	• Average link speeds. • Average link speeds during VSL activation. • 85th percentile link speeds. • 85th percentile link speeds during VSL activation. • Free-flow speeds. • Link length.
Vehicle throughput will remain the same or increase within the study location as a result of VSLs.	• Percent change in total vehicle throughput, daily, in peak periods and during VSL activation.	• Traffic counts (by vehicle class). • Link length.

Travel Speed

The congestion analysis specifically evaluated the effect of VSL on travel speeds on three facilities on which VSL were deployed. Table C-2 summarizes the hypotheses, measures of effectiveness, and data associated with this portion of the congestion analysis. Through the use of field data collection sensors placed on the PCMSs displaying VSL-related messages, the project team gathered travel speeds throughout each corridor within the pilot study area.

An additional objective of VSL is to alert drivers to congestion and to smooth the transition of traffic into recurring or non-recurring congestion conditions. As such, the project team used the speed data to develop a speed profile throughout the VSL pilot study sites. The slope of the speed profile line was a measure of the rate of vehicle deceleration.

Throughput

Since throughput is a fundamental measure of roadway performance, the project team assessed the extent to which vehicular throughput improved as a result of the VSL pilot studies. Vehicle throughput was determined by counting the number of vehicles passing through the VSL study sites using field data collection equipment. Person throughput was a measure that was beyond the scope of this project, particularly because of its short duration and the lack of mode alternatives being offered as part of this study.

Users' Perception Analysis Approach

Users' perceptions of the VSL project were a key factor in overall success. If travelers believed that their travel was improved as opposed to typical conditions when traveling through a facility with a VSL, public acceptance of the VSL would be enhanced. Furthermore, since VSL as it was implemented within the pilot studies was a new operational approach in Texas, public acceptance needed to be assessed through surveys. Anecdotally, European experience with VSL has shown that public acceptance correlates to compliance. If a driver accepts that the drop in speed is for a legitimate reason, then he or she will be more likely to comply with the reduced speeds. In addition to the perception questions that were asked as indicated in Table C-3, TTI surveyed travelers to assess their comprehension of the VSL signage, their understanding of appropriate behavior, and their overall view of VSL and their potential to improve operations on congested facilities.

Table C-3. Users' Perception Analysis Approach.

Hypothesis/Question	Measures of Effectiveness	Data
Travelers will understand the VSL system.	• Percentage of respondents citing an improvement in travel speeds within the VSL site. • Percentage of respondents citing a reduction in the duration of congestion within the VSL site. • Percentage of respondents who understand the VSL system.	• Travelers' reported speeds. • Travelers' reported duration of congestion experienced. • Travelers' reported reasons for VSL speed reductions.

Safety Analysis Approach

The second analysis category for the VSL pilot studies was safety. The hypothesis, as shown in Table C-4, was that VSL would improve safety by smoothing the speed profile during congested conditions and encouraging more uniform speed behavior on the part of drivers. For the safety analysis, the project team analyzed available crash data within the study sites. The specific crash data assessed are included in Table C-4. However, it is important to note that the statistical significance of any safety improvements is most likely questionable given the short duration of the analysis period. Robust safety analyses involve multiple years of before and after data, and this analysis period only lasted a few months. Additionally, the availability of data was dependent upon the time it took to obtain crash data from TxDOT's CRIS. The project team reports the safety analyses results herein with the intent of indicating any trends that may show promise in VSL improving safety.

Table C-4. Safety Analysis Approach.

Hypothesis/Question	Measures of Effectiveness	Data
The deployment of VSL will improve safety within the study site.	• Change in the number of crashes within the VSL site. • Change in the number of crashes during peak/congested periods in the VSL site. • Change in the distribution of severity of all crashes. • Change in the distribution of severity of crashes during peak/congested periods.	• Total number of all crashes. • Total number of crashes during VSL activation. • Severity of all crashes. • Severity of all crashes during VSL activation.

Note: The project team used data during the same period in previous years. It was expected that the limited timeframe of the evaluation would not produce statistically significant safety data and that the availability of crash data from CRIS would impact the analysis.

Benefit-Cost Analysis Approach

The purpose of the benefit-cost analysis was to quantify and monetize the potential benefits and costs that might be incurred from implementing the TxDOT VSL pilot projects. The intent was to determine whether the difference between the total benefits and the total costs would yield potential returns from the public investment. A benefit-cost analysis plays an important role in determining the feasibility of transportation projects because the results are easily understood and acknowledged from the perspective of the implementing agency, decision makers, and general public.

Table C-5 provides the specific data that were collected and assessed for the benefit-cost analysis. Expected benefits included vehicle operating cost savings and safety cost savings. On the cost side, the capital costs associated with the pilot projects were included along with operations and maintenance costs.

Table C-5. Benefit-Cost Analysis Approach.

Hypothesis/Question	Measures of Effectiveness	Data
What is the net benefit (benefit-cost ratio) of a VSL?	• Positive benefit-cost ratio for the VSL pilot studies.	• Costs (capital, operations, maintenance). • Benefits (vehicle operating cost savings, safety cost savings).

Evaluation Test Plans

Individual test plans were developed and conducted to collect and analyze the data needed to assess the hypotheses in the four evaluation analyses presented previously. The test plans for the TxDOT VSL pilot projects were:

- Traffic system data test plan.
- Surveys test plan.
- Safety test plan.
- Benefit-cost analysis test plan.

Table C-6 provides the specific data required for evaluation and shows which data elements were collected at each of the three VSL pilot study locations. Most of the traffic system data were used to support before and after comparisons of traffic conditions. Traffic sensor data were generated as each deployment came on line. Table C-7 lists the traffic system data elements that were used in calculating the primary evaluation performance measures used in these analyses.

The high-level data and analysis periods for each data source are summarized in Table C-8. For the weather VSL implementation, traffic data were gathered prior to the planned construction project scheduled for the facility. Once the construction project was active, additional data were gathered to determine if the presence of the construction project had an impact on traffic. For all three VSL sites, data were collected prior to the installation of the field equipment to assess the baseline conditions for the facilities. Once the equipment was installed and operating in shadow mode (operating but not displaying VSL—only displaying standard speed limits), data were collected to assess whether speeds being displayed on the PCMSs had an impact on driver behavior and operations. Finally, once the VSL equipment and algorithm were fully operational, the project team collected field data for the full evaluation analyses.

The intermittent use of law enforcement during data collection is not recommended. Research performed by Jerry Ullman et al. of TTI shows that the mere presence of law enforcement can impact speeds. In non-work-zone locations, speeds tend to be reduced in the presence of law enforcement, the magnitude of which depends on the type of enforcement method used, the frequency and duration of the enforcement activity, the extent to which traffic speeds exceed the posted speed limit, and other factors such as whether the emergency lights are flashing, the radar is activated, etc.[4] Since the project team had no means of documenting specific times and

[4] Ullman, G., S. Schrock, M. Brewer, P. Sankar, J. Bryden, M. Corkran, and C. Hubbs. *Traffic Enforcement Strategies in Work Zones*, NCHRP, National Academies, Washington, D.C., 2006.

locations of various police activities, the team would not be able to apply any such filters to the data. It would be more consistent if no enforcement occurred during the data collection periods, regardless of whether the VSL system was activated.

Table C-6. Data for Evaluation Analyses.

Evaluation Data	VSL Pilot Study Location		
	Construction	Weather	Urban Congestion
Traffic Data			
Travel speeds	X	X	X
Volume	X	X	X
Link length	X	X	X
Types of vehicles/fleet composition	X	X	X
Surveys			
Traveler behavior	X	X	X
Public/travelers' perceptions	X	X	X
Outreach documents	X	X	X
VSL Operational Data			
Time between VSL system notification and operator activation	X	X	X
VSL activation trigger, date, time	X	X	X
VSL activation specifics (speeds, step downs, etc.)	X	X	X
VSL deactivation date, time	X	X	X
Incident Data			
Number of incidents/crashes	X	X	X
Types of incidents/crashes	X	X	X
Severity of crashes	X	X	X
Incident duration	X	X	X
Incident response times	X	X	X
Clearance times	X	X	X
Cost Data			
Capital equipment costs	X	X	X
Operational costs	X	X	X
Maintenance costs	X	X	X

Table C-7. Data Requirements for Computing Performance Measures Used in Evaluation Analyses.

Evaluation Performance Measure	Congestion Traffic Data Element		
	Speed	Volume	Link Length
Average, median, and 85th percentile travel speeds	X		
Speed profile slope	X		
Total vehicle throughput		X	X
Percent change in hours operating below posted speed limit	X		X

Table C-8. Data and Analysis Timeframes.

Data Source	Timeframes			
	Historical	Pre-Installation	Pre-Deployment (Shadow Mode)	Post-Deployment
Traffic Sensor Data		X	X	X
VSL Algorithm Logs		X	X	X
Incident Databases	X	X	X	X
Construction and Maintenance Activities		X	X	X
Weather Information		X	X	X

Appendix D: Equipment Assistance

Objective

The objective of the equipment assistance task was to provide equipment assistance for the VSL pilot projects as indicated in the implementation plan. Each VSL pilot site had a specific combination of VSL operational approaches that individually met the requirements of the legislative document while offering researchers the opportunity to analyze the impacts of VSL for the intended purposes.

Equipment Overview

The project team developed a comprehensive equipment list sufficient to meet the objectives of the pilot project study within budget. The list of equipment included PCMSs adapted to display a regulator speed limit along with data collection equipment that gathered the necessary data to operate the VSL pilot application and transmit and record data for operational and analysis purposes. Primarily, the equipment required for this project had to be neither restrictive nor permanent on the affected roadways.

In terms of installing or testing road condition sensors and visibility sensors, TxDOT and TTI agreed that these activities should not slow traffic nor cause lane closures. Once installed, the sensors themselves could not debilitate any motorist's driving ability but needed to be able to detect road conditions from at least 20 ft away. Condition sensors also needed to measure the road surface moisture content (such as wet or icy) and coefficient of pavement friction at a maximum of five-minute intervals. Since such adverse pavement conditions would be either caused or influenced by the weather, both condition and visibility sensors needed to operate proficiently under all normal outdoor environmental conditions. Additionally, depending on geographic and structural surroundings, sensors had to make quality readings from a number of different angles and positions. All detected data needed to be transferred via a cellular data system for decoding by project personnel. For this reason, sensors had to provide a software user interface to allow for remote monitoring, configuration, and diagnostics.

Equipment Specifications

The following sections describe the specifications for the various equipment types required for the VSL pilot study locations.

Portable Changeable Message Signs

For all three sites, the PCMS systems required needed to be available for use by TTI for a four-month duration (May 1, 2014, through August 31, 2014). Additional lease extension options were assessed throughout the project timeframe. The following PCMS systems were necessary:

- Four modified "Reduced Speed Ahead" (RSA) PCMSs.
- Twenty-one VSL modified RSA PCMSs.

The PCMSs had to be solar-powered portable signs, trailer mounted, and three-line programmable message boards. The specific requirements for the PCMS traffic control devices were:

- Modified RSA PCMSs.
    - Base from Line 69: solar-powered portable sign, trailer mounted, three-line programmable message board.
    - Additions:
        - Cellular modem.
        - Cellular service with data package (no additional feeds for data overage).
        - Website access.
        - Minimum four drum protection per MUTCD.
        - Sign deployment at start of lease.
        - Sign pick-up at end of lease.
        - 24×7 four-hour response time for operational issues.
        - Monthly routine maintenance with report to procuring agency.
        - Ethernet CPU and (j) 20 ft 1¾ in. perforated Unistrut post with brackets for attachment of sensors.
- VSL modified RSA PCMSs.
    - Base from Line 69: solar-powered portable sign, trailer mounted, three-line programmable message board.
    - Additions:
        - Cellular modem.
        - Cellular service with data package (no additional feeds for data overage).
        - Website access.
        - Minimum four drum protection per MUTCD.
        - Sign deployment at start of lease.
        - Sign pick-up at end of lease.
        - 24×7 four-hour response time for operational issues.
        - Monthly routine maintenance with report to procuring agency.
        - Ethernet CPU.
        - 20 ft 1¾ in. perforated Unistrut post with brackets for attachment of sensors.
        - Two white LED character boards.
        - Lexan vinyl mask.
        - 48 in. × 60 in. aluminum R2-1 sign with character board cutout.

Road Condition Sensor

The following specifications were used for the procurement of the roadway condition sensors deployed at each VSL pilot study site:

- The device must use non-intrusive into-the-roadway technology, with no cabling cut into the roadway and no lane closures for installation/test.
- The technology must be safe for the passing motorists. Lasers, if used, must be safe for exposure to the unprotected eye.
- The sensor must provide an indication of the general conditions on the roadway. The sensor must detect at least the following conditions:
    - Dry roadway.
    - Wet/damp roadway.

    - Ice/frost on roadway.
    - Snow on roadway.
- The sensor must provide a coefficient of friction value for the monitored roadway.
- The sensor must provide a reading of the roadway conditions at least once per five-minute interval.
- The sensor must provide a real-time output that is capable of sending data to a remote location via a collocated cellular data system. A simple ASCII or Hex output frame is expected. Documentation must be available to decode all data the sensor measures and sends including definition of units used and data ranges per data element.
- The sensor must provide one of the following physical communication interfaces:
    - RS-232.
    - RS-422.
    - Ethernet.
- The sensor must provide a software user interface to allow for remote monitoring, configuration, and diagnostics.
- The sensor must operate and provide expected quality of readings when mounted on roadside equipment such as overhead sign bridges, closed-caption television (CCTV) camera poles, and DMS structures. The sensor must be able to operate from at least 20 ft from the roadway.
- The sensor must fully operate with expected accuracy in all normal outdoor environmental conditions (i.e., hot, cold, heavy rain, fog, dusty, smoky).

Roadway Visibility Sensor

The following specifications were used for the procurement of the roadway visibility sensor for the Eastland County site:

- The device must use non-intrusive into-the-roadway technology, with no cabling cut into the roadway and no lane closures for installation/test.
- The technology must be safe for the passing motorists. Lasers, if used, must be safe for exposure to the unprotected eye.
- The sensor must provide an indication of the current visibility conditions at the site using a standard definition of visibility (e.g., visibility range).
- The sensor must provide a reading of the visibility conditions at least once per five-minute interval.
- The sensor must provide a real-time output that is capable of sending data to a remote location via a collocated cellular data system. A simple ASCII or Hex output frame is expected. Documentation must be available to decode all data the sensor measures and sends including definition of units used and data ranges per data element.
- The sensor must provide one of the following physical communication interfaces:
    - RS-232.
    - RS-422.
    - Ethernet.

- The sensor must provide a software user interface to allow for remote monitoring, configuration, and diagnostics.
- The sensor must operate and provide expected quality of readings when mounted on roadside equipment such as overhead sign bridges, CCTV camera poles, and DMS structures. The sensor must be able to operate from at least 20 ft from the roadway.
- The sensor must fully operate with expected accuracy in all normal outdoor environmental conditions (i.e., hot, cold, heavy rain, fog, dusty, smoky).

Miscellaneous Equipment

The project team purchased additional equipment to facilitate the construction, installation, and operation of the VSL pilot study. These included the following:

- Detection system, vehicle, Wavetronix WX-SS-126, SmartSensor HD 126 with 22-lane functionality and related accessories and equipment.
- Routers and related equipment.
- Hinged covers and mounting panels.
- Surge protectors.
- Ground terminals.
- Cables.
- Miscellaneous electronic equipment.

VSL Trailer Cabinet Assembly

The project team developed detailed diagrams illustrating the complete assembly of the VSL trailers. These diagrams include electrical power diagram, connection diagrams for the various components, cabinet installation diagrams, and installation exhibits for the road condition and visibility sensors. The cabinet assembly diagrams are provided in Appendix E.

Appendix E: VSL Trailer Cabinet Assembly

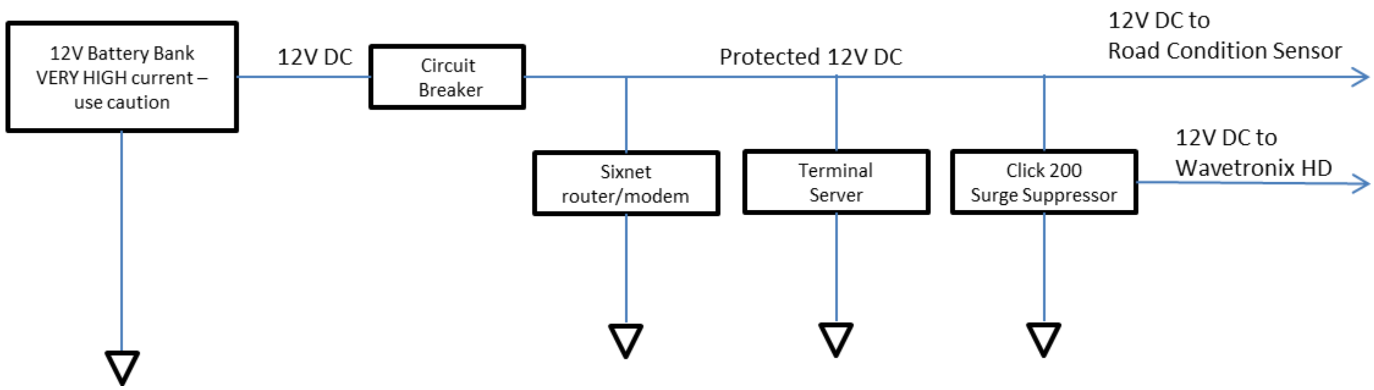


Figure E-1. VSL Trailer—Electrical Power Diagram.

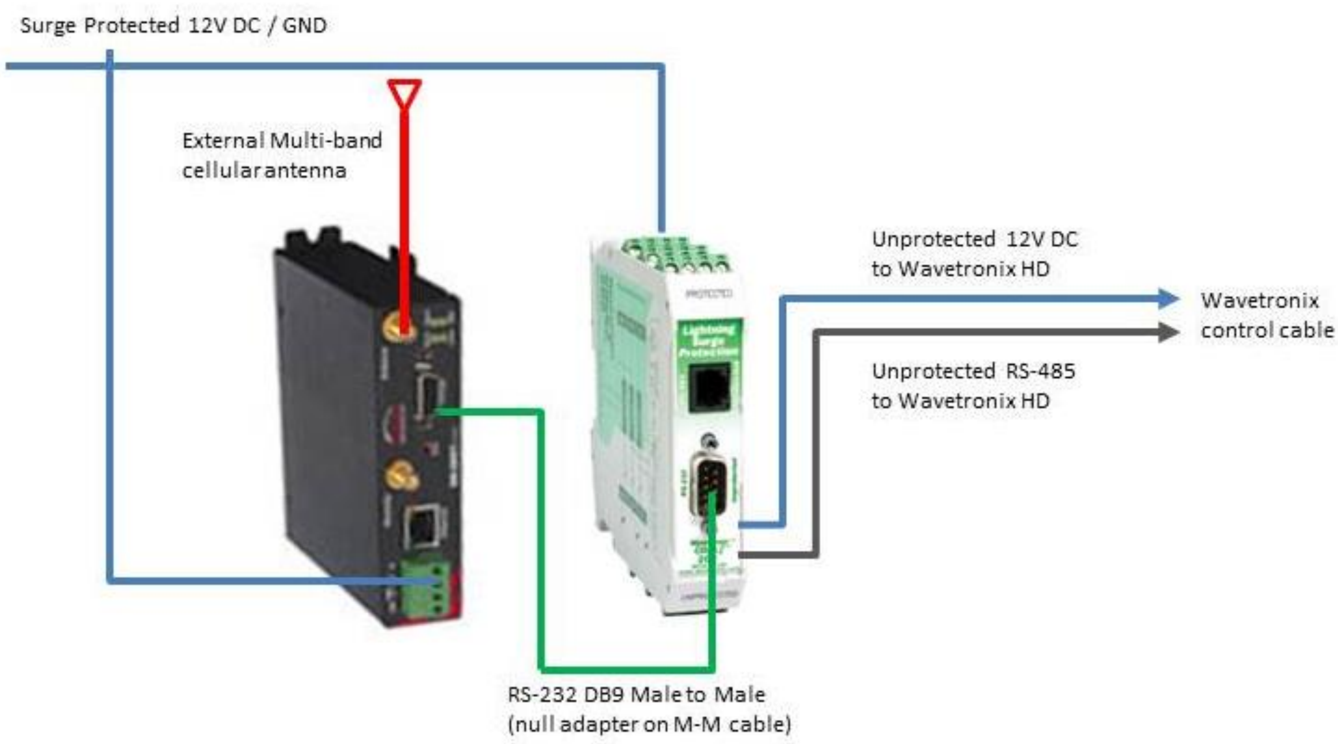


Figure E-2. VSL Trailer—Connection Diagram.

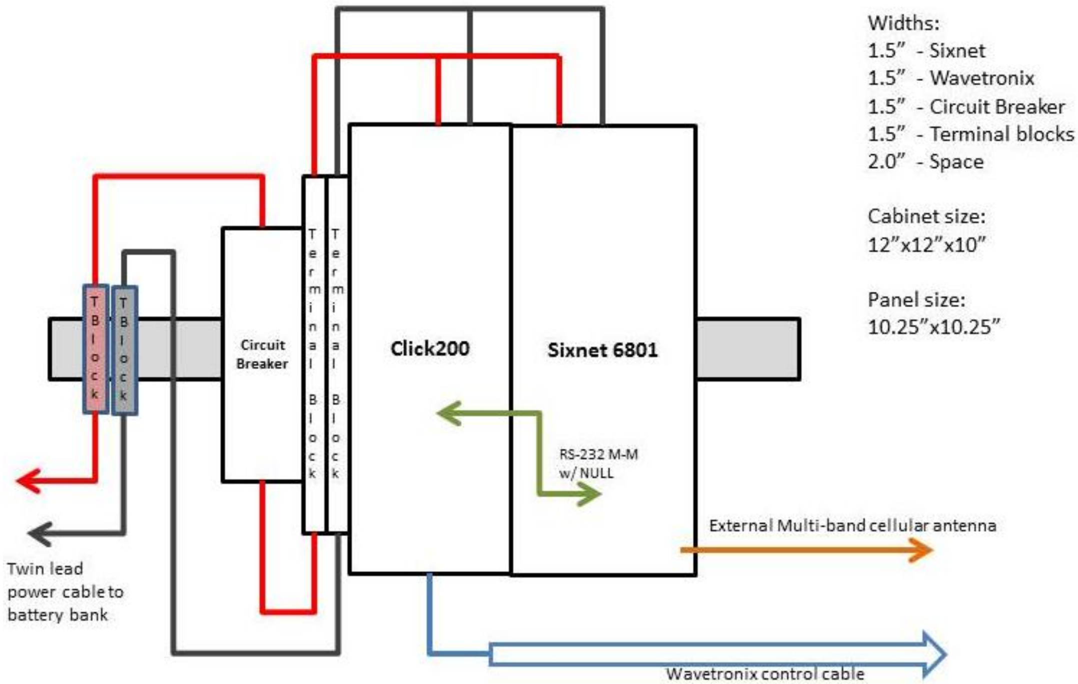


Figure E-3. VSL Trailer Cabinet Panel Diagram.

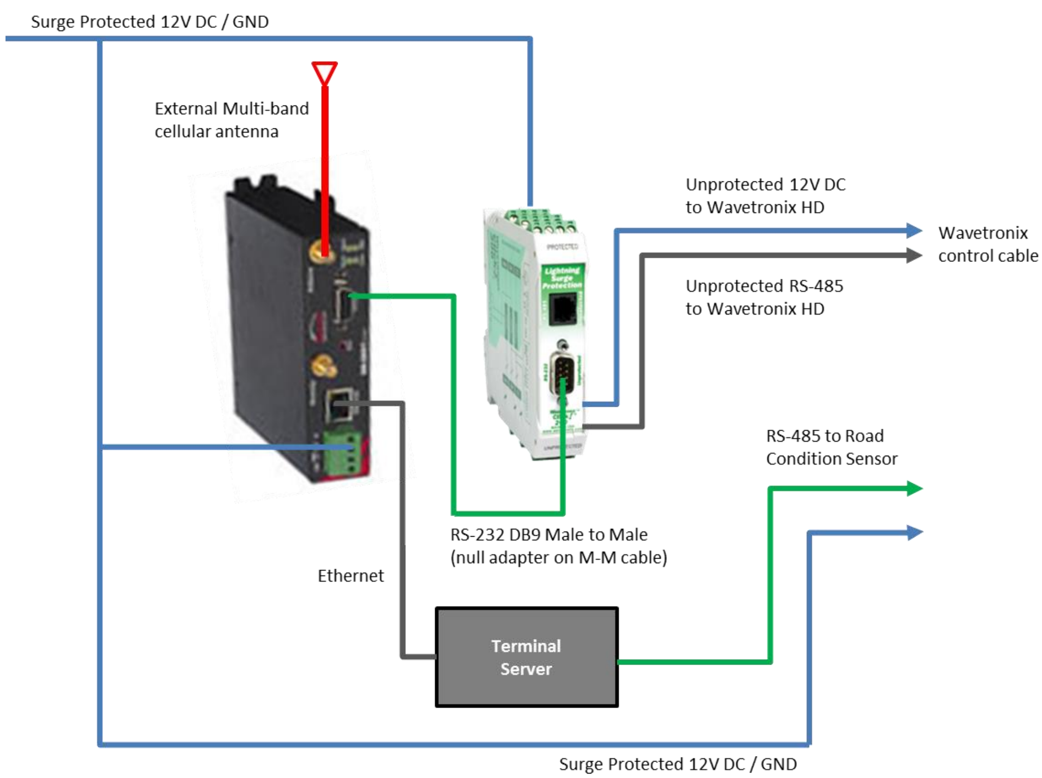


Figure E-4. VSL With Road Condition Sensor—Connection Diagram.

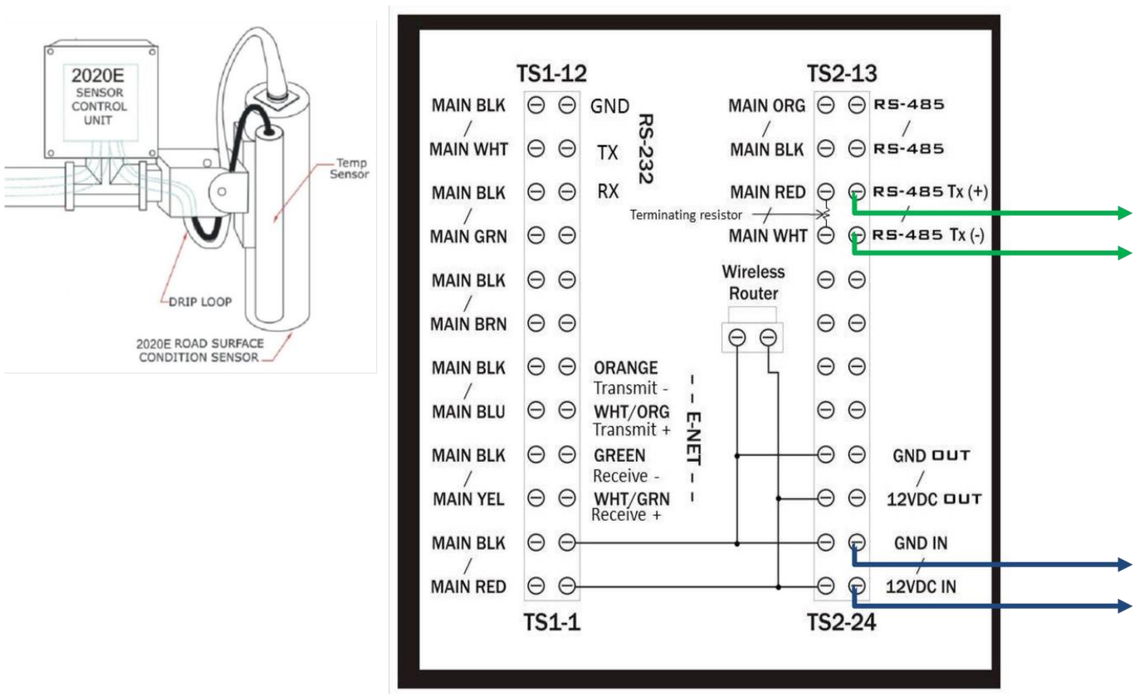


Figure E-5. VSL Road Condition Sensor—2020E Sensor Control Unit.

Mount the electrical cabinet to the 5" square vertical post
Cabinet has mounting holes 3" apart on top and bottom
Use unistrut as a mounting base
All thread or square U bolt to affix cabinet to vertical

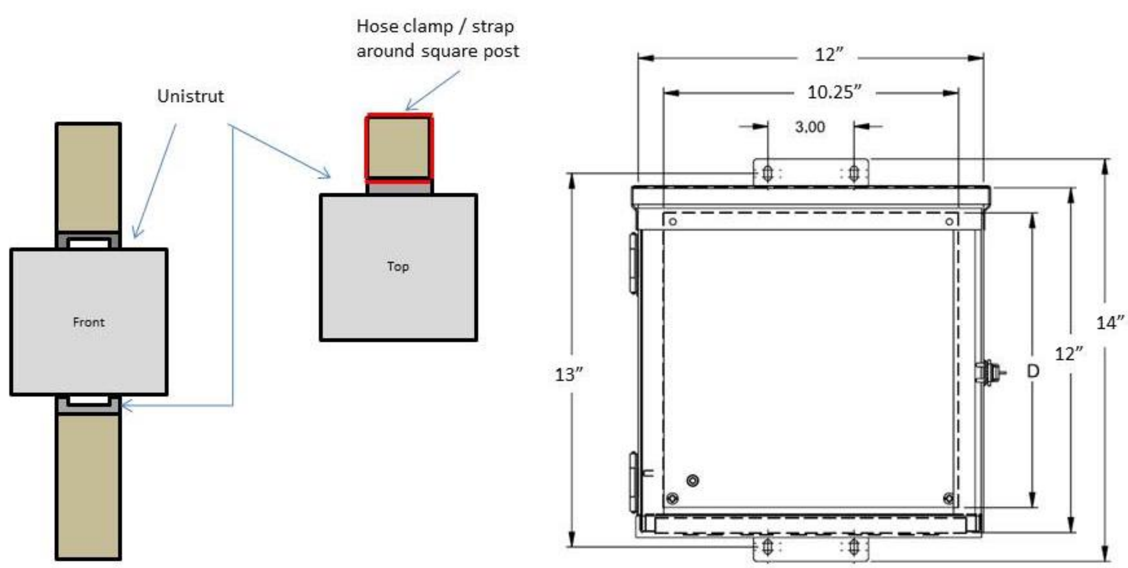


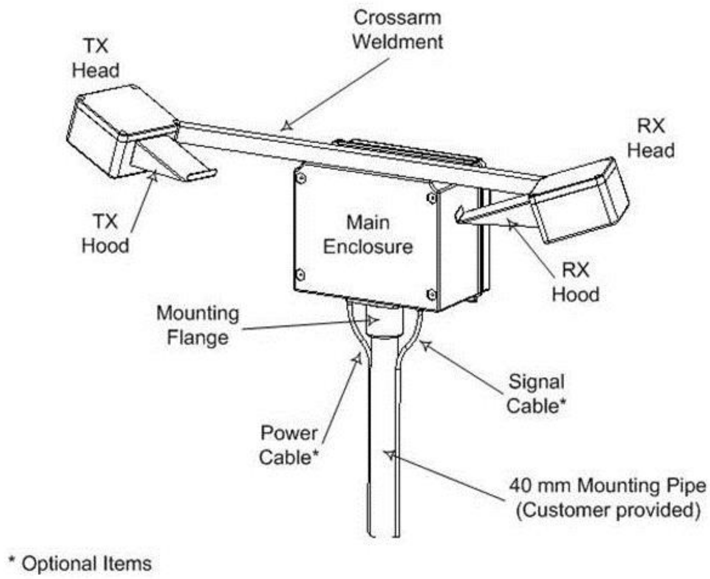
Figure E-6. Trailer Cabinet Installation.

Figure E-7. Trailer Equipment Installation, Photo 1.

Figure E-8. Trailer Equipment Installation, Photo 2.

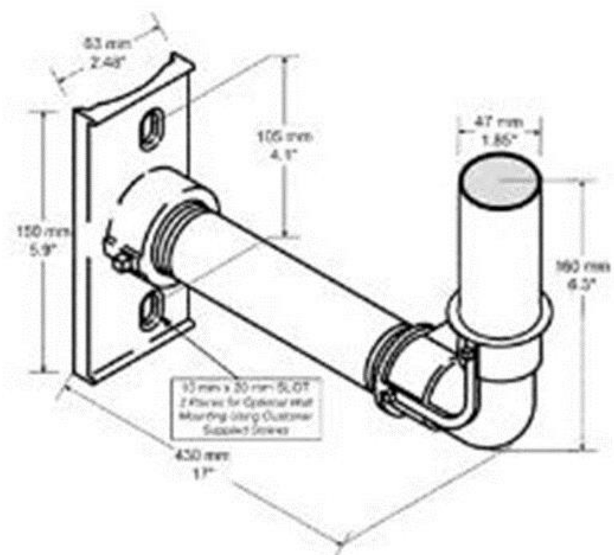
Figure E-9. Ranger Hill—Weather Sensor Installation, Closeup.

Figure E-10. Ranger Hill, Eastland County—Road Condition/Visibility Sensor Installation, Roadside View.



Externally, the Main Enclosure consists of a weatherproof enclosure with hinged door for easy access. A mounting flange is attached to the bottom of the Enclosure for attachment to a support pole of 40 mm diameter (1-½" Schedule 40) pipe. A mounting plate is attached to the backside of the Enclosure for use in calibrating the sensor (not shown in Figure 1.3-1).

Figure E-11. Ranger Hill, Eastland County—Visibility Sensor Installation, Diagram 1.



Used to mount the SVS1 Sentry Visibility Sensor with standard 1-1/2" Schedule 40 mounting flange.

Figure E-12. Ranger Hill, Eastland County—Visibility Sensor Installation, Diagram 2.

Figure E-13. San Antonio—Road Condition Sensor Installation, Closeup.

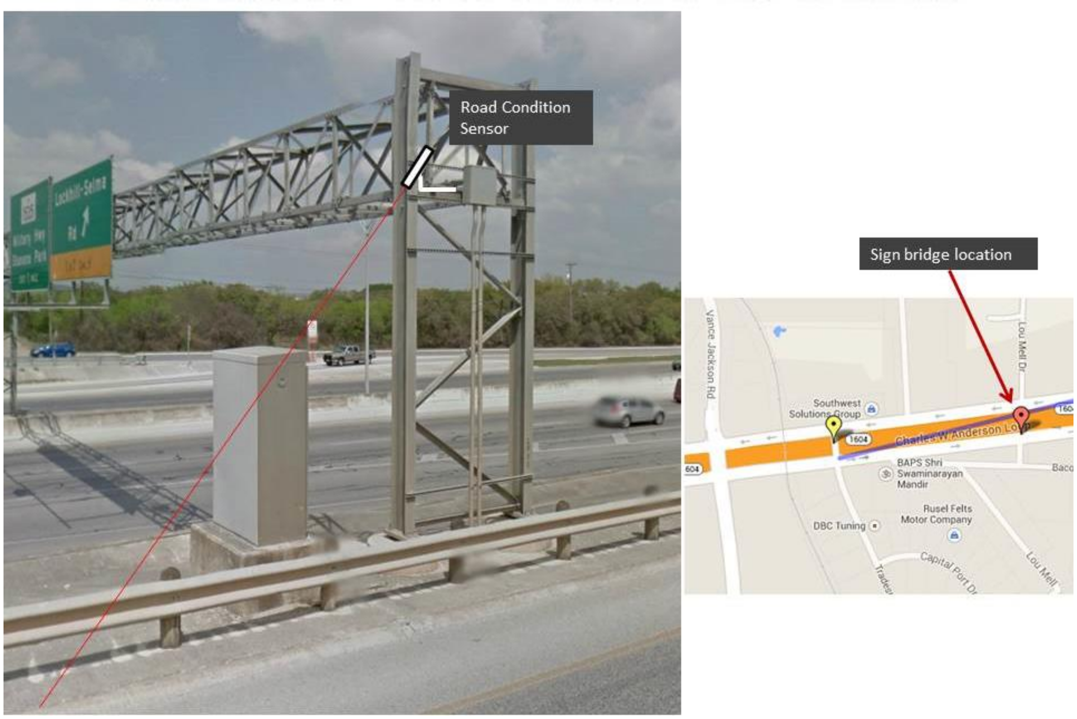


Figure E-14. San Antonio—Road Condition Sensor Installation, Roadside View.

Figure E-15. Temple—Road Condition Sensor Installation, Closeup.

Figure E-16. Ranger Hill, Eastland County (Top) and San Antonio (Bottom)—Road Condition Sensor Installation, Roadside View.

Figure E-17. Sample Sign Field Installation and Setup-Ranger Hill, Eastland County.

Appendix F: Implementation Assistance

Introduction

The purpose of this appendix is to describe the implementation and operation of VSL functionality into the Lonestar ATMS in use by TMCs at each deployment.

Lonestar Modifications

From an operational perspective, the addition of VSLs resulted in the following Lonestar user interface changes:

- System level.
  - VSL algorithm could be turned off/on.
  - VSL speeds could be overridden.
- Device status.
  - A new DMS type for VSLs was created.
  - VSLs in list views were grouped.
  - Queues for VSLs were not modifiable.
- VSL activations.
  - Operator approval screens were added.
  - New events could be created and maintained until conditions returned to normal speeds.
  - Acknowledgment of deactivation was added.
- Web view.
  - Web page with login for viewing system status was created.

System Level

The system allowed, with appropriate permissions, the following override capabilities:

- Turn automatic VSL posting on/off.
  - Operationally, the district sent an email with the reason the VSL was deactivated.
  - No automated posting occurred while deactivated, but normal speed limits were posted.
- Override VSL messages.
  - Operationally, VSL messages were only overridden with the normal speed limits.
  - Any overrides were logged.

Design

Variable speed limit conditions were processed in the data processing application (DPA). The various inputs were used to allow conditions combining, for example, weather and congestion data. The VSL module in DPA then suggested the appropriate speed limits for VSL devices and generated a request for approval. An overview of the data flow and Lonestar processes involved is depicted in Figure F-1. Details of this design are discussed in the subsequent sections.

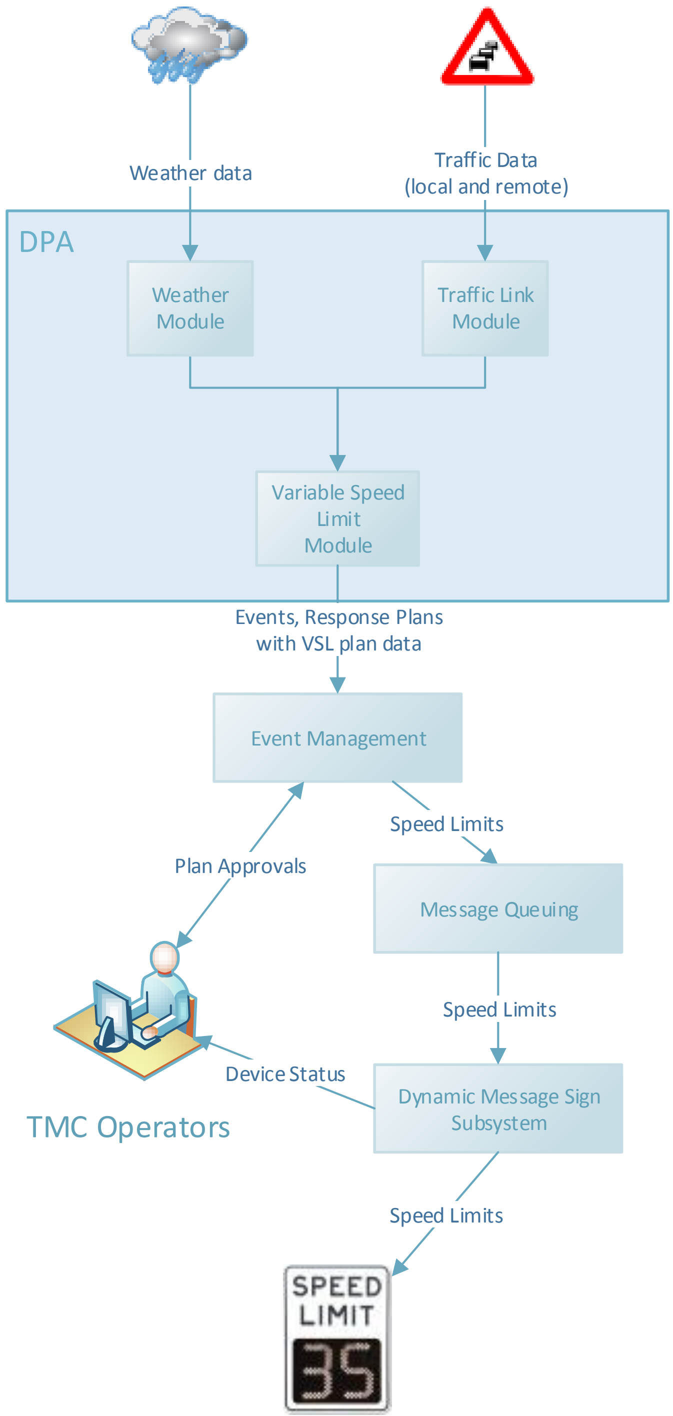


Figure F-1. VSL Data Flow.

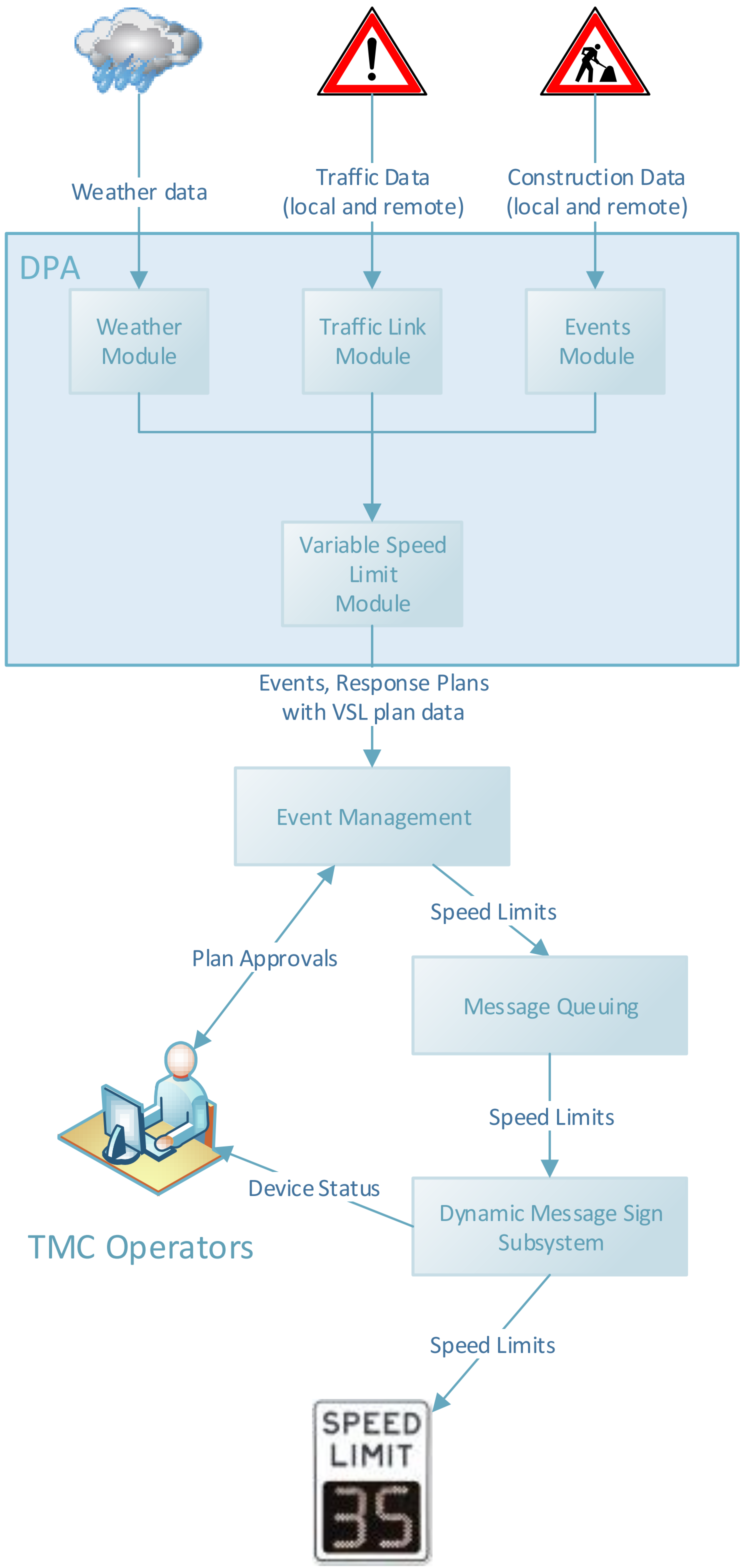


Figure F-1. VSL Data Flow (continued).

DPA Modifications and VSL Module

The Lonestar DPA was enhanced to implement the necessary VSL algorithms and gather associated data inputs. To support the VSL algorithm, new modules were added and some existing modules were expanded to ensure the necessary input data were available. These included:

- New DPA modules:
  - Weather data (pavement and visibility sensors).
  - VSL.
- Existing modules:
  - Existing traffic conditions module, used to monitor local and remote traffic links, provided data to the new VSL module.

The VSL module processes the data received from various input modules and determines if the current speeds are appropriate or if a change should be made. The overall concept is illustrated in Figure F-2. If a change should be made, a message is sent to authorized users requesting approval to implement the updated plan. If rejected, no changes are made and the VSL module waits for the next change in conditions to suggest a new plan.

If approved, the VSL module creates an event management (EM) event to track the occurrence of speed limit reductions. To prevent duplicate/redundant events from appearing on the statewide intelligent transportation system (ITS) website for VSL conditions such as lane closures, the VSL event is set to "private" to ensure it is not pushed out to C2C. After creation, the event's response plan of VSL devices is automatically executed. Upon response plan execution, the appropriate messages are added to the message queuing application (MQA) queue for each VSL device. Operators are unable to add, remove, or otherwise modify VSL plan items in a response plan.

If a change to conditions is detected, the VSL module modifies the existing event's response plan, updating the old VSL items with the new speeds. After the response plan has been successfully updated, the appropriate MQA queue messages are added or updated, as shown in Figure F-3.

Once conditions return to normal, the VSL module terminates the response plan and closes the event that was created. VSL sends the correct normal speed limit for that location, and the lower speed limit message is removed from the queue, as shown in Figure F-4. Returning to normal speed limits sends an operator acknowledgment for notification of the end of the event's timeframe.

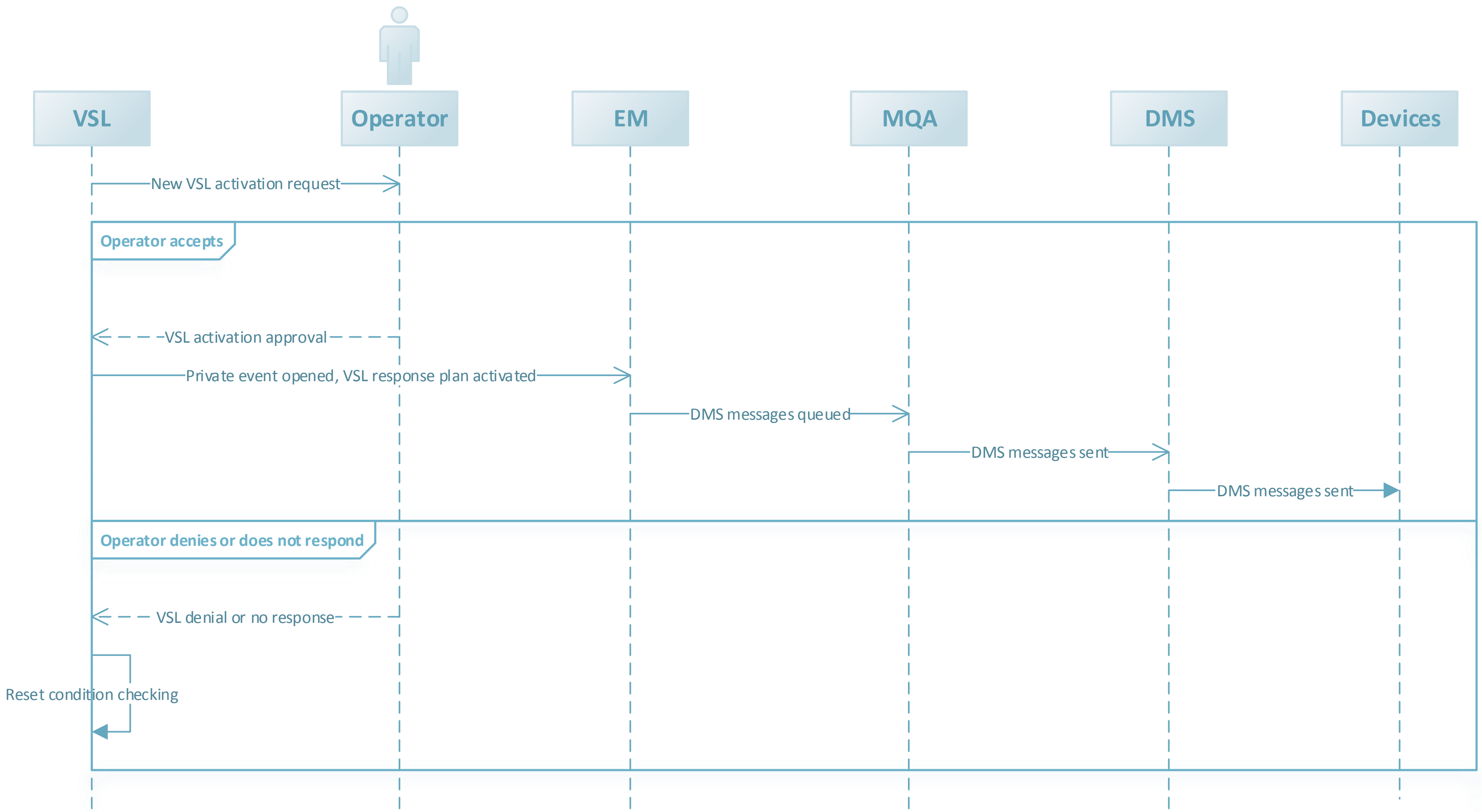


Figure F-2. New VSL Activation.

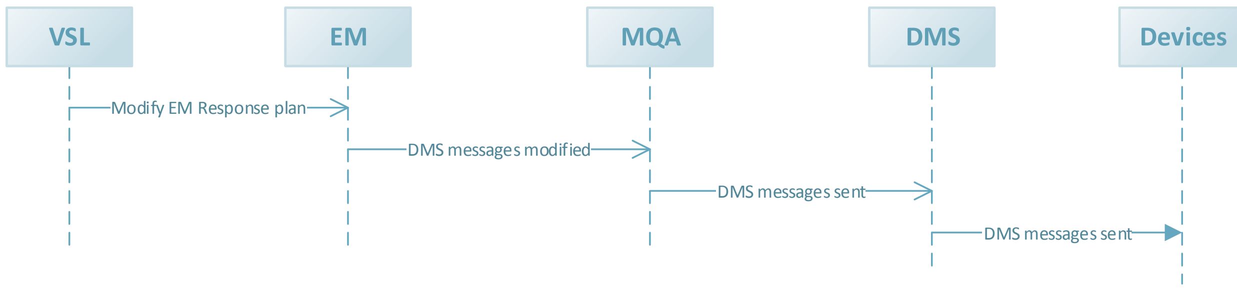


Figure F-3. VSL Modifications after Activation.

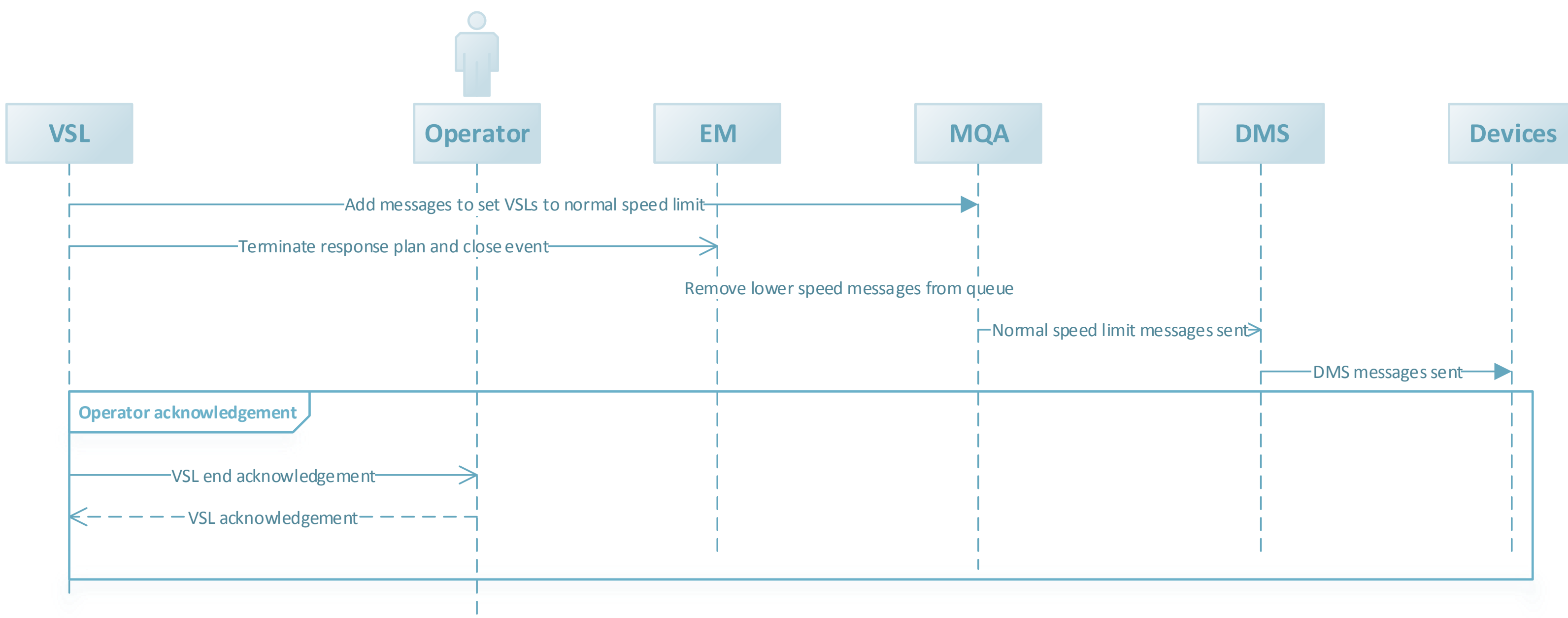


Figure F-4. Return to Normal Conditions.

Error Conditions

The following sections discuss handling of errors in detection devices and VSL devices.

Detection Device Errors

For the weather devices, any errors in communication or valid data not received result in the VSL weather algorithm not triggering modifications to speed limits for that device. For the radar detectors, a single detector not working causes the congestion algorithm to fail to trigger. For the pilot program, if a radar detector experienced loss in communication or was not reporting valid data, the algorithm ignored any missing data and triggered only those detectors that were working.

VSL Device Errors

Handling VSL device errors introduces a high degree of complexity to the VSL system. When communication to an individual VSL sign fails, the displays for the surrounding DMSs may provide inconsistent information. In the pilot program:

- VSLs were displaying the normal speed limits. Lower speed limits were sent to the VSLs, and one failed.
    - VSLs before and after the failed device may display a step down in speed greater than 15 MPH.
    - Until the communication failure timeout is reached by the sign, the failed VSL may display an inconsistent speed.
- VSLs were displaying reduced speed limits. Normal speed limits were sent to the VSLs and one failed.
    - After the failed VSL is blank, the VSLs before and after the failed device may display a step down and back up in speed which may be greater than 15 MPH.
    - Until the communication failure timeout was reached by the sign, the failed VSL may have displayed an inconsistent speed.

For the pilot, activation failures were logged and the results analyzed. The communication and power loss messages configured in the devices were set to ***blank messages***. The Reduced Speed Ahead sign may have displayed a message (i.e., "ROAD WORK AHEAD") while the VSL was not activated.

Algorithms

The following sections detail the algorithms for triggering lower speed limits and for displaying those speed limits on the VSL devices.

Triggering Algorithms

The individual algorithms for each type of input data can result in a set of speeds for VSL signs. If multiple condition types trigger lower speed limits, the lowest value is used.

Weather

Weather inputs consist of visibility and the coefficient of friction. The weather algorithm is shown in Table F-1. Thresholds and resulting speeds are configured per location. One weather device can be assigned one or more VSL devices and thresholds configured which affect each VSL.

Table F-1. Weather Algorithm.

		$F \geq F^{UT}$ **Good**	$F^{LT} < F < F^{UT}$ **Moderate**	$F \leq F^{LT}$ **Poor**
$V > V^T$	Good	Normal speeds	*Speed1*	*Speed2*
$V \leq V^T$	Poor	*Speed3*	*Speed4*	30 mph

Note: Coefficient of friction (F) thresholds are upper, F^{UT}, and lower, F^{LT}; visibility threshold is V^T.

Settings in Table F-2 are based upon the document (last table in "WRTM speed Limits.docx") provided by TTI on April 1, 2014, and modifications to weather speeds sent in emails. The San Antonio and Temple deployments did not have visibility sensors, while the Ranger Hill, Eastland County site had a visibility sensor. Sites without visibility sensors ignore visibility for triggering calculations, as shown in the table.

Table F-2. Weather Settings per Site.

Configuration Value	San Antonio	Temple	Ranger Hill, Eastland County
V^T	n/a	n/a	500′
F^{LT}	0.25 (25%)	0.25 (25%)	0.25 (25%)
F^{UT}	0.45 (45%)	0.55 (55%)	0.45 (45%)
Speed1	60	45	55
Speed2	45	30	45
Speed3	n/a	n/a	50
Speed4	n/a	n/a	40

Congestion

Each VSL has an associated detector. The following information from the detector is used in the algorithm:

- Smoothed speed: The detector's lanes are averaged together to create a link average. Then, a rolling average of the speeds collected during the averaging period is created. The rolling average is performed to smooth out spikes and valleys in the speed data.
- Raw volume: The detector's current volume (number of vehicles) is used to remove suspect data.
- Smoothed occupancy (percentage): A rolling average of the percent occupancy of the link.

Figure F-5 depicts the algorithm for triggering the VSL speeds using the data from a detector. The rule settings are configurable for occupancy and speed thresholds.

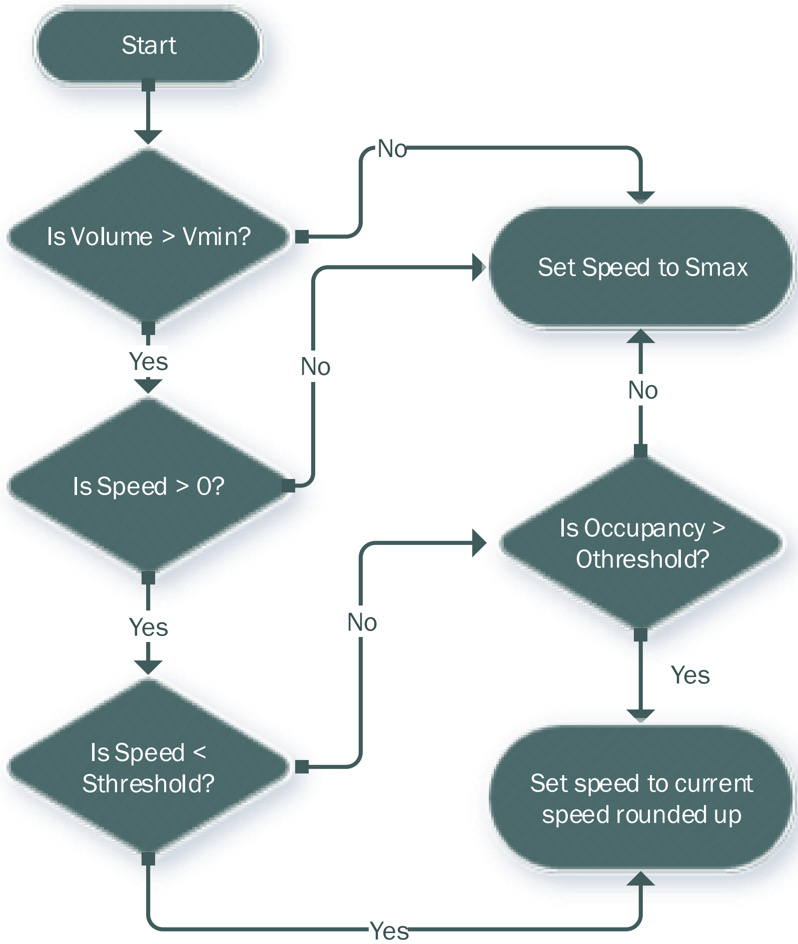


Figure F-5. Congestion Algorithm.

VSL Speeds

The VSL module runs the various triggering algorithms once per minute. Any triggered speeds (S_t) are evaluated, and for the pilot project, the lowest generated speeds for a VSL were used. The other VSLs are evaluated for use in stepping down the speed to the lowered values using these rules:

- Step downs occur in 5–15 mph increments, with 5 preferred.
  - Where a larger step down is required, the speeds displayed are higher than would have been generated (see Examples 5 and 6 in Table F-3.
  - If a larger drop is required on one VSL sign, the first sign shows the larger drop in speed (see Example 1 in Table F-3.).
- Speeds are not stepped up to the normal speed limit after slow speeds, per discussions at VSL meetings (see Examples 1, 2, 3, 4, 5 in Table F-3.).
  - Step ups may occur between two slow target speeds (see Examples 7 and 8 in Table F-3.).

Examples using eight VSLs and speed displayed (S_d) are shown in Table F-3. Direction of travel is from the top to the bottom of the table, and posted speed limit is 65. Target speed is shown only for devices that are not showing free-flow traffic.

Table F-3. Example VSL Speeds.

	Example 1		Example 2		Example 3		Example 4		Example 5		Example 6		Example 7		Example 8	
VSL	S_t	S_d	S_t	S_d	S_t	S_d	S_t	S_d	S_t	S_d	S_t	S_d	S_t	S_d	S_t	S_d
1	65	55	65	55	65	55	65	50	35	50	65	50	65	65	40	50
2	65	50	65	45	65	45	35	35	65	65	40	40	65	60	65	60
3	65	45	65	40	35	35	65	65	65	65	40	40	65	55	65	55
4	65	40	35	35	65	65	65	65	65	65	35	35	50	50	50	50
5	35	35	65	65	65	65	65	65	65	65	65	65	65	50	65	45
6	65	65	65	65	65	65	65	65	65	65	65	65	65	45	65	40
7	65	65	65	65	65	65	65	65	65	65	65	65	40	40	65	35
8	65	65	65	65	65	65	65	65	65	65	65	65	65	65	30	30

Data Collection

To assist in providing data for the report from the pilot project, information about the input data and results of the algorithm were collected and stored by Lonestar. The data were then provided to TTI for analysis.

- Input conditions—Data for the inputs were saved by Lonestar. These data included the weather conditions that were collected, traffic data from sensors, and lane closures.
- Triggering conditions—For each triggering of adjusted speed limits or return to normal speed limits, the inputs that caused the trigger were saved for the associated VSL plan.
- Time when operators were sent the approval request, time when it was approved or rejected, and which user responded to the request were saved.

A website with system status and downloadable files for each planned installation was available to users with logins. The website contains the following information:

- Current VSL plan status.
    - Location.
    - Current status time.
    - On/off.
    - Currently activated/not activated.
    - Last time activated.
    - Triggering conditions.
    - Downloadable historical activations.
- Detection devices (traffic links, weather devices).
    - Active/error/failed/out of service.
    - Current data feed.
    - Downloadable data feed files.
    - Last update time.
- VSL devices.
    - Active/error/failed/out of service.
    - Current displayed speed limit.
    - Downloadable historical data for status and display.

District Procedures

Following is a discussion of the overall district procedures for the operation of the VSL pilot projects. Specific information is provided in the following sections regarding procedures in each district. For each location, the VSL module processed the data received from various input modules and determined if the current speeds were appropriate or if a change should be made. If a change needed to be made, a message was sent to authorized users (i.e., operators in the TMC) requesting approval to implement the VSL plan. If the operator had access to camera images from the site, he or she could view them and confirm whether the request for the VSL was appropriate given the current conditions. The operator needed to accept the request for the VSL plan to go into active status. Rejection of the request caused the system to continue its current operation, and the VSL module waited for the next change in conditions to suggest a new plan.

If the operator observed that the VSL plan was not deploying correctly, he or she had to deactivate the VSL subsystem and notify the appropriate director of traffic operations for the district (or his/her designee) that the system was deactivated and provide a reason for the deactivation. When the VSL plan was deactivated, the signs reverted to the normal speed limits for that facility.

If the operator observed that one or more of the VSL signs were not functioning properly, he or she had to notify the appropriate director of traffic operations for the district (or his/her designee) of the problem and send TTI an email notifying staff of the problem as well.

San Antonio

Once installed, the San Antonio (SAT) operators could view the camera images from the site to confirm whether the request for VSL was appropriate given current conditions.

Temple

Operators in FTW controlled the Waco (WAC) operations for the approval of VSL plans for the Temple site using the RCA.

Ranger Hill, Eastland County

Operators in Fort Worth (FTW) controlled the Brownwood (BWD) operations for the approval of VSL plans for the Ranger Hill, Eastland County site using the remote command application (RCA).

Fort Worth

For the BWD/Eastland pilot study location, FTW operators could view the camera images from the site to confirm whether the request for VSL was appropriate given current traffic conditions. For the WAC pilot study location, no cameras were visible to confirm operating conditions.

VSL System Administration

The following sections detail the steps followed for setting up the VSL devices, rules, and configurable settings.

Add Devices

The first step was to add the appropriate DMSs, detectors, and weather devices to the Lonestar software.

VSL DMS

The DMSs used for VSL were configured the same as other National Transportation Communications for ITS Protocol (NTCIP) devices using TCP/IP. The only difference when adding these DMSs involved selecting the appropriate sign type on the “DMS Type” drop down. Standard VSL signs were “VSL,” while the RSA signs were “VSL RSA.” The configuration for the DMSs is provided in Figure F-6.

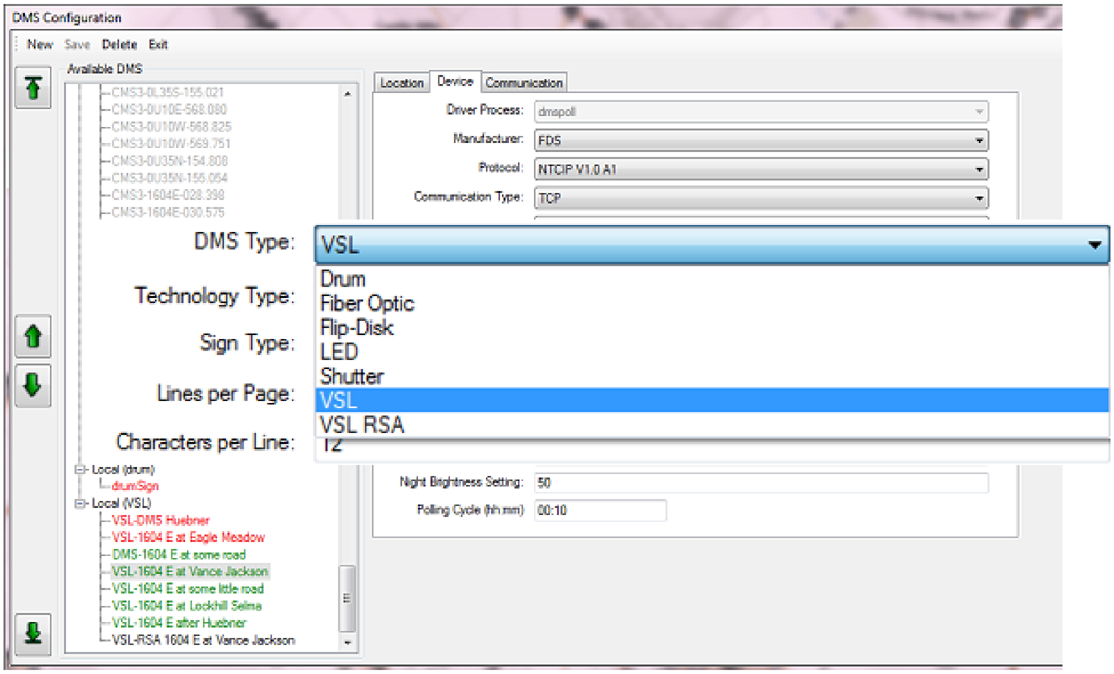


Figure F-6. DMS Configuration for VSLs.

Detectors

The radar detectors were Wavetronix 126 and were added to the Transportation Sensor Subsystem (TSS) using the WavetronixHD protocol and lanes configured according to information provided by TTI.

Weather Devices

Weather devices were defined in the configuration file for Lonestar. The weather devices were in the XML under the DPA weather module, as shown in Figure F-7. The configuration for the weather devices is shown in Figure F-7 as well.

```xml
<weatherModule>
    <!-- seconds to wait between polls to a given device -->
    <pollRate>60</pollRate>
    <!-- seconds to wait for a poll to timeout -->
    <pollTimeout>5</pollTimeout>
    <deviceList xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
        <!-- valid xsi:type values include: iceSight and rwisVisibility -->
        <weatherDevice xsi:type="iceSight" host="166.155.233.208" port="2110" serialAddress="A">
            <id providerName="dpa" centerId="SAT">tti-friction</id>
            <location>
                <roadway>IH-10</roadway>
                <direction>South</direction>
                <crossStreet>35 South</crossStreet>
                <latitude>25</latitude>
                <longitude>75</longitude>
                <locationName>tti-friction</locationName>
            </location>
        </weatherDevice>
        <weatherDevice xsi:type="rwisVisibility" host="166.155.233.208" port="2111">
            <id providerName="dpa" centerId="SAT">tti-visibility</id>
            <location>
                <roadway>IH-10</roadway>
                <direction>South</direction>
                <crossStreet>35 South</crossStreet>
                <latitude>25</latitude>
                <longitude>75</longitude>
                <locationName>tti-visibility</locationName>
            </location>
        </weatherDevice>
    </deviceList>
```

Tag	Values
pollRate	How frequently the devices should be polled, in seconds.
pollTimeout	How long to wait for a response from the device, in seconds.
weatherDevice	The information about connecting to the device and the location of the device: • Types are iceSight (friction) and rwisVisibility (visibility). • Host/port for the device. • iceSight devices have a serialAddress; visibility devices do not. • Location should be the same roadway/direction as VSL devices.

Figure F-7. Weather Device Configuration.

Roadway Order

Once the devices were configured, they were placed into the correct roadway order on the system administration application (SAA) equipment ordering screen, as shown in Figure F-8.

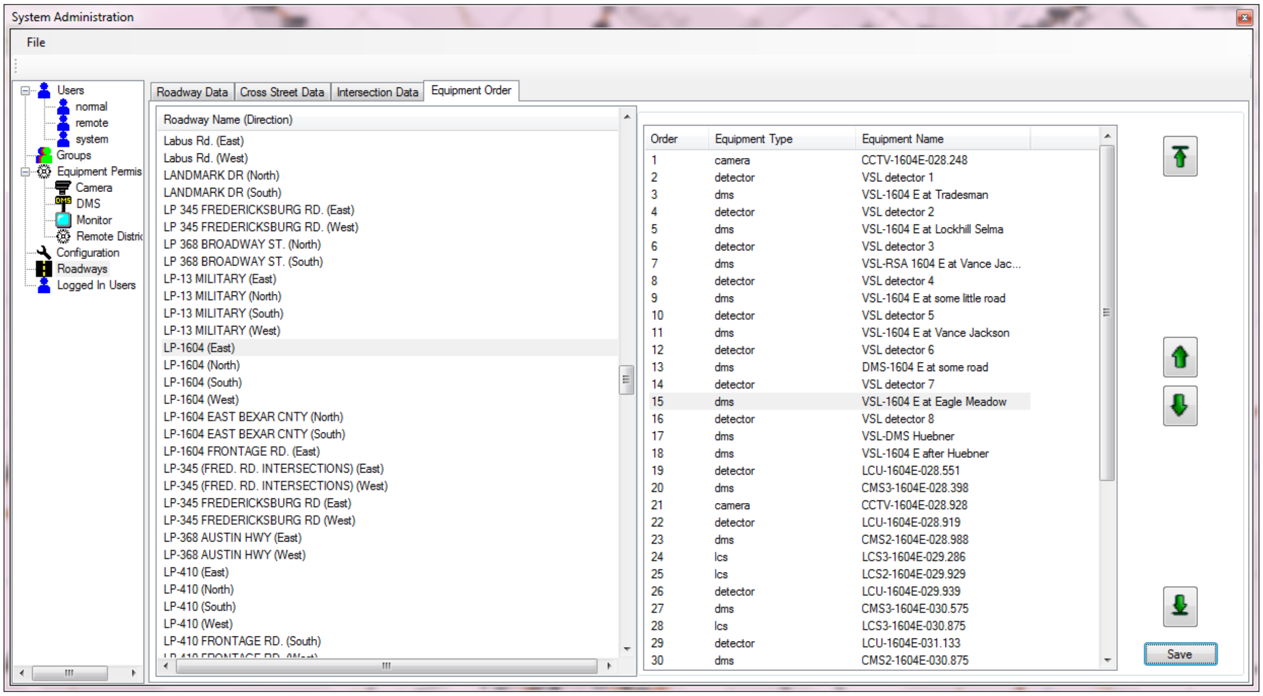


Figure F-8. SAA Roadway Ordering.

VSL Sign Configuration

For the congestion algorithm, each VSL sign was associated with a TSS detector link. The screen was accessed from the DPA/VSL/VSL Sign Configuration menu item, as shown in Figure F-9.

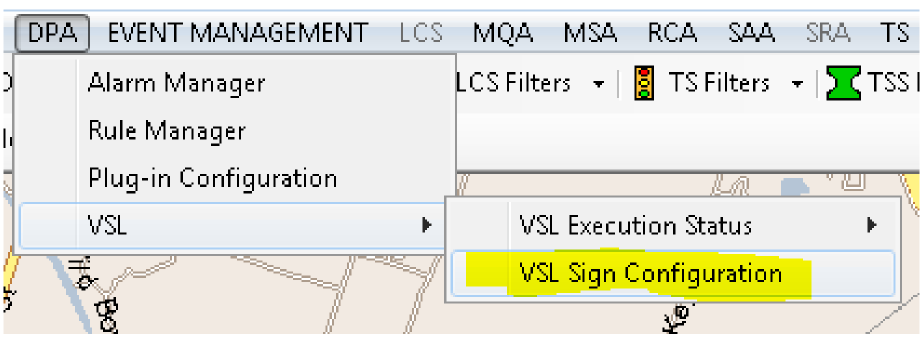


Figure F-9. Accessing VSL Sign Configuration.

The VSL Sign Configuration dialog allowed a speed limit and a TSS link to be associated with a VSL sign. Only DMSs of type VSL were displayed. Double clicking on the Speed Limit column allowed a number to be typed in the field. The Link ID drop down displayed detector links that were configured in the system and could be selected for association, as shown in Figure F-10. Entries were red until valid configuration items were saved.

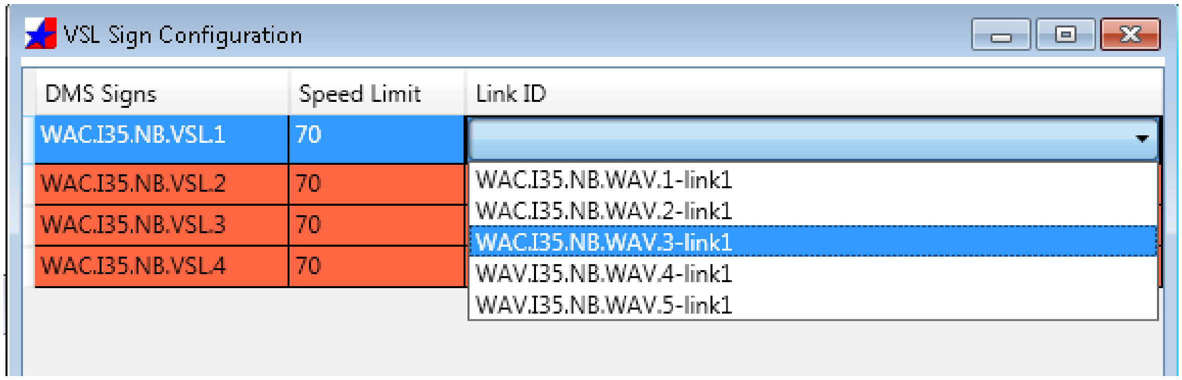


Figure F-10. VSL Sign Configuration.

Once each VSL sign had a speed limit and link associated and changes were saved, the red background became white to indicate valid configurations were saved, as shown in Figure F-11.

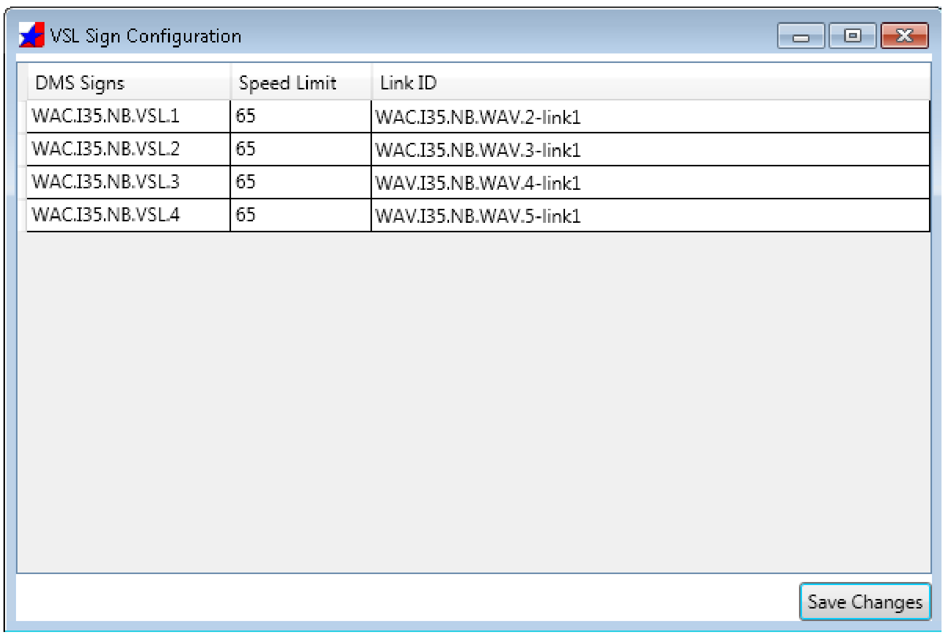


Figure F-11. Saved VSL Sign Configuration.

VSL Rules

Using DPA, VSL rules were created for the following:

- TSS link speed, volume, and occupancy thresholds.
- Weather device thresholds for friction.
- Weather device threshold for visibility (in BWD only).
- VSL plan rule.

TSS Rules

The rule for matching detectors included the minimum volume, speed, and occupancy for lowering the speed limits. For example, a minimum volume of five vehicles or 10 percent occupancy may be desired in order to lower speed limits. The speed value set in the rule was the value at which VSL speed limits were implemented. If 50 mph was set in the rule, the speed limits would not be lowered until speeds were less than 50. An occurrence threshold could also be set to specify how many consecutive poll cycles the conditions had to meet before triggering. Example rule settings are shown in Figure F-12, Figure F-13, and Figure F-14.

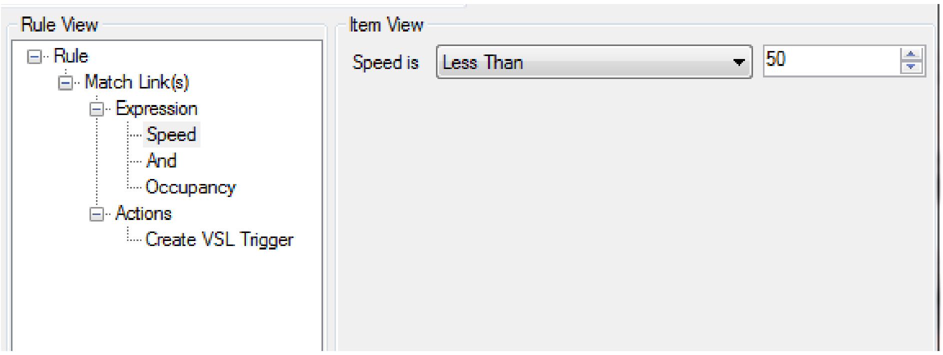


Figure F-12. VSL TSS Speed Threshold.

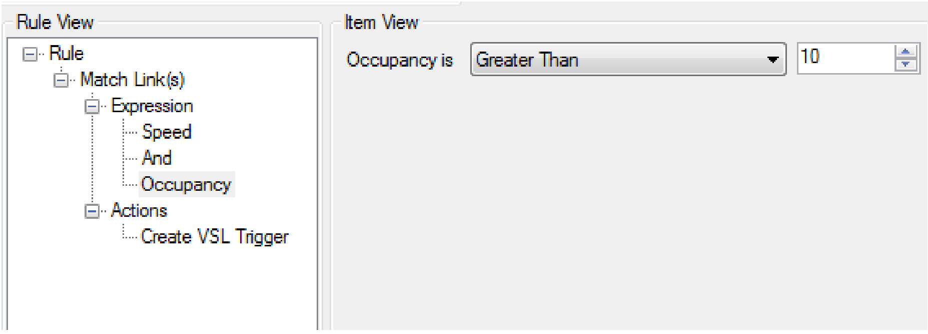


Figure F-13. VSL TSS Occupancy Threshold.

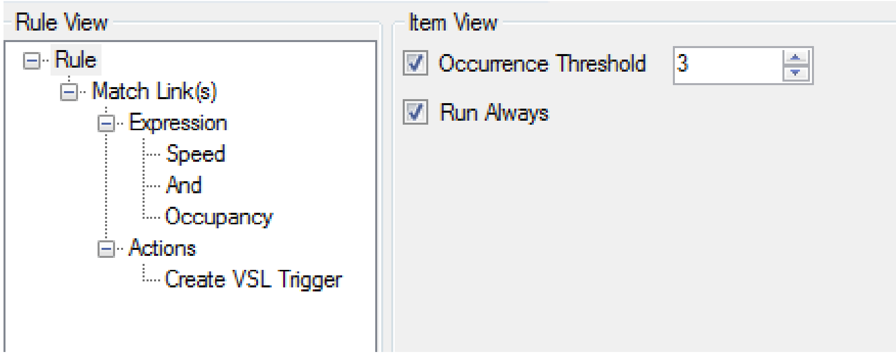


Figure F-14. VSL TSS Occurrence Threshold.

Friction Rules

The friction weather rules have just one setting for when the friction falls below a threshold or is between two values. For the purposes of the pilot, one rule was created with the setting less than 25 (percent) for poor friction, as shown in Figure F-15. A second rule for moderate friction was created with settings to be greater than or equal to 25 and less than 55, as shown in Figure F-16.

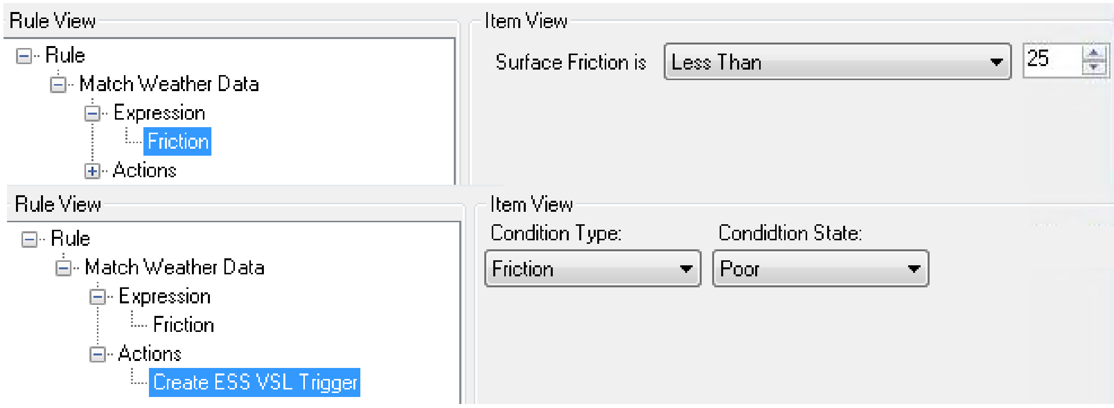


Figure F-15. Friction Poor Rule.

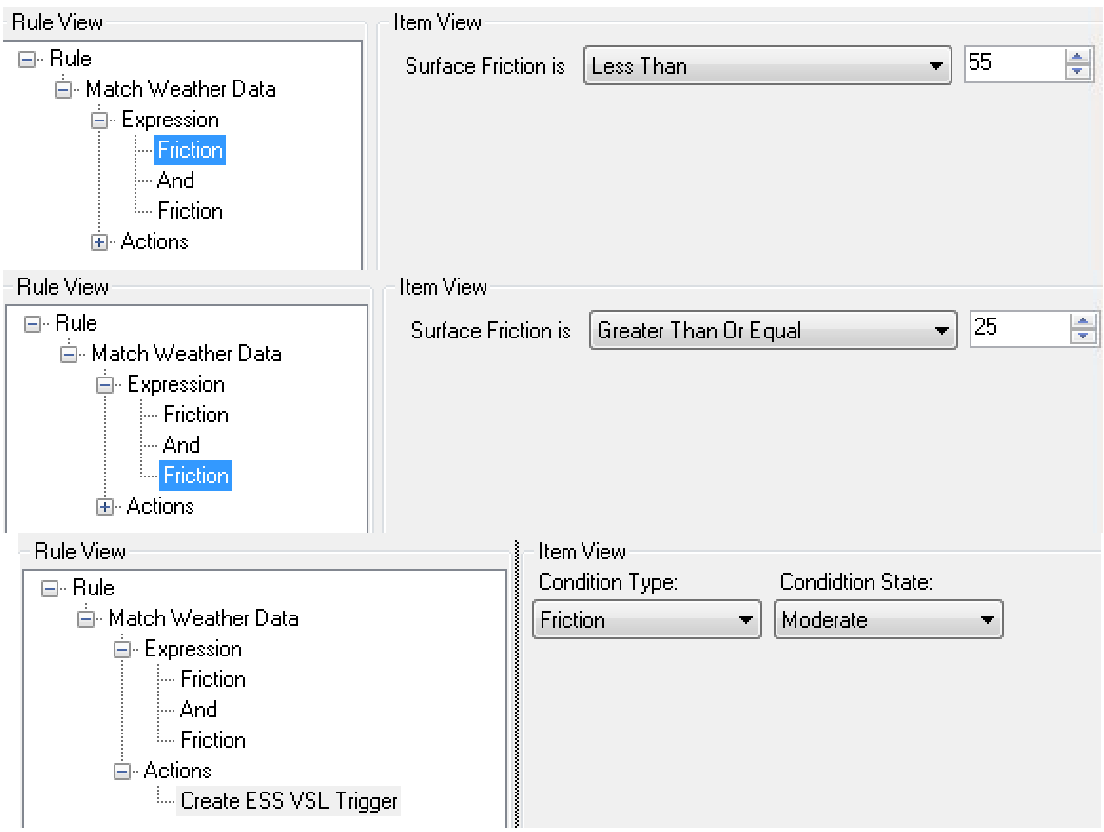


Figure F-16. Friction Moderate Rule.

<u>Visibility Rule</u>

One visibility rule was also created for BWD only with a setting of less than 500 ft designated as poor visibility, as shown in Figure F-17.

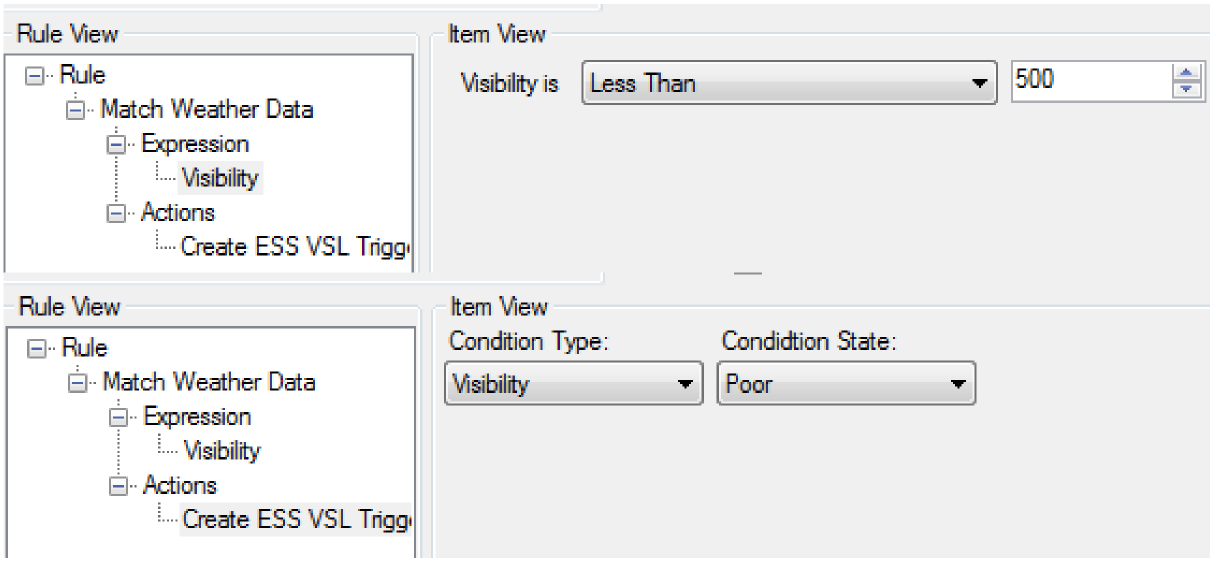


Figure F-17. Visibility Poor Rule.

<u>VSL Plan Rule</u>

The next rule was used for triggering VSL plans and alerts for VSL plans. There were no expressions on the rule and no options for the alert. This rule, as shown in Figure F-18, could be used for setting up contact notifications, a s described later.

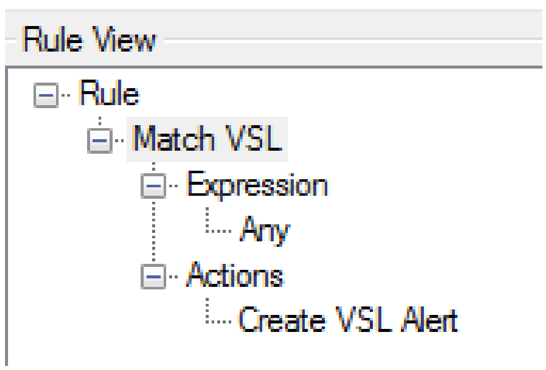


Figure F-18. VSL Plan Rule.

Permissions

New user permissions were added to Lonestar for VSL configuration, approvals, and override capabilities.

<u>VSL Configuration</u>

The DPA permission highlighted in Figure F-19 was required to view and edit the VSL configuration data. Permission to modify VSL alarms was required to approve or deny VSL plans.

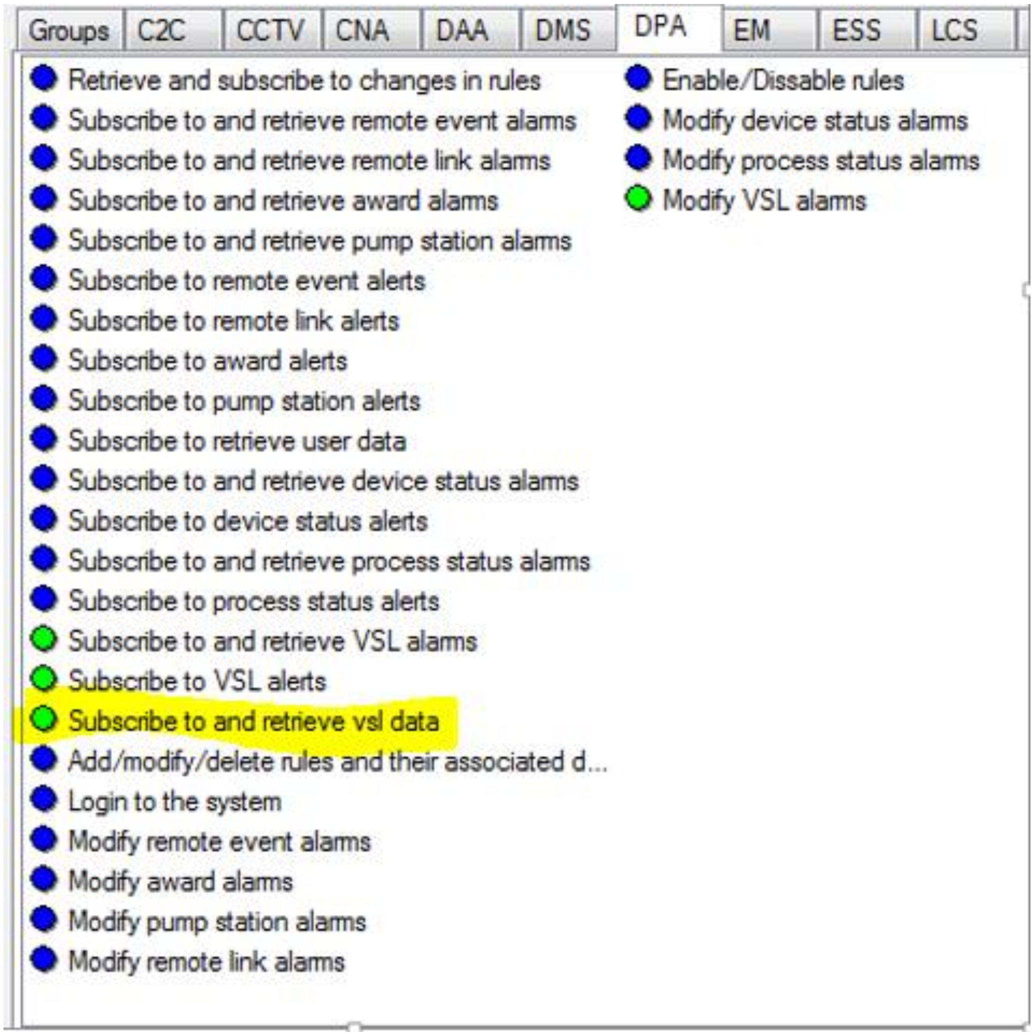


Figure F-19. DPA Permission for VSL Configuration.

VSL Plan Approval Permission

The modify VSL alarms permission allowed an operator to approve or deny a VSL plan activation, as shown in Figure F-20.

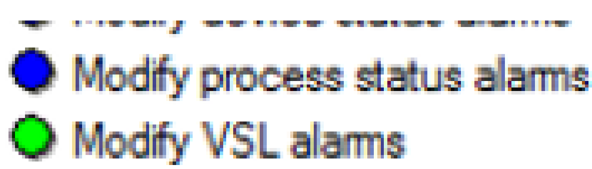


Figure F-20. DPA Permission for VSL Plan Approved.

VSL Override Permission

The DMS permission for sending a message to VSL DMSs (as shown in Figure F-21 as a non-allowed permission) allowed an administrator the ability to override the messages on the VSL signs. As mentioned, operationally, this feature should have only been used to send the default speed limits to the VSLs. This permission also affected whether a user could turn the VSL algorithm on or off.

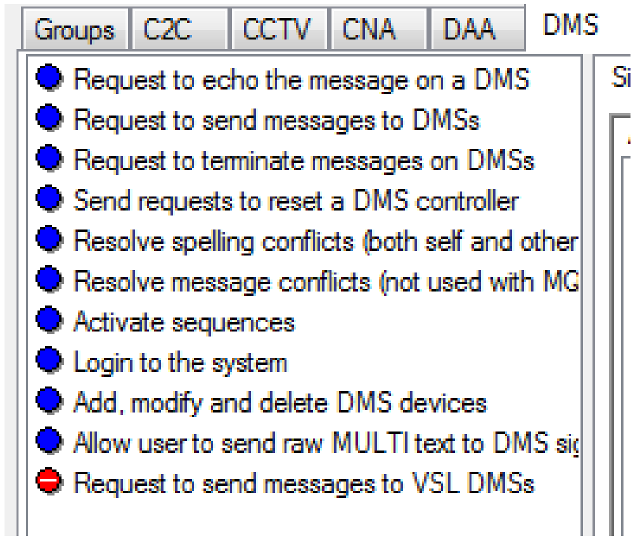


Figure F-21. DMS Permission Override VSL Message.

Configuration File Settings

The following sections detail the changes to the configuration file for VSL operations, as shown in Figure F-22.

```
<vslModule>
    <vslExecutionIntervalSeconds>60</vslExecutionIntervalSeconds>
    <minimumSpeedLimit>30</minimumSpeedLimit>
    <messageRow>2</messageRow>
    <!-- This only needs to be specified if justify-left should be used instead of justify-center on VSL messages -->
    <!--<messageColumn>4</messageColumn>-->
    <rsaMessage>[jl3]REDUCED[nl]SPEED[nl]AHEAD</rsaMessage>
    <loggingDatabase>
        <host>LS-ITS-DB</host>
        <databaseName>vsl_logging</databaseName>
        <user>user</user>
        <password>password</password>
    </loggingDatabase>
    <weatherSpeedLimits>
        <speedLimit level="1">45</speedLimit>
        <speedLimit level="2">30</speedLimit>
        <speedLimit level="3">50</speedLimit>
        <speedLimit level="4">40</speedLimit>
        <speedLimit level="5">30</speedLimit>
    </weatherSpeedLimits>
</vslModule>
```

Figure F-22. DPA VSL Module Configuration Settings.

<u>*VSL Operations*</u>

The flags in Table F-4 pertain to VSL operations.

Table F-4. VSL Operation Flags.

Tag	Values
vslExecutionIntervalSeconds	How frequently the VSL algorithm will run, in seconds.
minimumSpeedLimit	The lowest speed limit the algorithm should use (should always be 30, but made configurable in case this changes in the future).
messageRow	The row of the MULTI message that should contain the speed value.
messageColumn	Optional—only required if the speed messages should not be centered.
rsaMessage	The message used for the sign announcing reduced speeds.

Logging Database

The flags under the logging database contained the location and login information for the VSL logging database used by the website. This was the same for all sites.

Weather Algorithm Speeds

The next section of the configuration file defined the speeds that should be used in the weather algorithm. These speeds had to correspond to the speeds shown in Table F-2. The Level 5 speed limit was set to the minimum speed limit value (this represented the case of both friction and visibility being poor, as shown in Table F-1).

Administrative Operations

In addition to the Lonestar™ VSL operations defined in the next section, administrators with the override permission were able to perform the following functionality. Note that the software, with administrator permissions, did not prevent manual operations such as putting up lower than the default speed limits, but operational procedures were in place to specify what was allowed.

Turning VSL On/Off

VSL execution could be turned off by an administrator. Operationally, the reason for turning VSL off was noted for later inclusion in the evaluation of the pilot project. Turning VSL off terminated any existing response plan, causing the signs to return to default speed limits. A screen shot of this process is shown in Figure F-23.

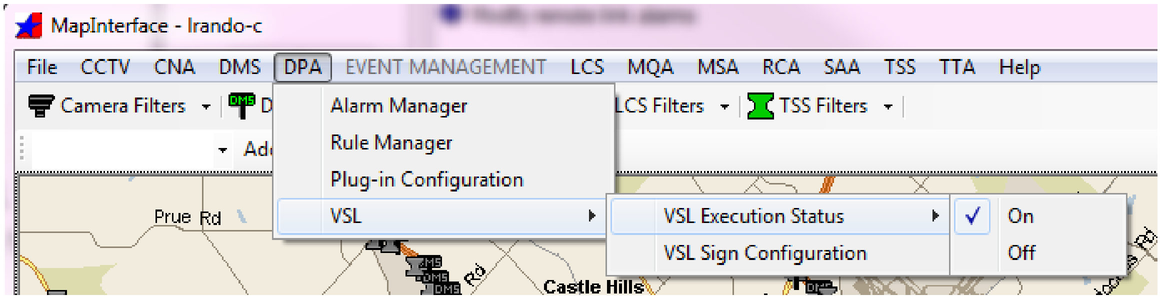


Figure F-23. Set VSL On/Off.

Overriding VSL Messages

With the appropriate permission, administrators were able to place messages in the queue for VSL and VSL RSA signs. This action was performed the same as sending messages to a normal DMS. To override a VSL automated speed limit, the user placed a new message with a higher priority. With this permission, the user could also modify messages in the queue. However, operationally, this was ***NOT*** recommended, as the queue messages are controlled automatically.

Adding Notifications

Notifications for VSL activations could be added to contacts or groups using the contact notification application (CNA). Users could select "Manage Contacts and Groups" from the CNA menu on the map interface or the CNA stand-alone user interface, as shown in Figure F-24.

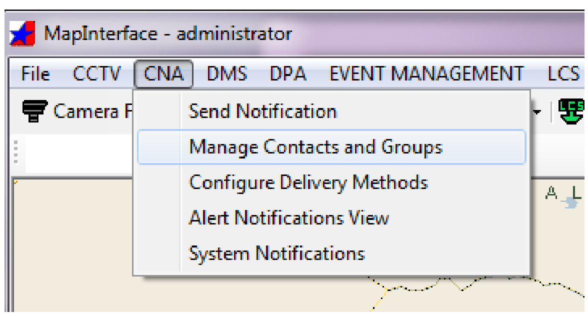


Figure F-24. Opening Contact Notification Setup.

Next, a user could select the user or group for which notifications should be created by selecting "Configure Notification" and then selecting the rule for the notification, as shown in Figure F-25.

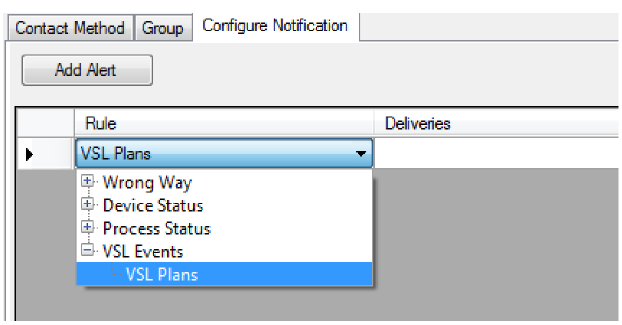


Figure F-25. Select VSL Plan Rule.

Next, the user could select the delivery method(s) that should be used for the notification, including both email and popups to the user interface. If configuring notifications for a group, the user could select the "Default Email" option, as shown in Figure F-26.

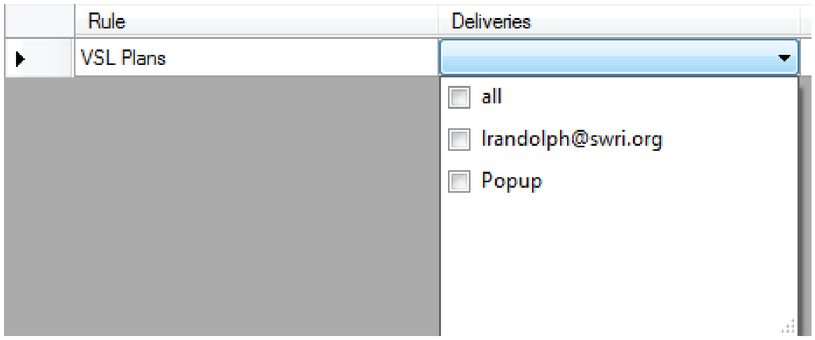


Figure F-26. Notification Methods.

Figure F-27 shows the notification setup for a contact group using default emails for all contacts in the group, all days of the week, and for the entire day.

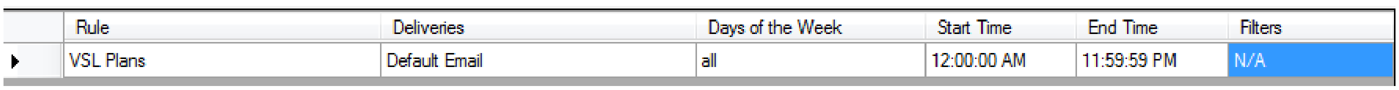


Figure F-27. Sample Notification Configuration.

Website

The VSL website (http://its.txdot.gov/VslWeb) was used to view the current or past status of the VSL operations. The website was an access-controlled website. When initially accessing the site, users saw the login page, as shown in Figure F-28. Users could create an account, if needed.

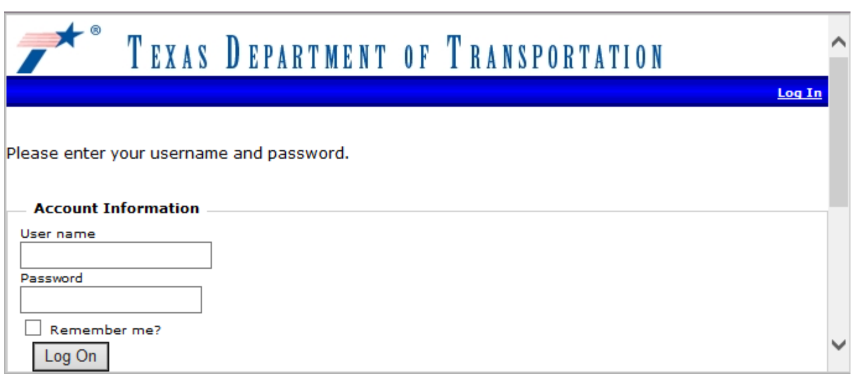


Figure F-28. Website Login.

User name and password had to be entered. The "Remember me?" checkbox allowed user information to be stored for quicker login. Once the user logged in, the list of districts was displayed, as shown in Figure F-29.

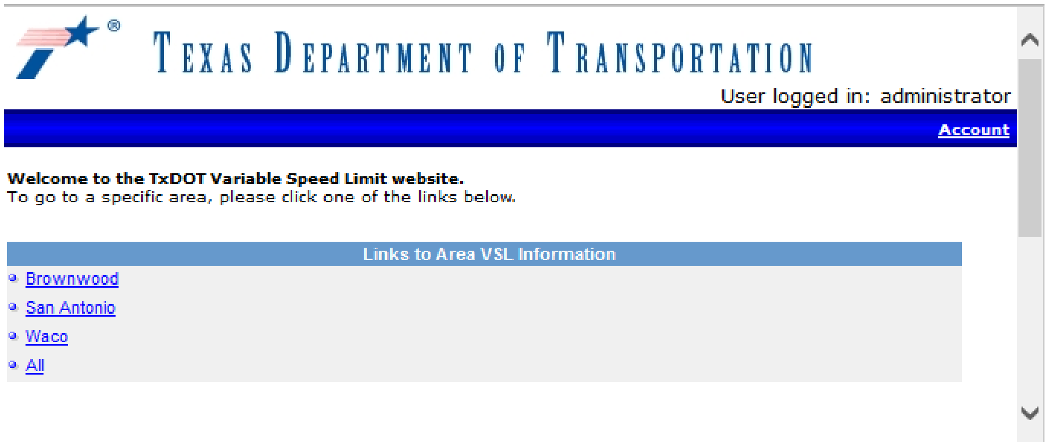


Figure F-29. Website Select District.

Once a district was selected (or the user chose "All" to select all districts), the website displayed the current plan status, as shown in Figure F-30. The current plan status showed the RSA and VSL signs with their current messages. In Figure F-31, the eastbound signs are showing normal speeds, while the westbound signs are displaying reduced speeds.

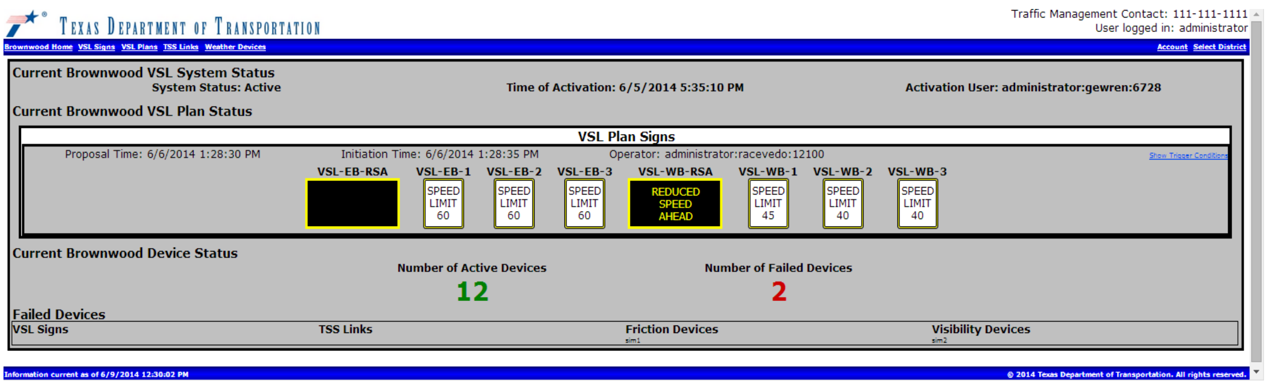


Figure F-30. Website Current VSL Plan Status.

Selecting the "Show Trigger Conditions" link allowed users to expand the plan to show the conditions that resulted in the currently displayed speeds, as shown in Figure F-31.

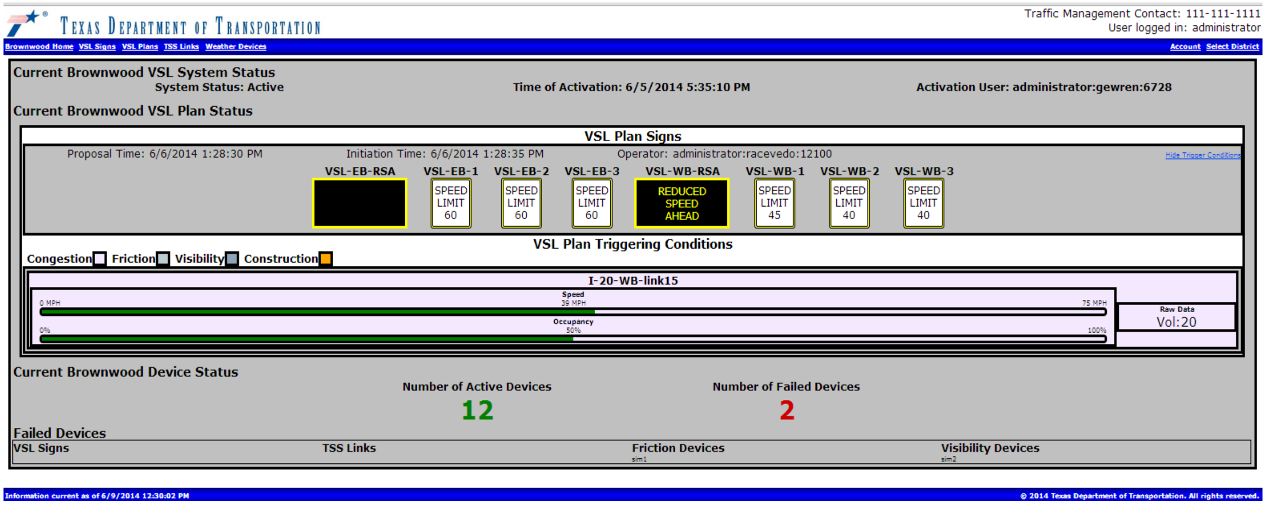


Figure F-31. Current Plan Status Triggering Conditions.

Other links across the top menu could be selected to view VSL signs, VSL plan history, TSS links, or weather device information.

VSL Signs

Current VSL sign status could be viewed from the "VSL Signs" menu link, as shown in Figure F-32.

The user could also search the history of one or more VSL signs and view their status. To view a graph of the speed limit and communication history, the user selected a start and end date/time, then selected one or more signs, and then clicked the "Search" button.

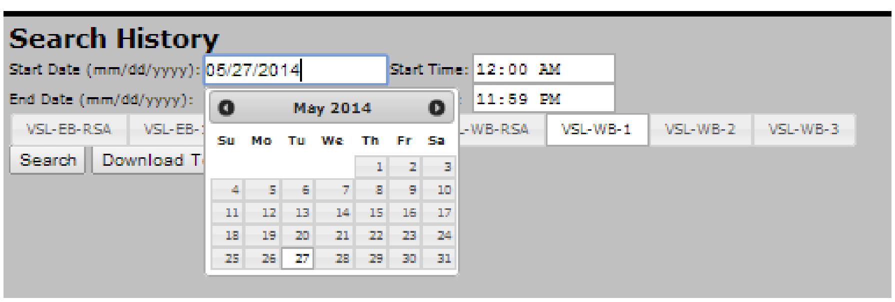


Figure F-32. VSL Sign Status Search.

The results of the search are displayed in Figure F-33. The points on the graph representing communication to the sign were blue when the sign was active. Errors were displayed in red, as shown at the beginning of the graph. If communication was lost to the sign, the graph showed a yellow line. Regaining communication caused the graph to display a green line, as can be seen at three different times in the graph in Figure F-33.

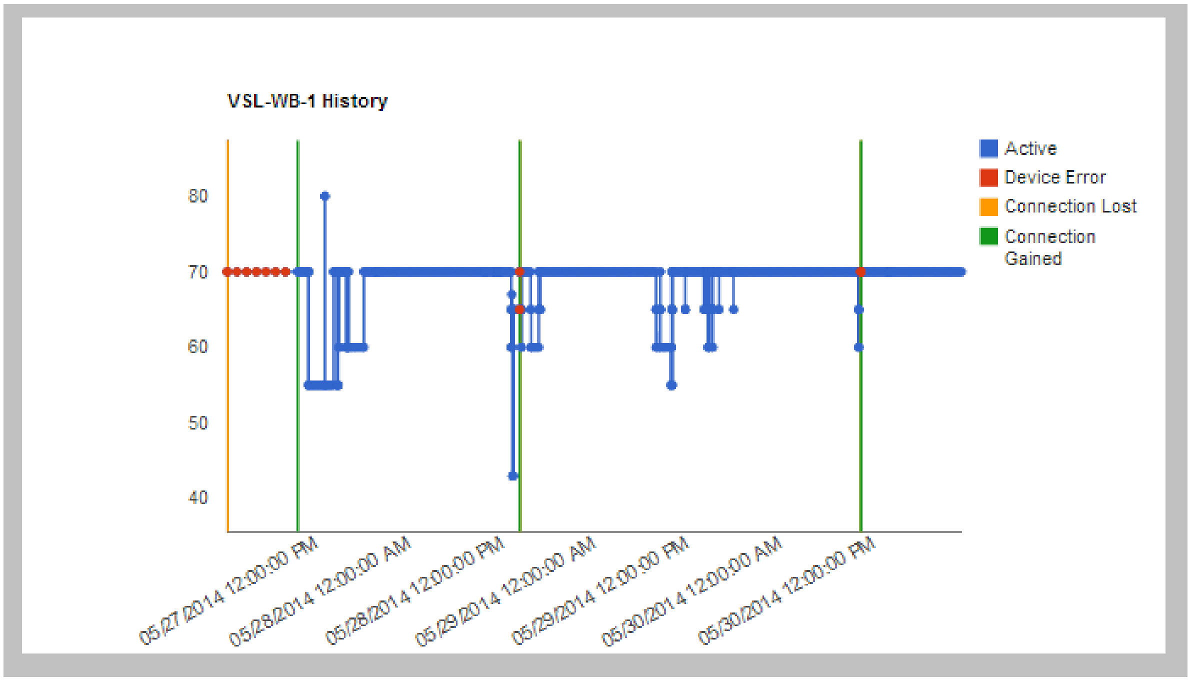


Figure F-33. VSL Sign Status Graph.

If communication was lost and immediately regained, the yellow line may not have been visible unless the timeline was zoomed in, as shown in Figure F-34.

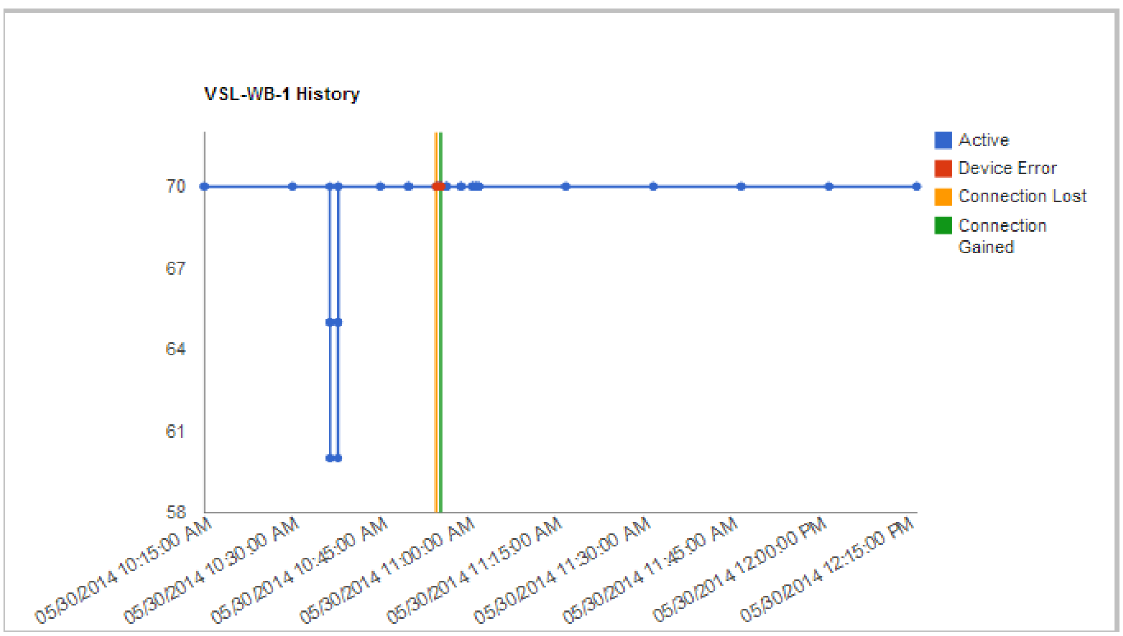


Figure F-34. VSL Sign Status Communication Loss.

The user could also choose the "Download to CSV File" option, as shown in Figure F-35.

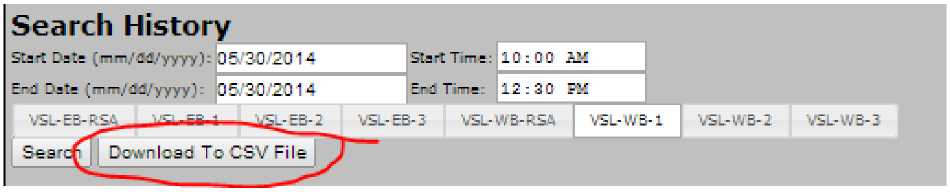


Figure F-35. Download to CSV File.

VSL Plans

The website could also be used to look at VSL plan history or download the plans to an XML file. The plan history was viewed in a similar manner as plans with the ability to toggle viewing the triggering conditions, as shown in Figure F-36.

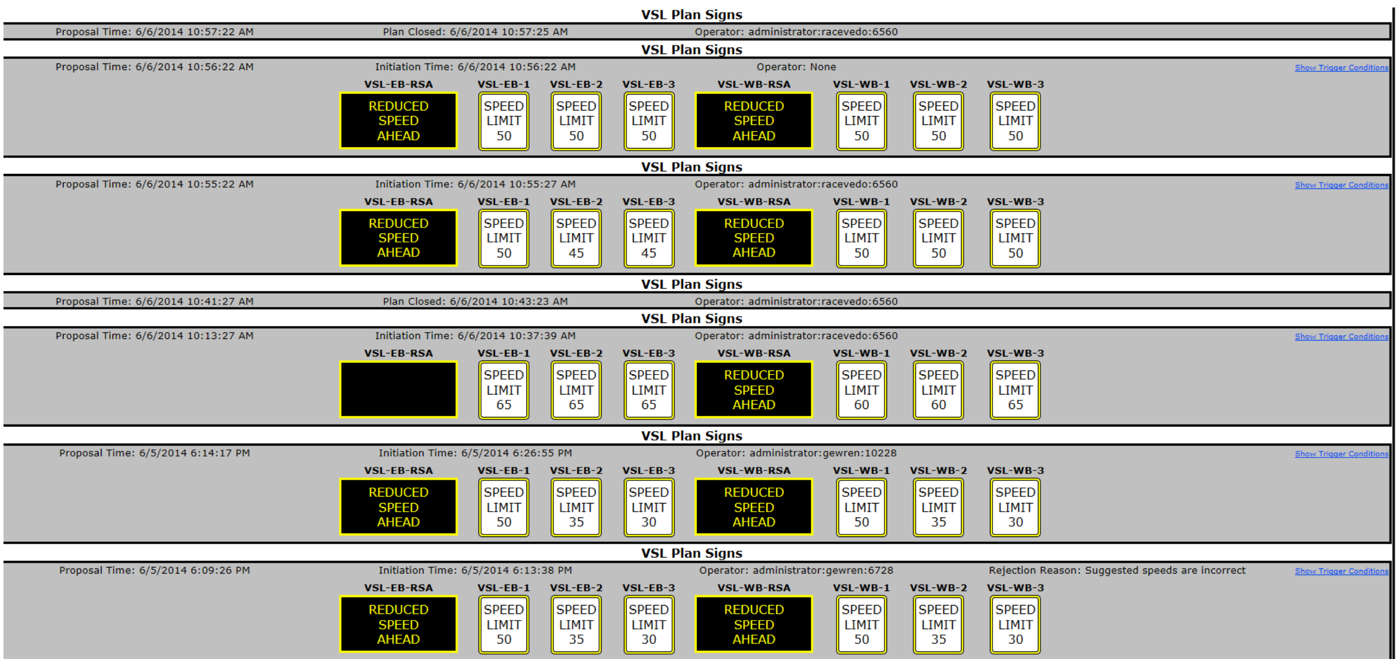


Figure F-36. VSL Plan History.

The VSL plan history entries consisted of the types shown in Table F-4.

Table F-4. VSL Plan History Entries.

VSL Plan History Entry	Description
Initial plan activations	The operator who approved the plan was noted at the top of the block along with the initiation time.
Plan rejections	The operator who rejected the plan was noted along with the rejection reason and the initiation time.
Automatic plan modifications	Subsequent to operator approval, modifications were made to speeds automatically; operator showed "none."
Plan deactivations	The operator who acknowledged the deactivation was noted at the top along with the closed time.

TSS and Weather Devices

TSS and weather device data could be viewed in a similar manner to the VSL signs. The appropriate website link was selected, and then the current status was displayed. Historical status could be displayed in a graphical format or downloaded to a CSV file, as shown in Figure F-37, Figure F-38, and Figure F-39.

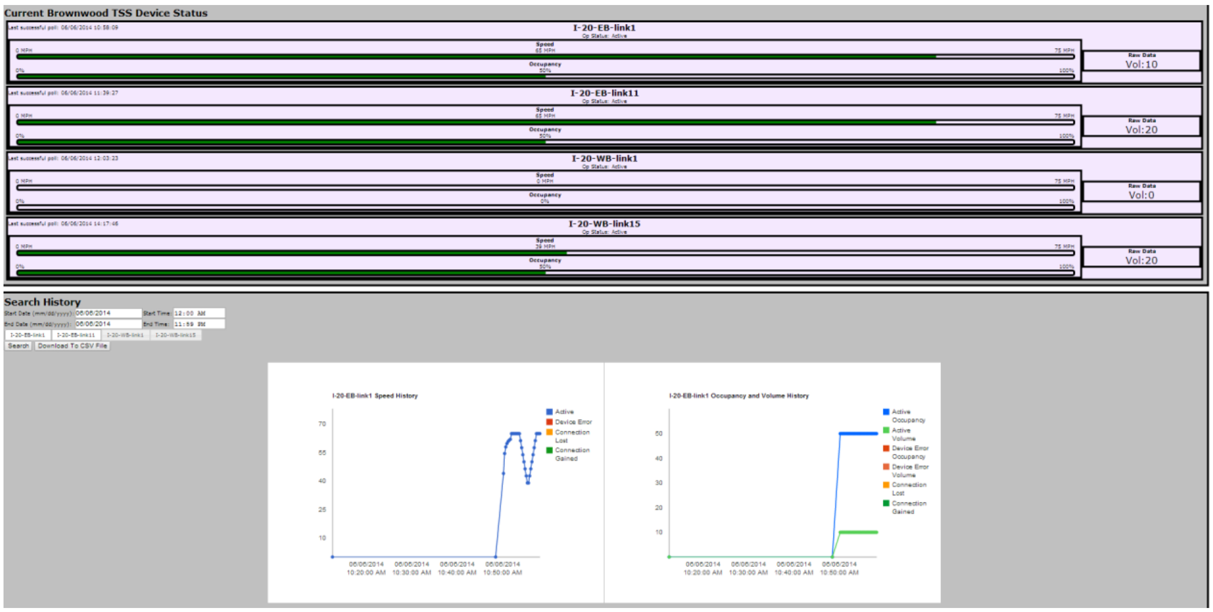


Figure F-37. TSS Link Data.

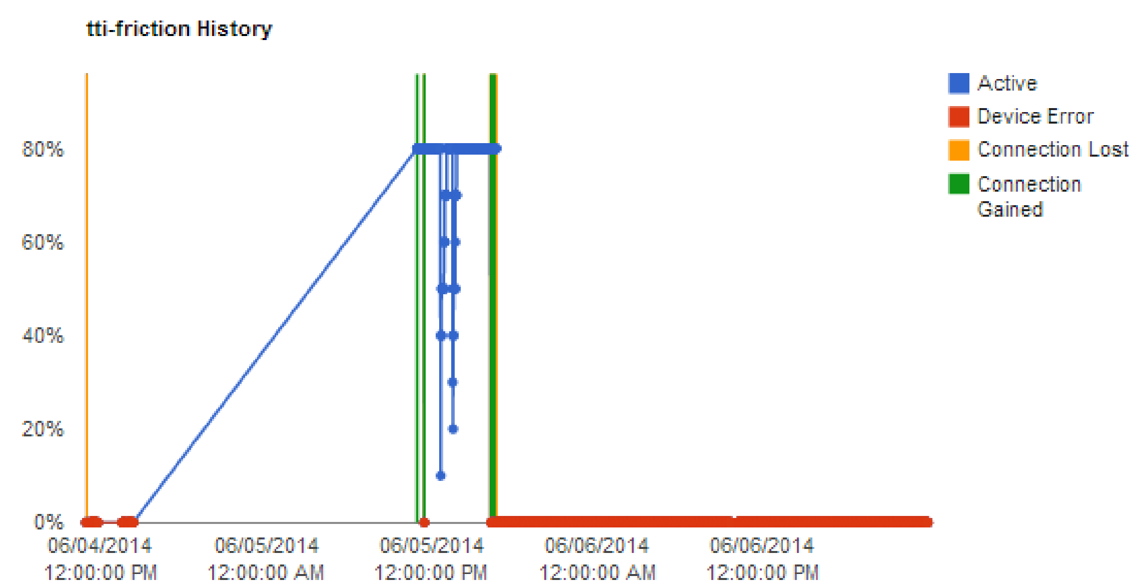


Figure F-38. Friction History.

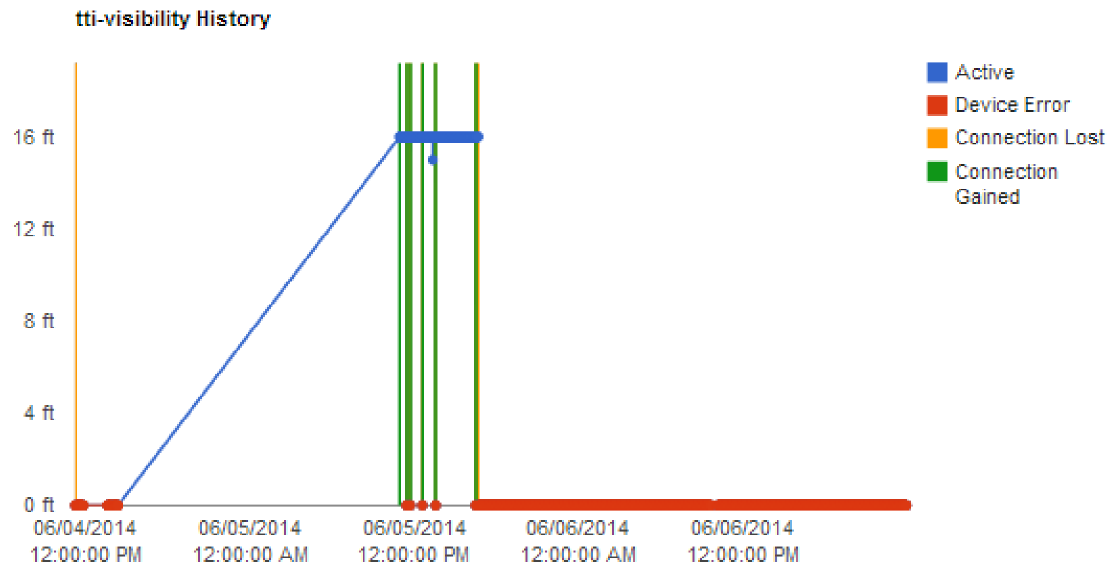


Figure F-39. Visibility History.

Lonestar VSL Operations

The following sections detail changes to the operator's view of the Lonestar user interface (UI) software. These include changes to status information displayed for DMS signs and changes for approving/denying the proposed speed limit changes.

Device Status

VSL signs are defined as a special type of DMS sign. Because of this, operators were able to perform typical DMS status commands such as polling, requesting pixel status, and setting devices in/out of service. However, operators were unable to access messaging or queue functionality for these devices. To ensure only speed limits using the algorithm that had been approved by the district engineer were posted, VSL messaging commands were initiated via an event response plan and not directly from a user command. The only messaging functionality operators were allowed to execute was a "resend" command, which resent the most recently approved speed limit to the device. This could be when a device recovered from failure and the message needed to be placed back on the sign.

All DMS View

The VSL devices displayed in their own tab on the All DMS View. The signs were displayed in DMS display order and included the RSA sign.

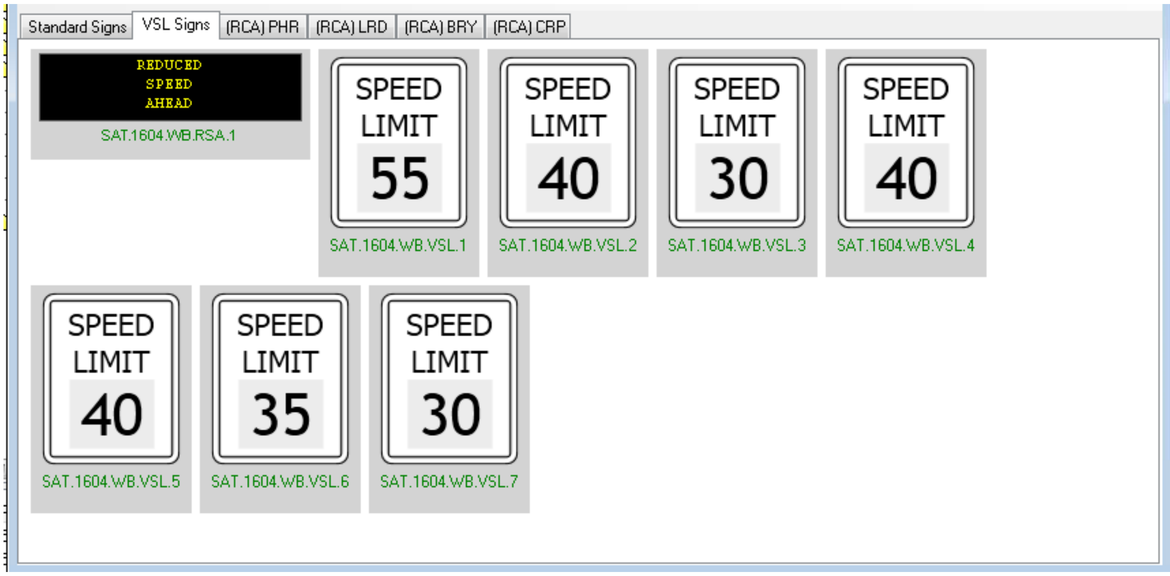


Figure F-40. All DMS View.

Status

The status screen displayed the VSL devices in their own tree node, as shown in Figure F-41. Remote VSL devices from the RCA were also displayed in their own tree node.

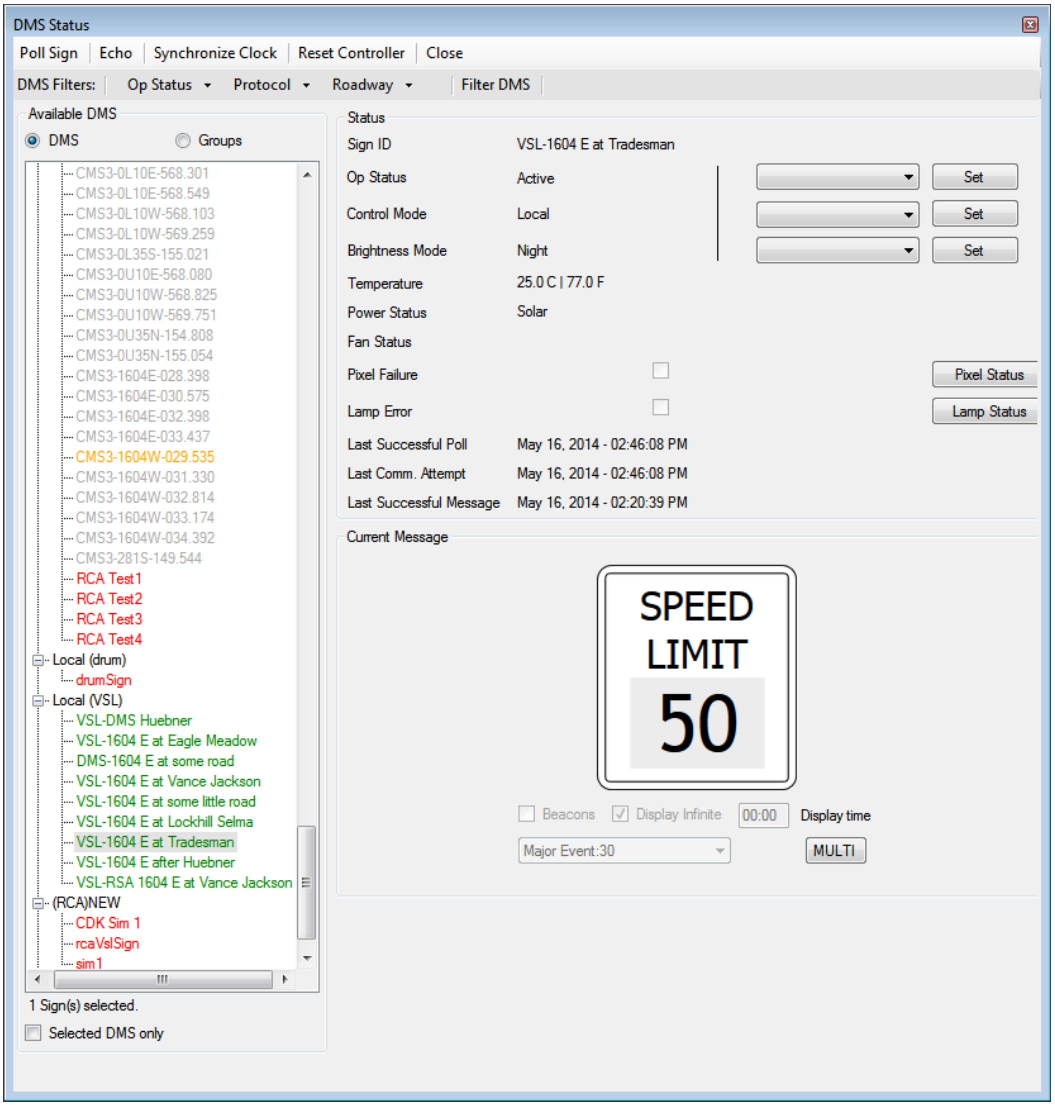


Figure F-41. VSL Status.

Send Message/Queue

The send message UI displayed the queue for the VSL device. As with the status UI, the VSL devices were displayed in their own tree node, as shown in Figure F-42. Remote VSL devices from the RCA were also displayed in their own tree node.

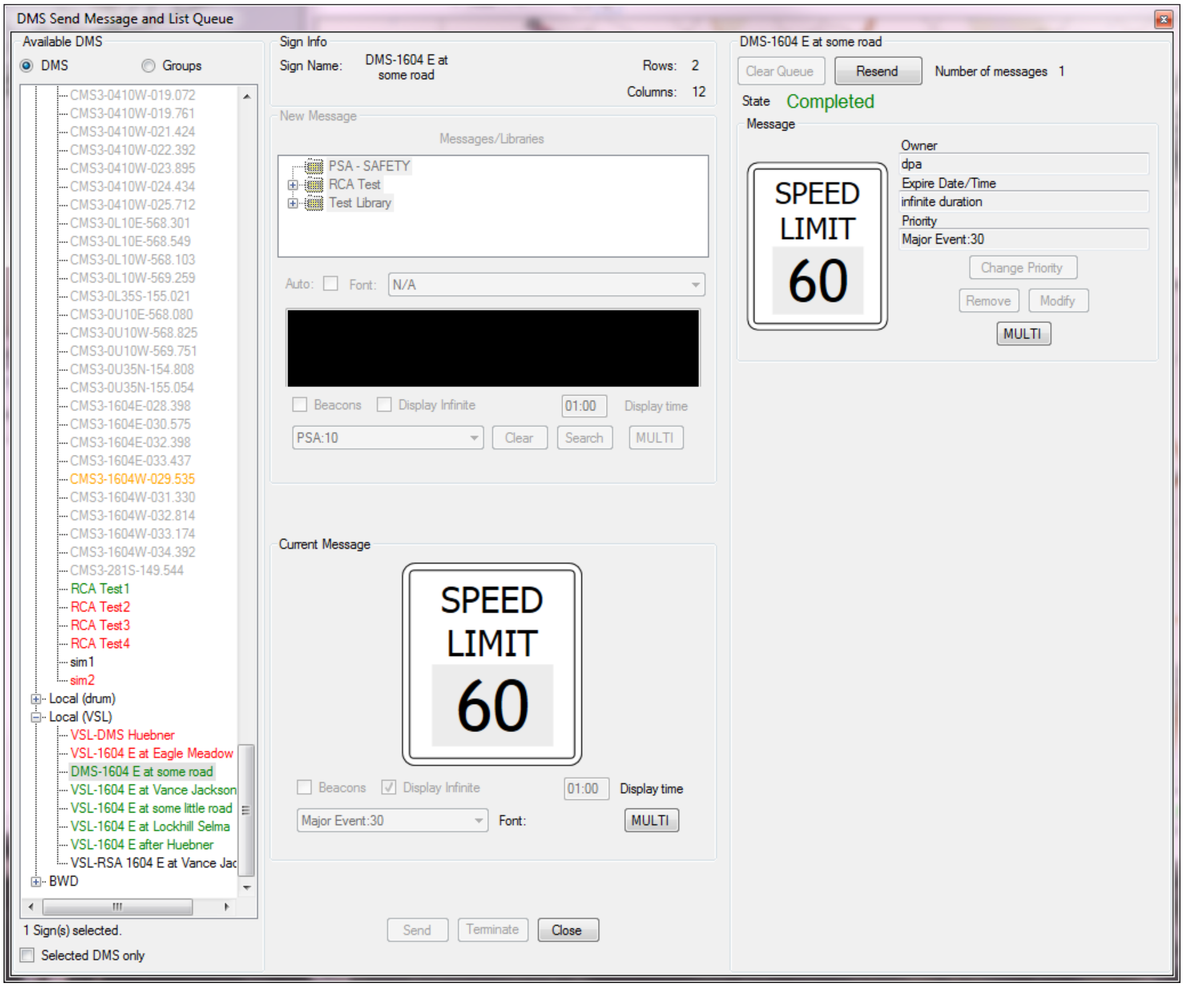


Figure F-42. VSL Send Message/Queue View.

A user without override permission was only allowed to resend the top message on the queue. Administrators with the override permission could send a message changing the speed on the VSL. Operationally, this feature should have only been used to place the default speed limit on the signs.

VSL Activations

The Lonestar system continuously monitored conditions of the roadway segments participating in the pilot deployments. Upon determining that a change in the posted speed limits was appropriate based on the detected conditions, the system provided a prompt to users to approve or reject the updated speed limits. This prompt appeared to any user with the appropriate approval permission. The prompt included details of the plan, including the involved VSL devices, the reason for triggering the speed change, and the suggested speed limits, as shown in Figure F-43.

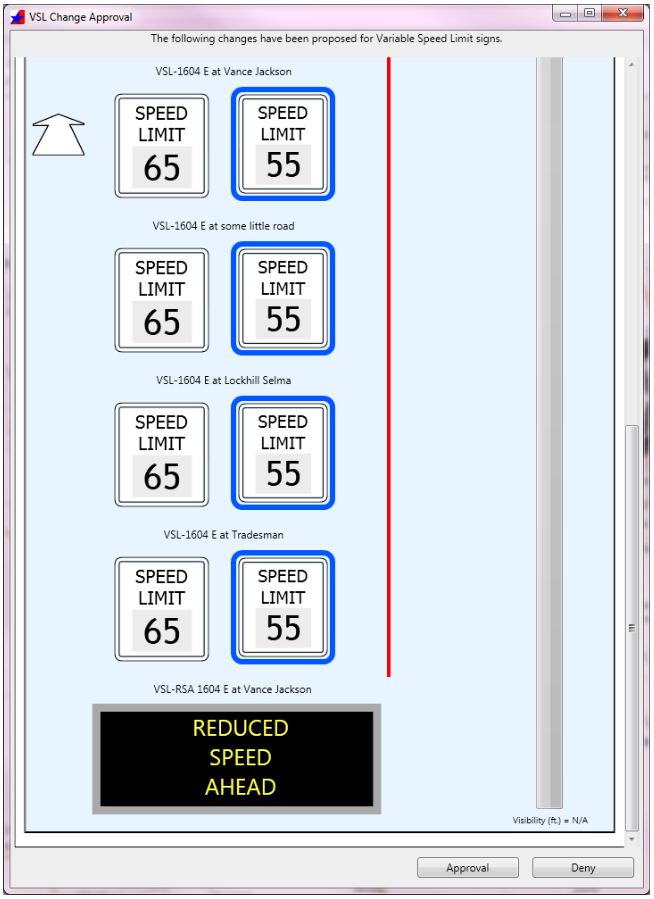


Figure F-43. VSL Approval Form.

Each operator with permission to approve plans was shown this UI. Once an operator selected either the approve or deny button, the approval form disappeared from the other operators' UIs. If an operator denied the plan, the dialog shown in Figure F-44 required the user to select a reason from the drop down or to select "other" and specify the reason.

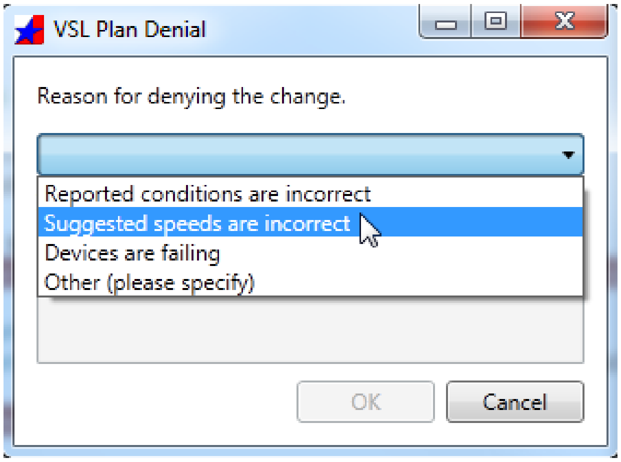


Figure F-44. Denying the Suggested Speed Limit Change.

After operator approval, the system automatically created an event and saved a response plan containing the appropriate VSL plan items. Operators were unable to modify VSL plan items added to an event response plan.

As roadway conditions continued to change, the system monitored and revised speed limits as necessary. Changes could be a further decrease in speed limits, an increase in speed limits, or a return to normal speed limits. These changes to a VSL plan were performed as a modification to the existing event response plan and did not require an operator to approve. Once a return to normal speed limits occurred, the event response plan was terminated and the event was closed. A notification was generated showing the return to normal conditions for an operator to acknowledge, as shown in Figure F-45.

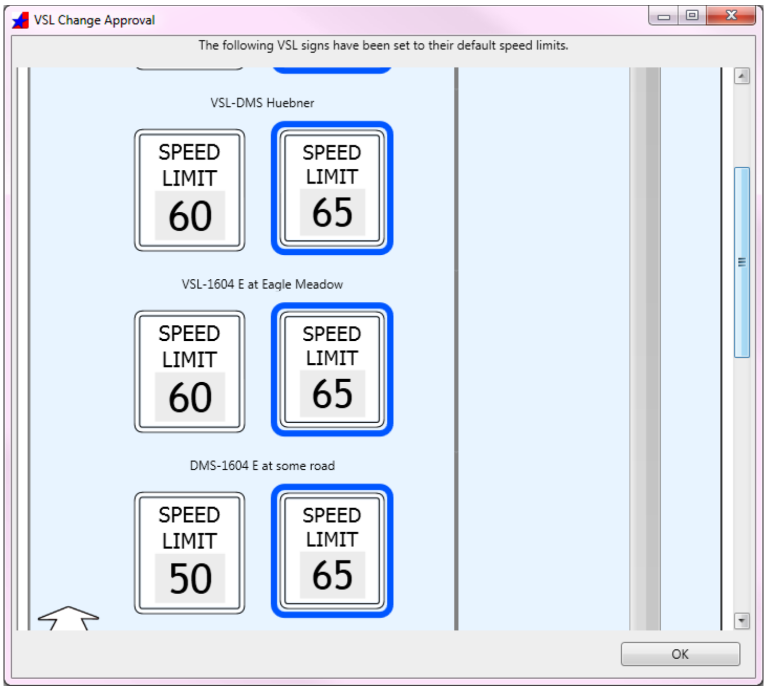


Figure F-45. End of VSL Plan Acknowledgment.

Appendix G: Implementation Lessons Learned

Background

By summarizing specific decision points regarding the design, deployment, and operational components of the pilot project, this appendix provides a high-level summary of the lessons learned throughout the pilot project.

Many of these items are directly attributable to being in a pilot project scenario with constraints on time and costs. These limitations were well understood by the project team and are listed here for completeness in cataloging potential impacts. They are not intended to detract from the overall conclusions presented in the Executive Summary and main body of the report.

Design

As characterized in Appendix D, the equipment base utilized for the pilot project was temporary infrastructure that could be procured, outfitted, deployed, operated, maintained, and removed during the project. Several items contributed to this overall equipment choice for use within the pilot tests.

- Constrained time: The pilot test timeframe was constrained, necessitating a unique approach to site design. The sites could not stay operational past the legislative authorization, which led to the need for temporary infrastructure that could be completely removed at the end of the testing, as TxDOT does not allow message signs that are not capable of being used or that do not support current operations to be in the right of way.
- Constrained funds: The available equipment costs for the project, while substantial, were only a small percentage of the funds that would be necessary to construct permanent infrastructure, such as sign gantries that would cross the roadway.
- Procurement: The lead time for purchasing permanent infrastructure was extensive, as this type of equipment is not kept in inventory and instead is manufactured according to need.
- Standards support: Because the equipment would operate within the Lonestar software environment, certain communication standards, such as the NTCIP, had to be supported, which limited the available equipment base.
- Operational capacity: The equipment base had to operate in a 24x7 situation with enough stored power from solar cells to operate the equipment basis throughout the nighttime or inclement weather conditions.
- Combined sensor/sign locations: The need for temporary infrastructure directly affected the choices related to sensors necessary to relay roadway information to the Lonestar algorithms. Cost constraints limited the number of installations, leading to a co-location of the roadway sensors with the signs, which proved to not be the ideal situation for correlating roadway information to the display of speeds seen by the public.

Design Lessons Learned

Overall, the project team accomplished the goals of the pilot project through the use of a temporary equipment base. The most significant lessons learned from the design component were that (a) the temporary equipment base was not suitable for long-term operations, and (b) a wider separation of the sensors and signs would be necessary for permanent installations.

Deployment

Appendix A detailed the site selection process for the pilot project. In addition to the overall site selection process, there were deployment decisions pertaining to the algorithm and at each site that affected the field placement for the pilot project.

1. Longitudinal Sign Spacing: Because these were temporary installations, the spacing of equipment in the field had to fit within the existing physical roadway constraints, including horizontal and vertical curvature, shoulder conditions, and matching with the existing on/off ramp configurations. This resulted in the VSL signage displayed at approximately 0.5 mile spacing across the three pilot project locations. Permanent installations would likely employ a wider longitudinal spacing with the midpoints being used for sensor detection to more accurately detect areas of slow conditions.
2. Horizontal Spacing: Due to the geometry of the roadway and the shoulder conditions, a few sign locations had to be placed a short distance further off of the roadside than a standard sign. At these locations, there may have been some visibility issues.
3. Sign Visibility: The pilot deployments utilized Portable Changeable Messages Signs (PCMS) on one side of the roadway. A permanent installation would utilize Dynamic Message Sign (DMS) panels across each lane using a gantry spanning the entire roadway. Project funds, timeframe, and available space did not allow for permanent installations. Project funds and in many cases, field site characteristics, did also not allow for PCMS boards on both sides of the roadway to enhance the overall visibility of the pilot zones to motorists.
4. Motorist Safety: A primary consideration in the deployment process had to be motorist safety. All equipment had to be crashworthy, delineated with orange construction barrels, and have sufficient space from the shoulder for placement. Some potential locations, such as a congestion site on Loop 410 in San Antonio, could not meet the motorist safety standards.
5. Safety during Deployment: Another primary consideration in the deployment process had to be the safety during deployment. Deployments were performed using TxDOT specifications for protection of work zone areas. Some pilot locations were identified where temporary infrastructure could not be safely deployed without significant impact to the public during deployment.
6. Sign Brightness: The brightness of the temporary infrastructure, run by solar power, is not as bright or conspicuous as permanent infrastructure. This was especially evident during times of bright sunlight, depending on the angle of the sun and the roadway. During the project, a field update was done on the temporary equipment base to increase the brightness of the signs. An additional step was taken to improve conspicuity by applying a black mask around portions of the number boards to increase contrast between the light emitting elements and the background.
7. Software Design: Incorporating a Variable Speed Limit algorithm inside the existing statewide management software on the short lead time necessary for project implementation was a significant effort. Some nuances of the algorithm related to trouping and smoothing of speeds were simplified in order to deliver the algorithm at the

required timeframe. This includes items such as the use of average vs. 85^{th} percentile speed.

8. Limited Full-Scale Field Testing: Overall, the available time and capability to field test deployments prior to full-scale operations was limited. Testing was performed under full traffic at a non-deployment site to ensure the overall functioning of communications and the algorithm, but it was not under the traffic conditions experienced at the pilot sites.

Deployment Lessons Learned

Field placement of the infrastructure was a significant constraint in the overall project. Future implementations must utilize a more comprehensive and rigorous site selection process that incorporates pertinent information beyond the need for VSL and basic field layout information. This includes longitudinal and horizontal spacing considerations in addition to a thorough understanding of how traffic operates with respect to ingress/egress locations along the variable speed corridor. Understanding the existing speed profile on any proposed corridors and significant data collection before implementation is highly recommended.

Appropriate lead times for design and construction of full-scale infrastructure should be allocated. Additionally, a full-scale, longer term testing capability where the algorithms can be tested in a "shadow mode", with resulting sign changes *not* being communicated to the public, is necessary to enhance the basic VSL operations for Texas driver conditions. Several items related to the development and implementation of the VSL algorithm, such as smoothing and notification intervals could have benefitted from additional testing and data analysis under actual field conditions.

Operations

The legislative authority for the operational pilot tests had a limited lifespan. A number of items were identified during the pilot test phase that could be evaluated and resolved.

1. Algorithm support for failed equipment: Due to the implementation timeframes, the deployed algorithm did not account for infrastructure which had failed when determining the sequence of messages. Although this was a rare occurrence, the impact is that in rare instances, the speed drop between successive signs exceeded the allowable 15 mph.
2. Algorithm recovery from failed communications: Due to the implementation timeframes, the deployed algorithm utilized existing sign message management schemes from Lonestar which could result in a situation where a sign that recovered from a communications issue did not repost the current calculated message. That resulted in some time periods where the deployed speeds across the recently recovered sign were out of sync with the overall operation of the reduced speed zone. This recovery mechanism differed across the pilot site implementations due to local District desires from their current Lonestar implementations.
3. Network resiliency issues: An upgrade to TxDOT networking infrastructure supporting one of the pilot test sites resulted in severely degraded communications performance of the field infrastructure. Field retrofits were made, and the situation was largely restored, although the underlying cause of the degraded performance was never identified.
4. Support for enforcement: A primary concern at one field site by the Department of Public Safety (DPS) was having officer know what the posted speed limit was at any time, for enforcement purposes. Typical enforcement practices by DPS dictate an officer facing oncoming traffic and targeting from the front. For the pilot test, this resulted in a

situation where an office could not see the sign that traffic was passing. For the length of the pilot, DPS was provided with the operations web site that tracked all pilot tests in real-time. Longer term, a more robust exchange of data pertaining to what speed limits are in place at what location, may be necessary for sufficient enforcement.

5. Driver understanding of the reason for the speed messages: Pilot tests used a "Reduced Speed Ahead" message when a variable speed limit was in effect. It is possible, that drivers would benefit from more specific information as to the cause of the reduced speed, such as indicating that it is from a congestion or pavement condition event. This would require additional software development and study to determine if compliance changed. Permanent infrastructure may need to provide the capability to convey additional informational messages, beyond the presentation of speed limits, relating the reasons for reduced speed at different points along the corridor.
6. Visual confirmation for operators: In any future implementations, if the operator is involved in approving the implementation, a confirmation capability to visually confirm the conditions should be provided. The use of snapshots from cameras within the deployment zone could also be incorporated into the confirmation screens as part of the presentation of the initiation dialogue to an operator.
7. Sensor improvements:
    a. Calibration process for sensors: Operations of a variable speed limit deployment would benefit from an enhanced calibration and testing process. As an example, the pavement friction sensor used for roadway weather conditions was directed at the shoulder instead of the main lanes so as not to be interrupted by passing vehicles in the traffic stream. However, in a recovery situation (such as drying pavement), the shoulder recovers at a different rate because there is no traffic on it. Additionally, shoulder pavement is often a different material than main lanes and may hold or trap water longer, leading to false readings for the main lane condition.
    b. Additional sensor input: Future deployments would benefit from additional sensor information to allow a more robust decision process on weather conditions. The full testing and analysis of this data stream was not available for the pilot test deployments.
8. Algorithm enhancements:
    a. Speed drop intervals: As implemented in the pilot test, the algorithm favored 5 mph speed drops over multiple signs. This had the effect of pushing a reduced speed limit further upstream. In some situations, drivers could not correlate a reduced posted speed limit with a traffic stream that appeared to be free-flowing. This likely led to a decrease in compliance. Depending on the geometrics of the zones, future implementations may need to favor steeper speed reductions to reduce how far upstream drivers are being told to slow down.
    b. Data smoothing: The use of data smoothing over multiple time intervals can be effective in reducing the "bouncing" of the algorithm in response to very transient situations. However, it also makes the algorithm less reactive to the current conditions. Future deployments should feature additional development to improve the trade-offs between smoothing and acceptable lag in reacting to current conditions.

   c. Reactive versus predictive: Current implementations of VSL are reactive to traffic. Future deployments should feature additional development work on the algorithm to develop predictive capabilities that forecast near-time breakdowns or disruptions in traffic conditions and lower speeds preemptively to offset the development of congested and/or breakdown conditions.
9. Ongoing data analysis: Future implementations should institute a process of periodic data analysis to ensure that the variable speed limit is responsive to the current operational characteristics in the corridor. Allowance for adjustments to the operations and/or refinements to the algorithm should be made as part of the long-term operational support.
10. Public outreach: Future implementations should develop a significant public outreach and education components to explain the Variable Speed Limits. The plan must have outreach components both before implementation and as an on-going need to help with driver understanding and compliance.

Operations Lessons Learned

In summary, there were four primary lessons learned from the operational components of the pilot tests:

1. The operational situation planning needs to be enhanced to account for more failure conditions in both equipment and communications. While these situations were rare, they were noted on occasion. With additional time and consideration on potential failure conditions, the algorithm can be enhanced to address these issues and increase the public confidence in the messages posted by ensuring that they are correct and consistent.
2. Additional efforts to improve the overall algorithm are warranted, with multiple avenues being identified to enhance future operations, such as adjustments to sensor inputs, analysis, and spacing.
3. In any permanent installations, consideration needs to be given to real-time data exchange to other agencies, such as DPS, and
4. Significant and on-going public outreach is necessary to assist drivers in both understanding and complying with variable speed limits.

Appendix H: Operational Evaluation Results

Overview

The following sections provide a summary of the operational analyses conducted as part of the VSL pilot studies.

VSL Activations

Table H-1 shows the number of requests and the number of approved activations of the VSL system in each deployment location for each month of the evaluation period. By far, the San Antonio deployment experienced the greatest number of system activations, while the Ranger Hill, Eastland County deployment experienced the fewest activations during the evaluation period. As mentioned previously, the San Antonio system was targeted primarily to address congestion related to queuing, while the Ranger Hill, Eastland County system was targeted primarily to address weather events on Ranger Hill.

Table H-1. Number of Recommended and Operator-Approved VSL Activations.

Month	San Antonio		Temple		Ranger Hill, Eastland County	
	Activations Requested by System	Activations Approved by Operator	Activations Requested by System	Activations Approved by Operator	Activations Requested by System	Activations Approved by Operator
July	82	74	84	44	-	-
August	165	133	81	44	6	5
September	218	136	42	33	19	11
October*	115	127	43	31	20	0
November	242	145	165	52	105	73
December	179	130	-	-	30	23
TOTAL	**1069**	**745**	**490**	**220**	**180**	**112**

Table H-2 shows the number of operator-approved activations by day of the week for each pilot deployment site. The table shows that the system activated more frequently on Fridays than any other day of the week, particularly at both the San Antonio and Temple pilot sites. A relatively high number of activations also occurred on the weekends at both the San Antonio and Temple deployment sites.

Table H-2. Number of Approved VSL Activations by Day of Week.

Day of Week	San Antonio	Temple	Ranger Hill, Eastland County
Sunday	44	30	5
Monday	97	15	5
Tuesday	132	29	39
Wednesday	121	16	38
Thursday	109	28	4
Friday	152	80	10
Saturday	90	22	11
TOTAL	**745**	**220**	**112**

Table H-3 shows the triggering events cited for activating the VSL at each of the deployment locations. In the Ranger Hill, Eastland County site, the majority of the VSL activations were caused by weather events, primarily reductions in pavement friction caused by rain events. In both the San Antonio and Temple deployments, the presence of congestion was cited as the primary reason for activating the VSL system, although both the San Antonio and Temple deployments experienced activations due to weather events as well. The combination of congestion and weather was cited as the triggering event once in both the Ranger Hill, Eastland County and Temple deployments.

Table H-3. Reasons for Activating VSL at Each Deployment Location.

Reason for Activation	San Antonio	Temple	Ranger Hill, Eastland County
Congestion/Queuing	766	236	9
Weather	76	54	136
Combination	0	1	4
TOTAL	**842**	**291**	**149**

As shown in Table H-1, not all requests for activations were approved by operators. The initial set of speed limits was not displayed on the variable message signs in the field until the request was approved by the operator. Table H-4 provides a summary of the reasons why activation requests were not approved by the operator. The reason "conditions returned to normal before plan was accepted" indicates that either the congestion or weather conditions improved above the triggering threshold before the operator approved activation of the VSL system. The reason "plan replaced by new plan" implies that the initial triggering conditions were superseded by a new activation request before the operator had a chance to approve the plan. In some cases, the new request was accepted and the VSL was eventually implemented. In other cases, the new request was not acted upon by the operator and the VSL was not activated before conditions returned to normal.

Table H-4. Reasons for Not Approving Activation Requests.

Reason for Not Approving Activation Request	San Antonio	Temple	Ranger Hill, Eastland County
Conditions returned to normal before plan was accepted	60	82	62
Plan replaced by new plan (Activation eventually accepted)	156	45	1
Plan replaced by new plan (Activation never accepted)	102	138	4
Other	5	6	3
TOTAL	**323**	**271**	**70**

Figure H-1, Figure H-2, and Figure H-3 show the distribution of initial VSL activation times at each deployment. In San Antonio (Figure H-1), a deployment focused on addressing congestion, most of the activations occurred during the traditional peak periods (between 7:00 a.m. and

9:00a.m. in the morning and between 3:00 p.m. and 4:00 p.m. in the evening). For Temple (Figure H-2), a substantial number of activations occurred during the middle of the day (between noon and 3:00 p.m.), particularly in the early months of deployment (July and August). In Ranger Hill, Eastland County (Figure H-3), which was a weather-related deployment, activations occurred throughout the day and were not focused on any particular period.

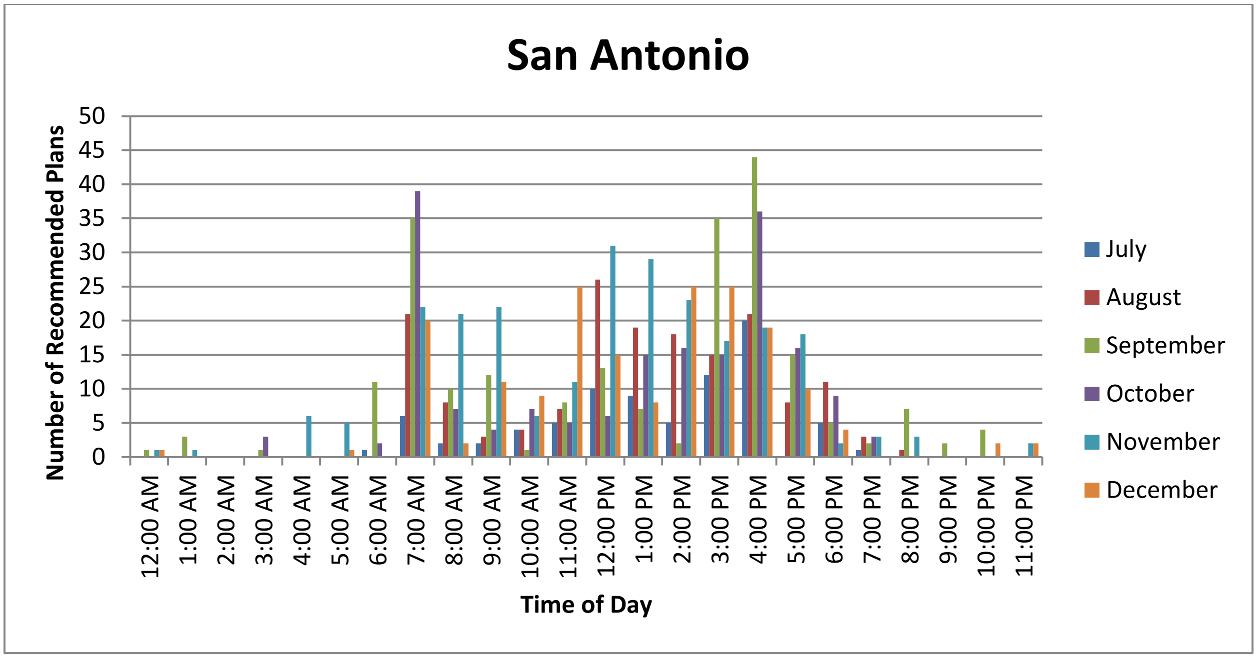


Figure H-1. Distribution of Activation Start Times—San Antonio.

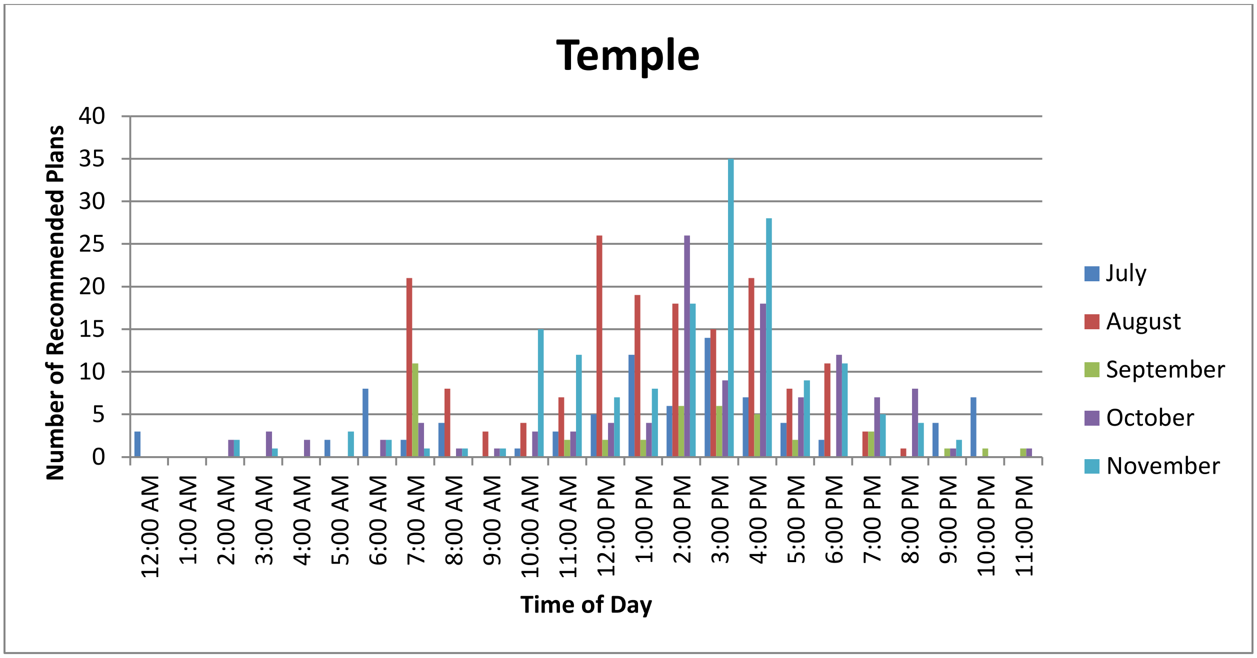


Figure H-2. Distribution of Activation Start Times—Temple.

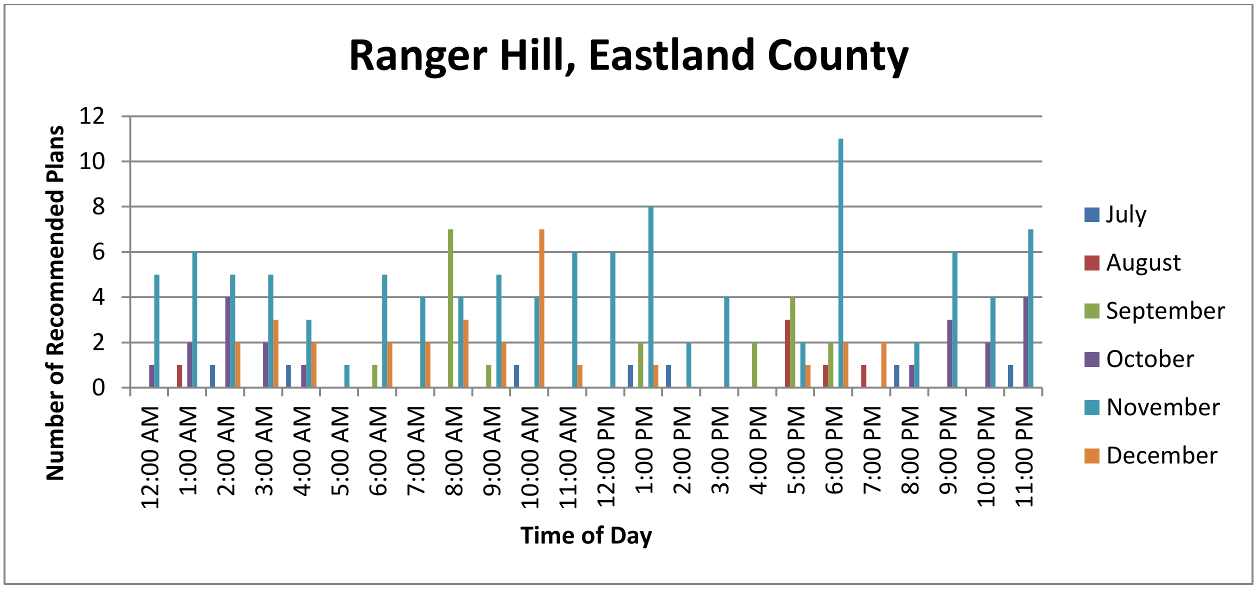


Figure H-3. Distribution of Activation Start Times—Ranger Hill, Eastland County.

After being activated, the VSL system was designed to automatically update the speed limits on the VSL signs (or change plans) based on measured travel conditions without operator intervention. Therefore, once activated, new speed limits could be posted on the signs every minute as long as conditions warranted a change. Table H-5 shows the average and maximum number of plan changes that occurred once the VSL system was activated, while Table H-6 shows a frequency distribution associated with the plan changes at each deployment site. Table H-5 shows that the Ranger Hill, Eastland County deployment experienced, on average, two plan changes each time the system was activated, with one activation experiencing a maximum of eight plan changes. On the other hand, the Temple and San Antonio deployments experienced on average 14 and 22 plan changes, respectively, each time the system was activated. This difference in the number of activations is primarily a result of the scenario under which the deployments were installed. The Brownwood deployment was primarily installed to reduce speed limits during inclement weather events that impacted either visibility, pavement friction, or both. For pavement friction, two threshold levels were identified—one associated with a moderate reduction in pavement friction and the other associated with a severe reduction in pavement friction. The initial evaluation of the Ranger Hill, Eastland County deployment occurred during the summer months when visibility was not an issue but rain associated with thunderstorms was the primary weather event. Most thunderstorms in this region involve a rapid release of rain during the initial period of the event, and then the rain becomes more moderate as the thunderstorm leaves the area. Therefore, the weather sensors would show a relatively large drop in pavement friction during the initial portion of the thunderstorm, and as the rain tapered off, the pavement friction would increase to a moderate level.

Table H-5. Average and Maximum Number of Plan Changes during an Activation.

Plan Changes (once activated)	San Antonio	Temple	Ranger Hill, Eastland County
Average number of plan changes	22	14	1
Maximum number of plan changes	269	157	10

Table H-6. Distribution of Number of Plan Changes per Activation.

Number of Plan Changes (once activated)	San Antonio	Temple	Ranger Hill, Eastland County
1 to 5 plan changes	393	137	113
6 to 10 plan changes	70	26	4
11 to 25 plan changes	82	25	0
26 to 50 plan changes	75	13	0
51 to 75 plan changes	73	6	0
76 to 100 plan changes	27	5	0
>100 plan changes	25	8	0
Total number of activations	**745**	**220**	**117**

Both the San Antonio and Temple deployments experienced a relatively high number of plan changes once activated; the San Antonio deployment experienced an average of 22 plan changes each time the system was active, while the Temple deployment experienced an average of 14 plan changes after being activated. In the San Antonio deployment, over 200 activations experienced more than 25 plan changes after initial activation. In San Antonio, one activation experienced a total of 269 plan changes once the VSL system was activated. In the Temple deployment, only 32 activations experienced more than 25 plan changes once the system was activated.

Table H-7 shows the average, median, maximum, 25th percentile, and 75th percentile durations of operations of the VSL signs. In Ranger Hill, Eastland County, the average duration that the VSL signs were active was 24 minutes, while in San Antonio and Temple; the average duration that systems were active was 45 minutes and 42 minutes, respectively. The median time for all three locations ranged between 2 minutes (Ranger Hill, Eastland County) and 11 minutes (San Antonio). The maximum activation duration in both San Antonio and Temple lasted longer than 6 hours, while the maximum duration of activation in Ranger Hill, Eastland County lasted almost 17 hours.

Table H-7. Duration of Activations at Each Deployment Site.

Duration of Activation (hour:minute)	San Antonio	Temple	Ranger Hill, Eastland County
Average	0:45	0:42	0:24
Median	0:11	0:06	0:02
Maximum	8:32	6:47	16:51
25th percentile duration	0:03	0:01	0:00
75th percentile duration	1:01	0:35	0:13

Congestion Analysis

The following sections provide a summary of the congestion analyses conducted as part of the VSL pilot studies.

VSL Effectiveness

The following sections provide a summary of the analyses conducted to assess the effectiveness of the VSL pilot projects at the three sites. Each section addresses the four metrics of average speeds, speed profiles, vehicle throughput, and congestion duration within the study locations.

San Antonio

The project team examined the impact of the VSL deployment on average speeds at each of the deployment locations. For the purposes of this initial report, the evaluation focused on the San Antonio deployment. Speed data from 4:00 p.m. to 6:15 p.m. were used in the analysis. This time period was selected because it represented the period when the VSL was most active at this deployment. The analysis also examined data only from Tuesdays and Thursdays, as these days were deemed by the TTI team to best represent typical weekday traffic. Because of communication issues, data from August and early September were not used in this comparison from this deployment site.

Table H-8 and Table H-9 show a comparison of the average speeds at each of the VSL sign locations without and with the VSL active for Tuesdays and Thursdays, respectively, in the San Antonio deployment. Figure H-4 and Figure H-5 show the profile of average speeds collected at each of the VSL sign locations during the p.m. peak period (4:00 p.m. through 6:15 p.m.). Figure H-4 shows the average speed measured at each VSL location for five Tuesdays (one without VSL active and four with VSL active), while Figure H-5 shows the average speed at each VSL location for five Thursdays. The figures show that at this particular deployment site in San Antonio, speeds had a tendency to decline beginning at approximately 65 mph at VSL Location #1 and declining throughout the corridor to VSL Location #7. At this particular location, VSL Location #7 was located closest to the point where congestion formed in the corridor (i.e., near the interchange to US 281). The red line in the graphs shows the average speeds computed at each station without the VSL active, while the solid purple lines show the average speeds for two days in July and the dashed blue lines show the average speeds from two days in September.

Table H-8, Statistical Comparison of Average Speeds With and Without VSL Active – San Antonio Deployment (Tuesdays).

VSL Status	Average Measured Speed (mph) at Each Sign Location							
	Date	VSL-1	VSL-2	VSL-3	VSL-4	VSL-5	VSL-6	VSL-7
w/o VSL	6/24	67.3	55.3	55.2	51.5	48.7	45.9	32.5
With VSL-	7/15	**65.8**	57.2	52.4	48.3	**58.4**	45.1	28.6
	7/22	**65.9**	51.9	**50.2**	**47.9**	52.1	**50.5**	30.5
	9/16	67.2	**62.2**	**64.8**	**55.3**	**63.6**	**60.9**	36.0
	9/23	67.5	**63.9**	**66.7**	**59.8**	**61.7**	**59.1**	**37.7**
	10/7	67.2	**62.8**	**64.9**	**55.6**	**61.8**	**61.5**	36.6
	10/21	67.0	**60.3**	**64.6**	**55.8**	**63.3**	**58.6**	**44.7**
	11/4	**66.4**	**60.4**	**64.2**	**53.1**	**55.6**	50.3	36.2
	11/25	**27.9**	**22.2**	**16.9**	**23.8**	**31.2**	**42.0**	**31.3**
	12/9	**32.6**	**26.2**	**50.6**	54.3	**64.4**	**62.5**	**55.6**
	12/16	38.2	**27.4**	**39.5**	41.4	**55.8**	**50.7**	23.5

Note: values shown in bold are statistically significant at a 95 percent confidence interval. These values are compared to the average speed without VSL active observed on 6/20.

Table H-9. Statistical Comparison of Average Speeds With and Without VSL Active – San Antonio Deployment (Thursdays).

VSL Status	Average Measured Speed (mph) at Each Sign Location							
	Date	VSL-1	VSL-2	VSL-3	VSL-4	VSL-5	VSL-6	VSL-7
w/o VSL	6/19	60.8	44.8	49.4	43.6	43.3	40.8	24.7
With VSL	7/17	**49.6**	**31.4**	**28.1**	**32.5**	**37.8**	**35.3**	**21.5**
	7/24	**51.2**	**37.1**	**32.5**	**33.6**	41.9	**37.3**	**22.4**
	9/25	**67.6**	**62.8**	**55.6**	**51.3**	**58.9**	**54.0**	**28.2**
	10/2	**66.1**	**61.6**	**63.6**	**49.5**	**49.0**	**53.0**	**28.7**
	10/09	**66.8**	**62.3**	**66.3**	**60.0**	**58.3**	**50.1**	**28.2**
	10/23	**67.0**	**60.3**	**64.6**	**55.8**	**63.3**	**58.6**	**44.7**
	11/13	**64.0**	**47.9**	48.1	**47.3**	**52.8**	**48.0**	**32.3**
	12/11	**63.3**	**40.3**	**32.7**	**33.0**	**55.3**	**48.7**	**28.8**
	12/18	**65.1**	**42.6**	**38.3**	**35.6**	**53.3**	**50.2**	**28.3**

Note: values shown in bold are statistically significant at a 95 percent confidence interval. These values are compared to the average speed without VSL active observed on 6/20.

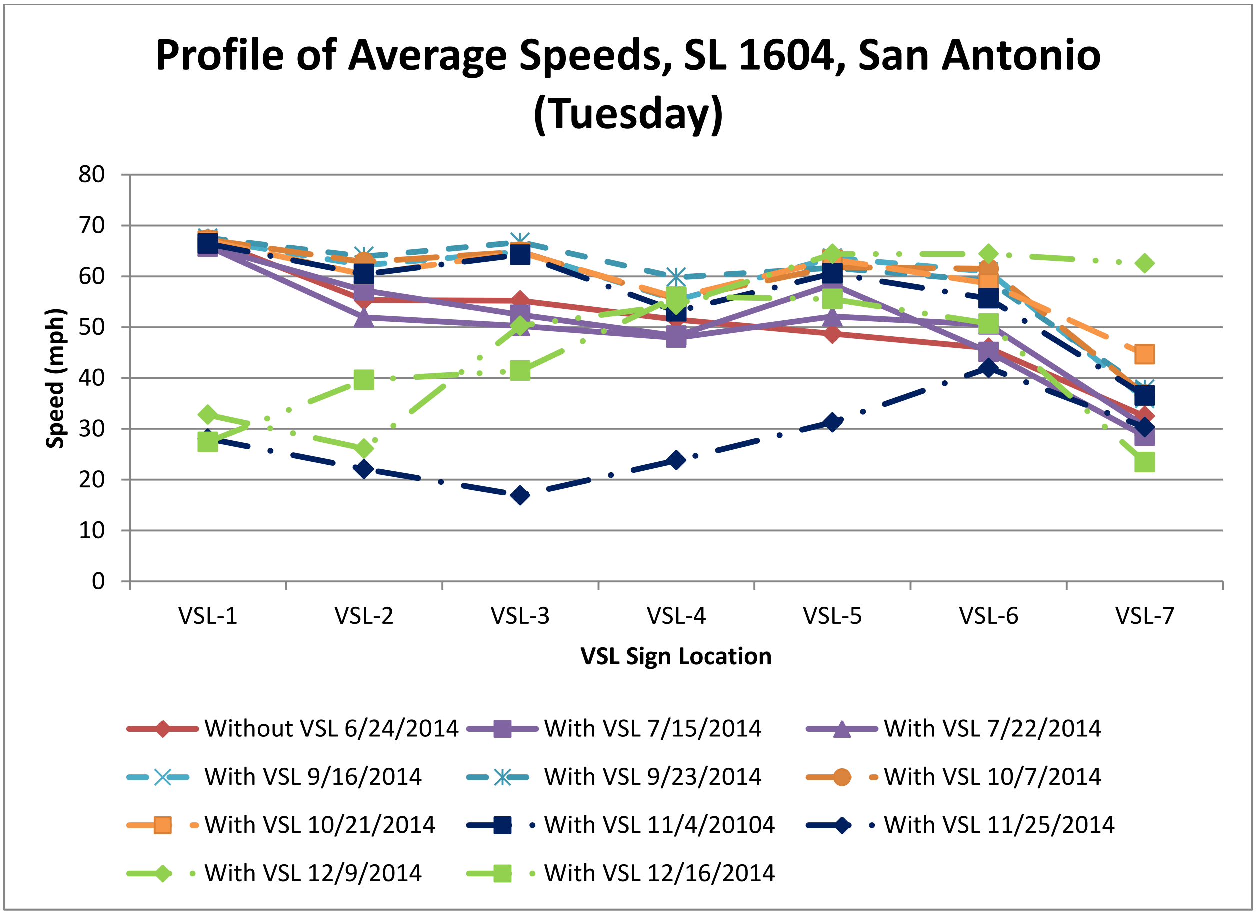


Figure H-4. Comparison of Tuesday's Average Speeds (mph) at Each VSL Sign Location, San Antonio.

Based on a comparison of the with VSL and without VSL average speeds for each individual day, the figures show some interesting results. On Tuesdays, average speeds from the locations with VSL in July were slightly less than the average speeds without VSL at VSL Locations #2 through #4 but were slightly higher at VSL #5 and #6 leading up to the primary congestion point (VSL Location #7), For the days in September, the average speeds were higher across all sites leading up to the primary congestion point. A similar trend was observed from the comparison of average speeds on Thursdays, with the data from July showing a drop in average speeds and the data from September showing an increase in average speeds across all VSL locations.

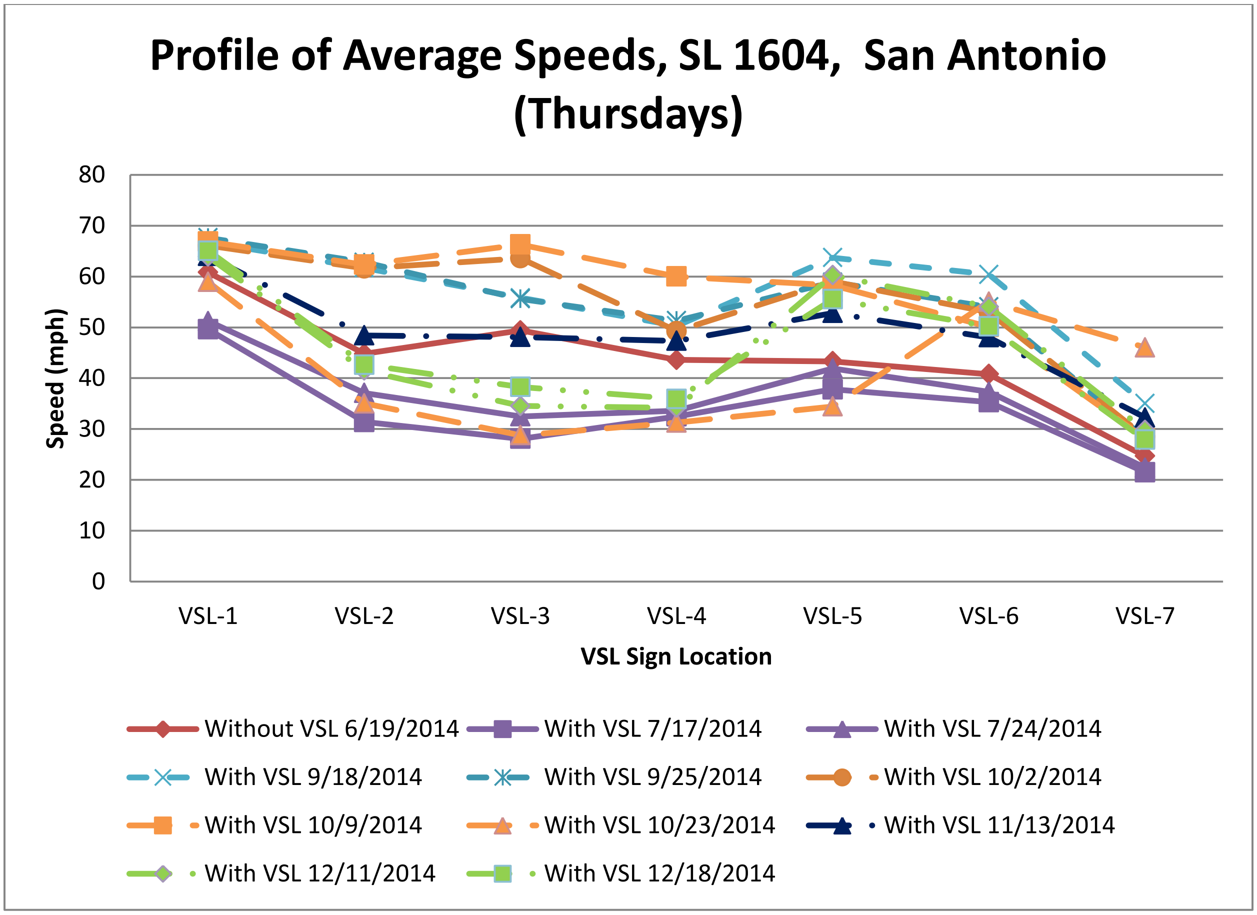


Figure H-5. Comparison of Thursday's Average Speeds (mph) at Each VSL Sign Location, San Antonio.

Table H-10 and Table H-11 provide a statistical comparison of the difference between the observed average speeds at each VSL sign location for each individual day. The statistical comparison involved using comparison of means techniques with unequal variance. These tests were performed at a 95 percentile confidence level. Table H-10 shows the comparison for the Tuesday data, while Table H-11 provides the same comparison for the Thursdays used in the analysis. The values shown in bold indicate statistically significant differences. Negative values indicate speeds with VSL being less than speeds without VSL. Positive values in the table indicate speeds being higher with VSL compared to speeds without VSL. The table confirms that the results of the VSL system performance in the San Antonio corridor changed throughout the course of the study, with performance of the VSL in July generating statistical reductions in speeds and the performance of the VSL in September resulting in statistical increases in speeds.

Two potential reasons are hypothesized to explain the increase in September average speeds:

- The without VSL data were collected during the summer months when area-wide schools were not in session. September's speed data came from days after area-wide schools were back in session. The with VSL data from July exhibited similar characteristics to the without VSL data collected in June, which suggests that there was a fundamental difference in driver behavior in the corridor when school was back in session.

- Over the course of the evaluation period, the novelty effect of seeing speed limits posted on the VSL wore off, and drivers began returning to their normal driving behavior when no signs were present in the corridor.

Additional without VSL data from a month when school is in session is needed to clarify what was happening with the data.

Table H-10. Statistical Comparison of Difference in Average Speeds with and without VSL—Tuesdays, San Antonio.

VSL Status	Difference in Speeds with VSL and without VSL (mph)							
	Date	**VSL-1**	**VSL-2**	**VSL-3**	**VSL-4**	**VSL-5**	**VSL-6**	**VSL-7**
w/o VSL	6/24	2.7	14.7	14.8	18.4	21.3	24.1	37.5
With VSL	7/15	**-4.9**	**-3.5**	**-4.4**	**-0.8**	**-12.6**	**-3.5**	**9.3**
	7/22	**-3.8**	**2.3**	**-1.9**	**0.9**	**-7.2**	**-6.8**	**9.7**
	9/16	**-2.1**	**-1.9**	**-6.9**	**-0.6**	**-10.6**	**-11.3**	**10.4**
	9/23	**-2.8**	**-2.6**	**-8.3**	**-4.2**	**-9.9**	**-8.4**	**10.4**
	10/7	2.0	**0.7**	**9.9**	**4.1**	**11.6**	**13.9**	**-7.6**
	10/21	**0.4**	**-3.4**	**3.6**	**-2.8**	**4.8**	**2.3**	**-9.7**
	11/4	**1.1**	**-0.5**	**7.3**	**-0.7**	**6.1**	**3.5**	**-10.7**
	11/25	**-27.2**	**-22.3**	**-20.5**	**-14.2**	**-10.0**	**-2.2**	**-12.3**
	12/9	**-15.0**	**-15.6**	**7.0**	**8.0**	**15.0**	**8.1**	**-6.9**
	12/16	**-11.0**	**-11.1**	**1.2**	**3.1**	**15.3**	**5.1**	**-31.7**

Note: Values shown in bold are statistically significant at a 95 percent confidence level and imply a reduction in speeds compared to the without VSL condition. Positive values imply an increase in speeds compared to the without VSL condition. .

Table H-11. Statistical Comparison of Difference in Average Speeds with and without VSL— Thursdays, San Antonio.

VSL Stata	Difference in Speeds with VSL and without VSL (mph)							
	Date	**VSL-1**	**VSL-2**	**VSL-3**	**VSL-4**	**VSL-5**	**VSL-6**	**VSL-7**
w/o VSL	6/19	9.2	25.2	20.5	26.4	26.7	29.2	45.3
With VSL	7/17	6.6	**11.3**	**5.3**	**1.8**	**-2.3**	**-1.6**	**9.6**
	7/24	5.6	**6.7**	**2.2**	**1.2**	**-5.3**	**-2.7**	**8.8**
	9/25	**-5.9**	**-8.0**	**-6.2**	**-3.9**	**-12.9**	**-12.1**	**9.6**
	10/2	**0.9**	**-0.1**	**4.9**	**-5.5**	**5.6**	**2.4**	**-20.2**
	10/09	**3.8**	**3.9**	**12.1**	**10.0**	**12.5**	**7.9**	**-10.5**
	10/23	**0.4**	**-3.4**	**3.6**	**-2.8**	**4.8**	**2.3**	**-9.7**
	11/13	7.7	**2.7**	**9.1**	**6.8**	**10.1**	**-6.5**	**-20.7**
	12/11	**-6.2**	**-8.0**	**-10.6**	**-11.0**	**-7.6**	**-4.2**	**-31.2**
	12/18	**-4.9**	**-7.7**	**-6.0**	**-8.4**	**13.0**	**4.0**	**-27.2**

Note: Values shown in bold are statistically significant at a 95 percent confidence level. Negative values imply a reduction in speeds compared to the without VSL condition. Positive values imply an increase in speeds compared to the without VSL condition.

Figure H-6 and Figure H-7 show the relative differences between the measured average travel speeds and the posted speed limits. This differential was computed by subtracting the posted speed limit from the average measured speed limit. A positive value indicated that the actual average travel speeds were higher than the posted speed limit, while a negative value indicated that average travel speeds were lower than the posted speed limit. Again, separate analyses were performed for Tuesdays and Thursdays with and without VSL.

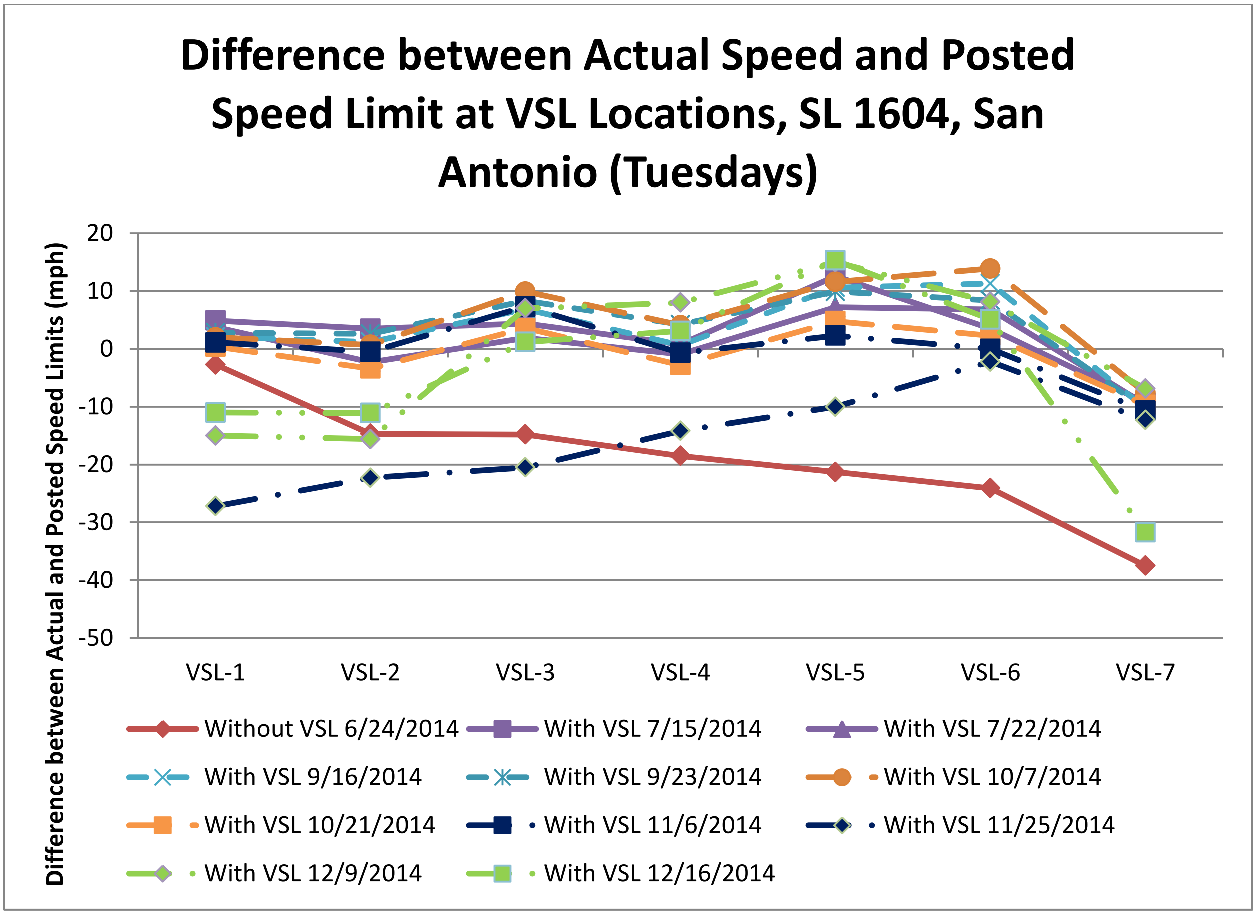


Figure H-6. Difference between Actual and Posted Speeds with and without VSL Active—Tuesdays, San Antonio.

These figures show that at all VSL locations, measured average travel speeds were within ±10 mph of the posted speed limit. This suggests that the process of stepping down speed limits in advance of the congestion points does not create substantial speed differentials between posted and actual speeds. On the contrary, not reducing speeds in advance of congestion locations can create much greater differentials between posted and actual travel speeds.

One issue with examining average speeds is that the effect of changing the individual speed limits is lost in the analysis by aggregating to an average. Figure H-8 and Figure H-9 show how one-minute average speeds changed at each VSL station. Looking at the deployment in this way allowed the research team to generate a heat map showing the relative changes in speeds between detector stations across each time step. The diagram was generated by varying the shading in each cell, with red tones favoring speeds at 30 mph and green tones favoring 70 mph. These heat maps show how the individual speeds varied as a result of the different speed limits posted in a single VSL application. Figure H-9 compares the heat signature of a particular VSL deployment on July 22 to the heat signature of the data from the same time period without the VSL active.

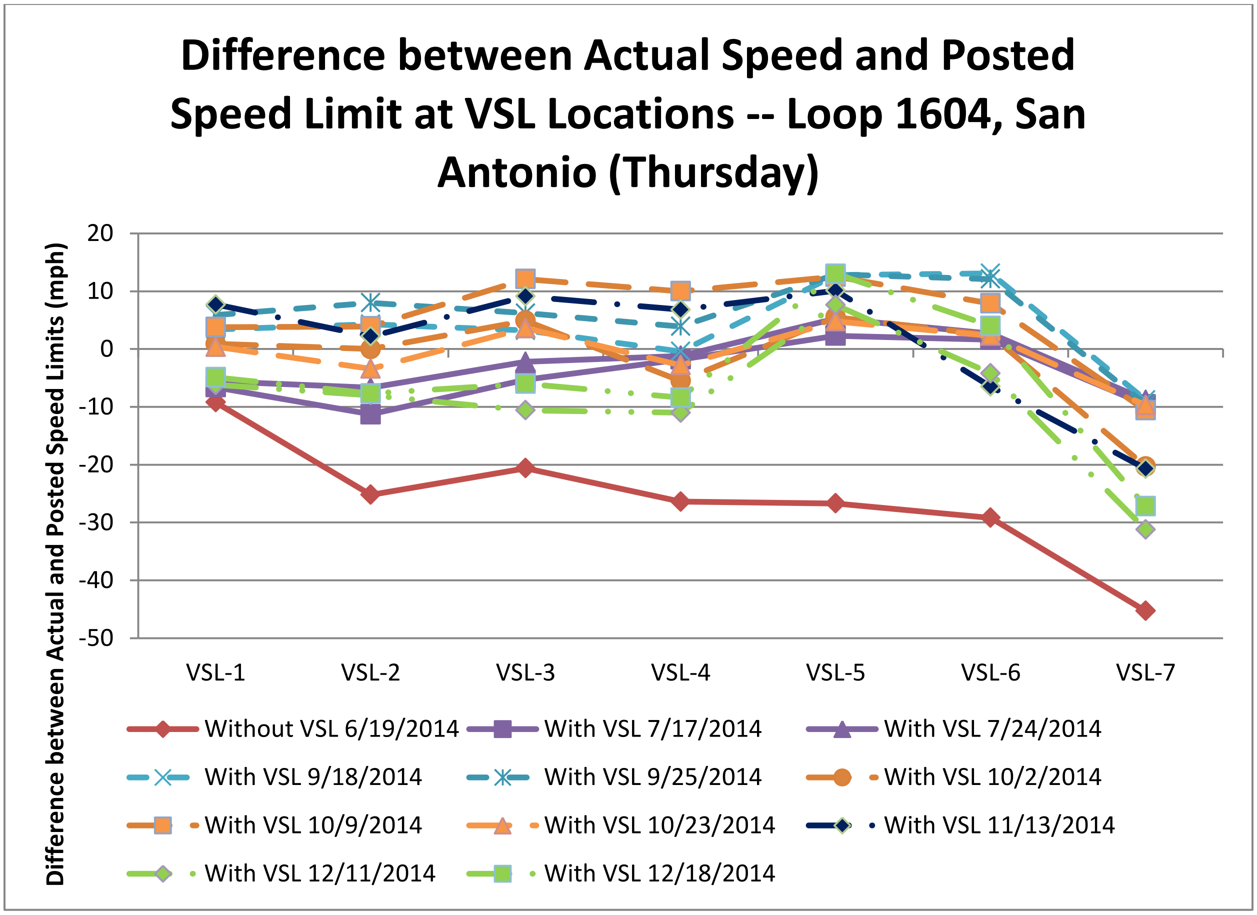


Figure H-7. Difference between Actual and Posted Speeds with and without VSL Active – Thursdays—San Antonio.

Table H-12 shows a comparison of the average per lane flow rate with and without VSL active at the San Antonio deployment. The table shows that average per lane flow rate remained relatively constant between with VSL was active compared to when VSL was not active. The table suggests that implementing VSL did not have a negative impact on vehicle throughput at this site at this site. Per lane vehicle flow rate were statistically equal with and without VSL.

Table H-12. Comparison of Average per Lane Flow Rate with and without VSL Active – San Antonio.

Day	Condition	Date	Average per Lane Flow Rate						
			VSL-1	VSL-2	VSL-3	VSL-4	VSL-5	VSL-6	VSL-7
Tuesday	w/o VSL	6/24	1147	1407	1408	1733	1816	1800	1418
	w/ VSL	7/15	**715**	**857**	**850**	**1044**	**1081**	**1066**	**770**
		7/22	**745**	**854**	**882**	**1057**	**1033**	**1055**	**782**
		9/16	1111	**1347**	**1343**	1678	**1700**	1730	1257
		9/23	1119	1362	**1341**	1683	**1731**	**1706**	**1282**
		10/7	1108	**1341**	1374	1718	1769	1747	**1304**
		10/21	1114	**1339**	**1339**	1683	1749	**1729**	**1319**
		11/4	1101	1402	1380	1730	1706	1657	1225
		11/25	**978**	**1058**	**954**	**1485**	**1412**	**1401**	**1053**
		12/9	**1026**	**1104**	**1160**	**1636**	**1697**	**1655**	1354
		12/16	**1011**	**1045**	**1125**	**1507**	**1511**	**1466**	**994**
Thursday	w/o VSL	6/19	1203	1358	1361	1737	1746	1709	1252
	w/ VSL	7/17	**720**	**777**	**810**	**1021**	**977**	**973**	**691**
		7/24	**737**	**818**	**803**	**985**	**961**	**986**	**703**
		9/18	1169	1405	1392	1737	1791	**1789**	1292
		9/25	1184	1416	1406	1767	**1817**	**1785**	1244
		10/2	1171	1413	1386	1718	1759	1754	1270
		10/9	**1128**	1380	1411	1756	1773	1746	1228
		10/23	**1200**	**1284**	**1286**	**1669**	**1653**	**1633**	**1277**
		11/13	1210	1390	1344	1704	1735	1682	1246
		12/11	**1099**	**1214**	1374	1787	1636	1326	1311
		12/18	**1063**	**1165**	**1186**	1721	1708	1753	1242

Note: Values shown in bold are statistically significant at a 95 percent confidence level.

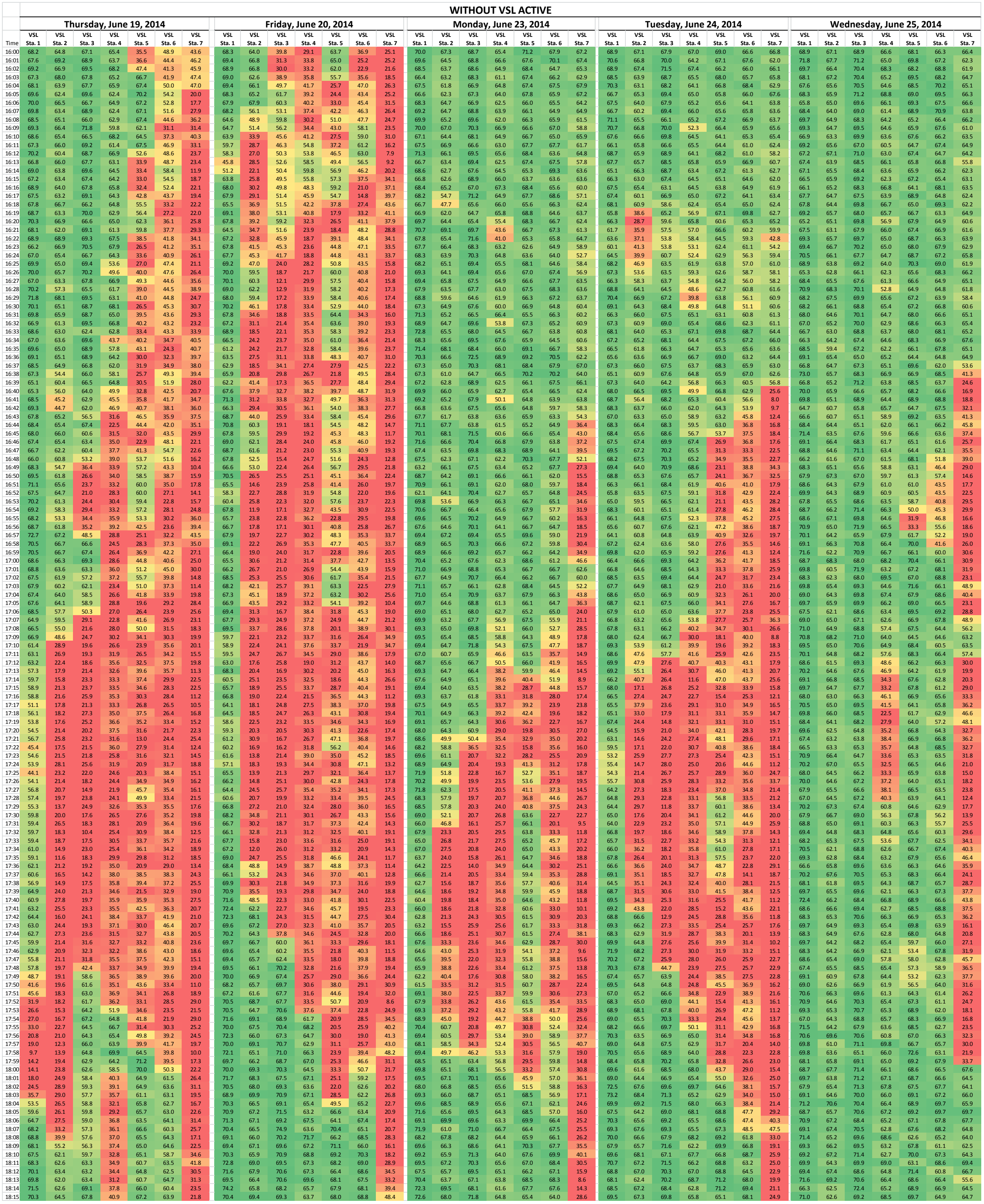


Figure H-8. Heat Map without Active VSL, San Antonio.

	WITHOUT VSL ACTIVE (6/24/2014)							WITH VSL ACTIVE (7/22/2014)															
	1-minute Average Speeds							Speed Posted on VSL Sign							1-minute Average Speeds							
Time	VSL Sta. 1	VSL Sta. 2	VSL Sta. 3	VSL Sta. 4	VSL Sta. 5	VSL Sta. 6	VSL Sta. 7	VSL Sta. 1	VSL Sta. 2	VSL Sta. 3	VSL Sta. 4	VSL Sta. 5	VSL Sta. 6	VSL Sta. 7	VSL Sta. 1	VSL Sta. 2	VSL Sta. 3	VSL Sta. 4	VSL Sta. 5	VSL Sta. 6	VSL Sta. 7	Time
16:00	68.9	67.1	67.9	67.0	69.0	66.6	66.8	70	70	70	70	70	70	70	67.1	64.7	69.2	65.0	68.5	67.2	65.7	16:00
16:01	70.6	66.8	70.0	64.2	67.1	67.6	62.0	70	70	70	70	70	70	70	67.3	65.0	68.0	64.1	67.8	68.0	64.3	16:01
16:02	68.9	67.4	71.5	67.4	66.2	64.0	66.1	70	70	70	70	70	70	70	68.2	65.2	68.1	60.7	68.4	68.1	66.1	16:02
16:03	68.5	63.9	68.7	65.5	68.0	65.7	65.8	70	70	70	70	70	70	70	68.4	65.9	67.9	64.8	67.8	68.9	65.3	16:03
16:04	70.3	63.1	68.2	64.1	66.8	68.4	62.9	70	70	70	70	70	70	70	67.5	66.4	68.5	65.8	67.0	64.8	64.7	16:04
16:05	66.7	65.3	69.4	65.0	65.8	66.0	67.6	70	70	70	70	70	70	70	68.0	64.1	66.8	66.5	67.5	64.3	60.8	16:05
16:06	67.5	64.0	67.9	65.2	65.6	64.1	63.8	70	70	70	70	70	70	70	67.8	64.8	67.1	66.8	67.7	67.5	61.0	16:06
16:07	66.7	60.2	69.4	66.0	65.6	65.8	63.6	70	70	70	70	70	70	70	67.9	66.1	69.2	66.1	67.4	67.3	63.8	16:07
16:08	71.1	65.5	66.1	65.2	67.2	66.9	63.7	70	70	70	70	70	70	70	68.0	64.9	68.3	66.8	66.5	65.8	64.1	16:08
16:09	70.7	66.8	70.0	52.3	66.4	65.9	65.6	70	70	70	70	70	70	70	68.2	66.0	67.3	64.0	66.0	65.8	57.4	16:09
16:10	67.6	66.6	69.8	64.5	64.1	65.3	65.4	70	70	70	70	70	70	70	67.7	65.6	68.2	62.1	66.2	67.8	52.3	16:10
16:11	66.1	65.8	66.6	65.5	64.4	61.0	62.4	70	70	70	70	70	70	70	66.8	65.8	67.5	61.5	67.3	67.7	59.3	16:11
16:12	68.7	65.9	68.9	64.1	68.2	61.0	58.2	70	70	70	70	70	70	70	66.1	64.7	68.5	61.7	67.7	67.2	63.7	16:12
16:13	67.7	65.7	68.5	65.8	65.9	66.9	60.7	70	70	70	70	70	70	70	66.5	63.7	68.2	66.2	66.3	66.7	61.5	16:13
16:14	65.1	66.3	68.7	63.4	67.2	61.3	62.7	70	70	70	70	70	70	70	65.8	63.0	66.8	65.8	67.5	66.1	59.4	16:14
16:15	66.3	63.0	67.4	64.5	65.1	64.6	62.0	70	70	70	70	70	70	70	64.3	59.3	67.8	64.2	67.8	68.0	55.1	16:15
16:16	67.5	65.4	63.1	64.5	63.8	64.9	61.9	70	70	70	70	70	70	70	67.7	59.9	66.8	59.7	67.2	66.3	59.5	16:16
16:17	67.4	60.1	66.9	65.0	67.2	64.1	63.4	70	70	70	70	70	70	70	67.8	65.4	67.3	55.5	65.8	67.2	57.0	16:17
16:18	68.1	60.9	58.6	62.4	65.4	65.0	62.4	70	70	70	70	70	70	70	67.1	64.8	66.6	62.0	62.3	65.4	37.1	16:18
16:19	65.8	38.6	65.2	56.9	67.1	69.8	62.7	70	70	70	70	70	70	70	67.0	63.9	66.5	65.5	63.0	59.8	33.6	16:19
16:20	66.3	28.7	59.6	65.8	60.6	65.3	65.2	70	70	70	70	70	70	70	67.8	63.3	67.8	63.8	66.7	58.1	29.8	16:20
16:21	61.7	35.9	57.5	57.0	66.6	60.2	59.9	70	70	70	70	70	70	70	69.0	64.3	69.2	65.5	65.7	60.2	37.3	16:21
16:22	63.6	37.1	53.8	58.4	64.5	59.3	42.8	70	70	65	60	55	50	45	67.5	66.3	69.1	65.7	65.5	60.2	42.3	16:22
16:23	60.1	41.3	53.8	53.1	62.4	61.1	54.2	70	70	65	60	55	50	45	66.4	65.6	67.1	63.2	68.0	64.2	41.9	16:23
16:24	64.5	39.9	60.7	52.4	62.9	56.3	59.4	70	70	65	60	55	50	45	65.9	64.2	67.0	61.5	67.8	65.7	40.5	16:24
16:25	68.2	46.9	63.5	61.9	63.8	57.0	61.0	70	70	65	60	55	50	45	67.3	63.8	66.8	62.2	65.8	63.7	50.3	16:25
16:26	67.3	53.6	63.5	59.3	62.6	58.7	58.1	70	70	65	60	55	50	45	67.3	62.7	67.0	58.8	63.2	64.1	42.2	16:26
16:27	66.3	58.3	63.7	54.8	64.2	56.0	58.2	70	70	65	60	55	50	45	68.5	62.4	65.7	58.6	62.5	63.5	20.2	16:27
16:28	68.8	64.1	64.5	48.6	62.7	60.8	61.6	70	70	65	60	55	50	45	68.2	66.2	66.8	60.8	62.4	61.3	14.1	16:28
16:29	70.4	66.9	67.2	39.8	63.8	56.1	60.9	70	70	65	60	55	50	45	67.3	64.1	68.4	61.8	64.3	57.2	22.0	16:29
16:30	69.1	64.3	68.4	49.8	64.8	51.1	60.6	70	70	65	60	55	50	45	67.8	61.3	67.5	63.5	64.8	53.3	30.5	16:30
16:31	66.3	66.0	67.5	65.1	63.1	60.8	61.3	65	60	55	50	45	40	35	66.8	59.2	67.3	61.3	63.8	50.0	28.9	16:31
16:32	67.3	60.9	69.0	65.4	68.6	62.3	61.1	65	60	55	50	45	40	35	66.7	60.7	67.7	60.3	62.5	55.3	25.7	16:32
16:33	68.1	64.0	65.3	67.1	69.8	68.7	64.4	65	60	55	50	45	40	35	68.2	65.2	67.1	63.9	62.0	60.5	24.7	16:33
16:34	67.2	65.2	68.1	64.4	67.5	67.2	66.0	65	60	55	50	45	40	35	65.2	66.0	68.2	63.7	66.0	57.7	21.6	16:34
16:35	66.5	61.8	66.3	64.7	65.3	65.6	63.6	65	60	55	50	45	40	35	66.1	65.2	68.3	63.1	68.3	54.0	30.5	16:35
16:36	65.6	63.6	66.9	66.7	69.0	63.2	64.4	65	60	55	50	45	40	35	68.0	64.2	67.8	62.7	66.2	57.4	30.7	16:36
16:37	67.3	66.0	67.5	63.7	68.3	65.9	63.0	65	60	55	50	45	40	35	69.2	64.0	67.4	60.8	63.7	62.7	32.0	16:37
16:38	65.1	60.9	67.6	64.8	65.9	67.0	62.6	65	60	55	50	45	40	35	67.9	64.1	67.7	61.9	61.1	63.0	34.7	16:38
16:39	67.3	64.0	64.2	56.8	66.3	60.5	56.8	65	60	55	50	45	40	35	67.8	61.9	65.6	62.3	62.0	56.5	36.3	16:39
16:40	68.0	66.5	69.5	49.9	66.8	62.9	25.6	65	60	55	50	45	40	35	66.9	62.8	64.5	61.0	63.8	57.3	40.0	16:40
16:41	68.7	56.4	68.2	65.3	60.4	56.6	8.0	70	70	70	65	60	55	50	67.7	63.5	66.0	61.3	63.3	60.2	47.9	16:41
16:42	68.3	63.7	66.0	66.0	64.3	53.9	9.7	70	70	70	65	60	55	50	68.5	64.1	66.3	63.1	63.2	61.9	53.0	16:42
16:43	67.0	63.3	65.0	58.9	63.2	45.8	12.4	70	70	70	65	60	55	50	68.6	62.5	66.5	62.0	65.1	63.0	49.0	16:43
16:44	68.3	66.4	68.3	59.5	63.0	36.8	16.8	70	70	70	65	60	55	50	68.8	63.2	66.8	61.8	64.9	64.7	32.7	16:44
16:45	68.4	65.6	68.6	56.7	53.7	37.5	18.4	70	70	70	65	60	55	50	66.6	61.5	66.7	64.7	66.4	62.0	20.6	16:45
16:46	67.5	67.4	69.9	67.4	26.9	36.8	17.6	70	70	70	65	60	55	50	66.9	62.8	66.1	61.3	66.0	59.5	29.0	16:46
16:47	69.5	67.2	70.2	65.5	31.3	33.3	22.5	70	70	70	65	60	55	50	66.9	63.9	65.8	59.1	57.5	60.2	34.4	16:47
16:48	68.2	67.5	70.3	65.2	34.9	35.5	22.7	65	60	55	50	45	40	35	66.5	62.0	66.4	62.7	55.9	58.4	30.3	16:48
16:49	69.4	64.0	70.9	68.6	23.1	38.8	34.3	65	60	55	50	45	40	35	67.5	61.2	61.5	56.8	64.8	57.9	25.7	16:49
16:50	68.8	65.3	67.6	65.7	24.1	36.7	32.5	65	60	55	50	45	40	35	67.5	63.7	62.3	46.8	65.5	53.2	29.3	16:50
16:51	66.3	66.1	68.4	61.9	40.6	41.0	17.9	65	60	55	50	45	40	35	65.8	65.2	66.0	37.3	61.1	53.0	38.4	16:51
16:52	65.8	63.5	67.5	59.1	31.8	42.9	22.4	65	60	55	50	45	40	35	65.8	62.7	66.6	34.8	60.0	50.5	37.4	16:52
16:53	65.0	59.5	66.5	62.1	21.1	43.5	28.2	65	60	55	50	45	40	35	67.0	60.2	65.9	36.9	62.1	52.3	28.3	16:53
16:54	68.3	60.1	65.1	61.4	27.8	46.2	28.4	65	60	55	50	45	40	35	66.4	61.5	65.8	39.8	63.1	58.7	27.0	16:54
16:55	66.1	64.8	67.5	52.3	37.8	45.2	27.5	60	50	45	40	45	40	35	67.5	65.6	67.8	38.8	61.8	61.3	29.2	16:55
16:56	65.6	60.7	67.6	62.1	47.2	38.6	18.7	60	50	45	40	45	40	35	67.3	64.3	68.7	42.3	64.1	56.3	16.6	16:56
16:57	64.1	60.8	64.8	63.9	40.9	32.6	19.7	60	50	45	40	45	40	35	65.7	61.6	65.4	52.3	66.2	51.6	17.0	16:57
16:58	67.2	62.4	63.6	58.0	27.6	35.5	14.6	60	50	45	40	40	35	30	67.5	59.6	62.9	53.3	65.4	51.8	22.2	16:58
16:59	69.8	62.0	65.9	59.2	27.6	41.3	12.4	60	50	45	40	40	35	30	66.3	61.7	62.0	53.0	63.7	55.3	20.5	16:59
17:00	66.4	66.6	69.3	64.2	36.2	41.7	18.5	60	50	45	40	40	35	30	62.8	61.6	62.9	55.4	63.0	52.2	22.8	17:00
17:01	66.8	64.6	68.5	64.3	33.3	37.8	25.9	60	50	45	40	40	35	30	65.7	59.8	62.4	58.8	63.3	42.1	32.8	17:01
17:02	68.5	63.5	69.4	64.4	24.7	31.7	23.4	60	55	50	45	40	35	30	67.2	63.5	61.5	53.5		38.3	36.3	17:02
17:03	67.7	64.9	68.1	62.9	21.0	33.6	21.6	70	65	60	55	50	45	40	67.5	64.7	63.7	44.8		41.5	38.3	17:03
17:04	68.6	65.0	66.9	60.9	32.3	26.1	20.0	70	65	60	55	50	45	40	66.1	64.6	65.0	49.5		44.9	38.8	17:04
17:05	68.7	62.1	67.5	66.0	34.1	27.6	16.7	70	65	60	55	50	45	40	66.0	64.3	66.0	58.7		45.1	26.7	17:05
17:06	67.9	61.0	65.0	63.6	37.7	23.8	25.5	70	65	60	55	50	45	40	67.3	60.4	66.8	61.3	50.5	44.1	19.3	17:06
17:07	66.8	63.2	65.6	53.8	27.7	25.7	36.3	70	65	60	55	50	45	40	67.1	53.6	64.0	52.8		42.7	29.3	17:07
17:08	67.8	63.1	66.2	40.2	34.7	30.1	26.6	65	60	55	50	45	40	35	65.8	55.9	62.8	42.8	48.9	44.6	30.3	17:08
17:09	68.0	62.4	66.7	30.0	18.1	40.0	8.8	65	60	55	50	45	40	35	65.3	60.3	65.7	32.3	38.5	49.6	28.5	17:09
17:10	69.3	53.9	61.2	39.9	19.6	39.2	18.3	65	60	55	50	45	40	35	63.3	58.4	63.2	30.5	28.0	49.2	26.4	17:10
17:11	68.6	47.6	57.7	41.6	25.9	42.6	23.5	65	60	55	50	45	40	35	62.5	48.4	58.7	33.5	30.0	52.7	26.9	17:11
17:12	69.9	47.9	27.6	40.7	40.3	43.1	17.9	65	60	55	50	45	40	35	65.8	50.7	48.0	34.1	40.5	55.5	20.9	17:12
17:13	69.2	55.1	26.4	30.7	46.0	41.3	20.7	60	50	40	35	40	35	30	67.2	49.0	27.4	32.8	44.2	53.4	15.7	17:13
17:14	66.2	40.7	26.4	11.6	47.0	43.7	25.6	60	50	40	35	40	35	30	65.7	51.8	26.0	26.8	50.9	49.9	16.8	17:14
17:15	68.0	17.1	26.8	25.2	32.8	33.9	15.8	60	50	40	35	40	35	30	65.7	36.9	27.9	25.7	52.3	50.0	22.3	17:15
17:16	66.5	27.4	24.7	22.7	15.4	25.3	12.1	60	50	40	35	40	35	30	64.3	18.3	26.7	29.5	52.5	39.2	31.5	17:16
17:17	65.5	37.9	23.6	29.1	31.0	34.9	16.5	55	40	30	35	40	35	30	63.0	25.2	27.3	34.8	59.4	28.7	32.6	17:17
17:18	65.1	33.0	17.9	31.1	33.1	35.9	14.7	55	40	30	40	45	40	35	59.3	31.9	19.8	34.6	59.5	25.4	26.1	17:18
17:19	67.4	24.4	14.8	32.1	33.1	31.0	15.1	55	40	30	40	45	40	35	58.3	33.7	14.3	32.2	59.6	30.8	29.3	17:19
17:20	64.5	15.9	21.0	34.0	42.1	28.3	19.7	55	40	30	40	45	40	35	60.5	22.2	23.0	33.7	56.8	42.3	28.5	17:20
17:21	63.1	14.6	24.2	27.4	48.1	29.6	17.1	55	40	30	40	45	40	35	60.8	14.2	22.7	36.7	46.8	46.6	14.8	17:21
17:22	59.5	17.1	22.0	30.7	40.8	38.6	18.4	55	40	30	40	45	40	35	59.3	19.7	18.3	36.7	32.3	47.8	13.9	17:22
17:23	53.2	25.9	27.7	27.3	25.4	42.3	15.1	55	40	30	40	40	35	30	60.2	24.7	17.2	36.3	30.5	48.8	18.4	17:23
17:24	55.4	14.7	28.0	25.0	20.6	44.6	11.2	55	40	30	40	40	35	30	62.5	24.1	17.1	34.3		45.7	14.2	17:24
17:25	54.3	21.4	26.7	25.7	28.9	36.0	24.7	55	40	30	40	40	35	30	61.0	17.4	21.1	34.8		39.6	19.8	17:25
17:26	55.7	30.8	25.9	28.3	33.2	35.6	33.7	55	40	30	40	40	35	30	61.1	16.0	21.0	35.0		37.5	31.2	17:26
17:27	64.2	27.3	18.3	23.4	37.0	34.8	21.4	55	40	30	40	40	35	30	61.3	21.3	20.7	35.4		35.0	28.5	17:27
17:28	64.8	29.3	22.8	33.1	56.8	33.5	21.2	55	40	30	40	40	35	30	63.9	19.7	25.8	35.3	56.0	25.9	17.6	17:28
17:29	64.4	29.7	11.8	33.7	60.1	38.6	13.4	55	40	30	40	40	35	30	63.7	16.8	22.2	33.7	56.3	32.2	15.0	17:29
17:30	65.0	17.6	20.4	34.1	61.2	44.6	20.0	55	40	30	40	40	35	30	62.1	20.3	22.7	32.5	55.8	41.3	19.8	17:30
17:31	64.0	22.9	23.2	35.0	57.1	44.9	25.9	55	40	30	40	40	35	30	61.8	21.2	26.3	32.0	50.7	39.2	18.6	17:31
17:32	66.8	19.7	18.6	34.6	58.9	37.8	14.3	55	40	30	35	40	35	30	62.2	17.2	25.0	32.8	28.9	29.5	16.6	17:32
17:33	65.7	31.5	22.7	33.2	54.3	31.3	12.1	55	40	30	35	40	35	30	65.1	23.2	22.8	33.8	28.2	24.5	23.1	17:33
17:34	66.0	36.2	18.2	35.8	61.0	27.8	17.1	55	40	30	35	40	35	30	67.1	31.2	21.3	37.8	41.0	31.8	19.3	17:34
17:35	67.8	26.4	20.1	31.3	57.5	23.7	22.0	55	40	30	35	40	35	30	67.0	35.2	25.0	33.7	45.1	36.8	12.8	17:35
17:36	66.6	36.6	24.0	34.7	48.7	22.8	29.1	55	40	30	35	40	35	30	66.7	32.7	23.6	33.5	34.5	40.6	19.8	17:36
17:37	69.1	35.1	18.5	32.7	47.8	14.1	18.7	55	40	30	40	40	35	30	62.8	28.7	24.0	37.8	21.9	40.3	30.3	17:37
17:38	64.5	35.1	24.3	32.4	40.0	28.1	21.5	55	40	30	40	45	40	35	64.1	24.2	28.3	34.0	30.8	33.0	31.8	17:38
17:39	68.7	31.5	30.6	33.0	41.5	38.4	12.5	55	40	30	40	45	40	35	63.9	19.6	26.7	29.1	36.8	26.3	23.8	17:39
17:40	69.5	34.3	25.3	31.6	25.5	41.7	11.2	55	40	30	40	35	30	35	62.5	26.7	24.5	32.3	39.9	31.8	21.7	17:40
17:41	69.2	43.8	22.0	28.5	15.2	43.6	22.1	55	40	30	40	35	30	35	63.3	33.6	19.3	34.3	38.5	37.1	19.2	17:41
17:42	68.8	66.6	12.9	24.5	28.8	35.6	11.8	55	40	30	35	35	30	35	64.8	41.2	21.8	33.6	34.6	35.7	18.0	17:42
17:43	69.3	66.2	27.3	33.5	25.4	25.7	17.6	55	40	30	35	35	30	30	65.8	39.4	26.7	31.2	32.0	29.9	20.1	17:43
17:44	68.3	62.9	31.9	28.7	38.3	20.1	13.9	55	40	30	35	35	30	30	64.8	33.8	26.3	26.6	32.1	20.8	17.9	17:44
17:45	69.9	64.8	27.6	25.6	39.9	31.4	10.2	55	40	30	35	35	30	30	65.2	31.3	23.9	29.8	40.0	27.5	21.5	17:45
17:46	71.9	68.2	27.3	30.0	31.9	33.2	15.1	55	40	30	35	35	30	30	66.2	26.9	20.7	32.2	51.2	37.5	21.8	17:46
17:47	70.2	67.2	25.9	28.0	26.0	25.9	22.7	55	40	30	40	35	30	30	65.2	30.6	20.3	34.4	51.8	38.2	12.9	17:47
17:48	70.3	67.8	44.7	23.9	27.5	25.7	22.9	55	40	30	40	35	30	30	61.3	33.4	20.8	31.2	33.5	31.6	15.2	17:48
17:49	67.4	65.7	63.9	24.4	38.5	27.5	22.8	55	40	30	40	35	30	30	61.8	38.4	19.4	30.9	27.0	23.4	21.3	17:49
17:50	69.5	64.8	64.8	24.8	45.5	36.9	16.2	55	40	30	40	35	30	30	64.7	35.2	15.8	34.3	42.8	30.4	27.3	17:50
17:51	67.0	65.2	66.6	34.8	22.9	38.9	21.6	55	40	30	40	35	30	30	66.1	25.6	22.4	35.0	52.7	34.3	34.7	17:51
17:52	68.3	65.0	69.0	44.1	15.4	41.3	16.1	55	40	30	40	35	30	30	66.3	15.3	24.3	36.4	51.3	37.9	28.4	17:52
17:53	68.9	68.1	67.8	40.0	26.9	47.2	11.2	55	40	30	40	35	30	30	64.3	23.0	22.2	32.2	36.8	40.8	24.3	17:53
17:54	69.0	65.5	70.3	33.3	29.4	45.6	13.7	55	40	30	40	35	30	30	65.6	37.9	23.3	27.0	21.2	41.1	25.0	17:54
17:55	68.2	66.6	69.7	50.1	31.1	42.9	16.8	55	40	30	40	40	35	30	67.3	49.7	30.1	26.4	25.8	37.4	23.8	17:55
17:56	70.3	63.5	66.9	65.0	31.4	34.8	16.8	55	40	35	40	40	35	30	67.5	58.1	34.5	29.0	29.3	33.2	20.9	17:56
17:57	69.0	64.8	67.5	62.9	31.7	20.4	14.0	55	40	35	35	40	35	30	68.7	63.7	32.8	30.8	39.9	39.1	22.8	17:57
17:58	70.5	65.6	68.9	64.0	28.8	22.3	22.8	55	40	35	35	40	35	30	67.8	61.2	25.9	32.9	47.1	42.2	23.7	17:58
17:59	68.4	65.8	70.2	65.8	32.8	26.6	23.0	55	40	35	35	40	35	30	66.4	61.2	23.0	32.8	60.3	42.6	21.6	17:59
18:00	69.6	61.6	68.5	68.0	43.7	29.0	15.4	55	45	35	35	40	35	30	66.9	61.6	23.8	35.8	62.5	44.2	25.0	18:00
18:01	69.0	64.4	66.9	65.4	55.0	32.6	25.0	55	40	30	35	40	35	30	67.3	63.3	26.5	35.5	62.8	45.3	23.6	18:01
18:02	72.5	67.6	69.6	69.7	64.6	38.1	15.7	55	40	30	35	40	35	30	67.0	63.5	31.6	33.7	63.3	44.7	18.1	18:02
18:03	73.2	68.4	71.3	65.2	62.9	34.0	15.0	55	40	30	35	40	35	30	67.5	63.6	41.8	33.7	60.8	48.8	16.4	18:03
18:04	69.9	69.2	71.5	68.0	66.3	38.4	21.4	55	40	30	35	40	35	30	65.8	63.0	57.3	38.7	58.8	56.8	14.3	18:04
18:05	67.5	64.2	69.0	68.1	68.8	47.7	29.2	55	40	30	35	40	35	30	64.3	63.4	64.4	41.5	60.6	58.9	17.9	18:05
18:06	70.3	65.6	69.2	65.5	68.6	47.4	40.3	55	40	30	35	40	35	30	66.5	61.8	65.0	52.6	62.1	55.6	19.2	18:06
18:07	69.3	67.6	69.3	65.5	67.3	48.5	47.5	55	40	30	35	40	35	30	67.9	62.9	66.6	63.2	62.0	54.9	15.0	18:07
18:08	70.0	66.6	67.9	68.2	69.2	61.8	33.0	60	50	40	35	40	35	30	66.5	65.5	66.9	61.0	63.8	54.7	17.5	18:08
18:09	67.9	65.7	71.6	62.2	69.9	66.8	19.1	60	50	40	35	40	35	30	67.0	61.2	64.3	59.2	65.3	57.1	21.3	18:09
18:10	69.6	68.1	67.1	67.7	66.8	68.7	25.9	60	50	40	35	40	35	30	68.3	64.6	63.2	58.7	64.8	62.3	27.1	18:10
18:11	70.7	67.2	71.5	66.2	68.8	63.2	25.0	60	55	50	45	40	35	30	68.0	65.1	67.7	52.8	66.3	63.8	23.0	18:11
18:12	68.8	67.0	70.3	67.0	68.8	64.5	22.9	60	55	50	45	40	35	30	68.1	64.7	67.8	58.3	64.3	62.0	12.8	18:12
18:13	68.1	62.4	70.2	68.7	71.2	68.0	19.9	60	55	50	45	40	35	30	67.8	64.9	67.6	62.3	65.0	59.8	13.8	18:13
18:14	68.5	67.2	68.4	62.8	71.2	69.4	21.1	60	55	50	45	40	35	30	67.8	62.9	65.8	60.8	66.7	60.8	18.7	18:14
18:15	69.5	67.3	69.8	65.8	65.1	68.1	24.9	60	55	50	45	40	35	30	66.3	63.7	64.0	54.2	67.3	57.4	15.7	18:15

Figure H-9. Heat Map Comparison with and without Active VSL—July 22, 2014, San Antonio.

Temple

For the I-35 deployment in Temple, the VSL system was most active on Friday. Traffic conditions on I-35 caused the system to active almost every Friday afternoon during the evaluation period. The project team used the time periods shown in Table H-13 for evaluating the Temple VSL deployment.

Table H-13. VSL Activations Used in Evaluating Temple VSL Deployments.

Evaluation Condition	Date of Activation	Start Time of Activation	End Time of Activation
Without VSL Active	6/20/2014	2:34 p.m.	5:20 p.m.
With VSL Active	7/11/2014	2:00 p.m.	5:44 p.m.
	7/25/2014	1:17 p.m.	6:31 p.m.
	8/8/2014	1:20 p.m.	5:59 p.m.
	8/15/2014	2:00 p.m.	6:17 p.m.
	8/22/2014	2:00 p.m.	6:46 p.m.
	9/12/2014	3:43 p.m.	6:17 p.m.
	9/19/2014	3:50 p.m.	6:07 p.m.
	9/26/2014	3:23 p.m.	6:49 p.m.
	10/3/2014	3:56 p.m.	7:21 p.m.
	10/10/2014	3:56 p.m.	6:23 p.m.
	10/17/2014	2:58 p.m.	9:47 p.m.
	10/24/2014	2:50 p.m.	5:42 p.m.

Figure H-10 shows the average speed at each of the VSL signs and the "Reduced Speed Ahead" (RSA) sign averaged over the duration when the sign was active. The figure shows that average speed at each of the sign locations had a tendency to be higher immediately following the deployment when compared to speeds late in the deployment. The figure shows that average speed at each of the sign locations had a tendency to be higher in July and then declined in both August and September.

Table H-14 shows a statistical comparison of the average speeds measured at each sign location in the VSL deployment. The values shown in bold red in the table represent speeds that were judged to be statistically significant with the VSL active compared to the speeds measured at the same location without the VSL active. These statistical comparisons were performed using a standard t-test with unequal variance. A 95 percent confidence interval was used in the statistical comparisons.

As shown in Table H-14, average speeds at each sign location were statistically higher during the two days evaluated in July at this location, while average speeds were statistically lower at all the stations in the last two days in September. For those activations studied in August, average speed where similar to the before conditions at each of the study locations.

Table H-15 and Figure H-11 show a comparison of the average difference between the speed limit and the measured travel speeds at each of the sign locations (including the "Reduced Speed Ahead" sign). As expected, the speed differential is greatest and continues to worsen as travelers traverse through the congestion when no VSL is active. With the exception of the activations on 9/19 and 9/26, actual travel speeds and posted speeds are within 10 mph at each of the sign locations when VSL is active. On 9/19 and 9/26, the difference between posted and measured speeds is greatest further upstream of the congestion point. This suggests that traffic is spilling back past the beginning of the VSL signs.

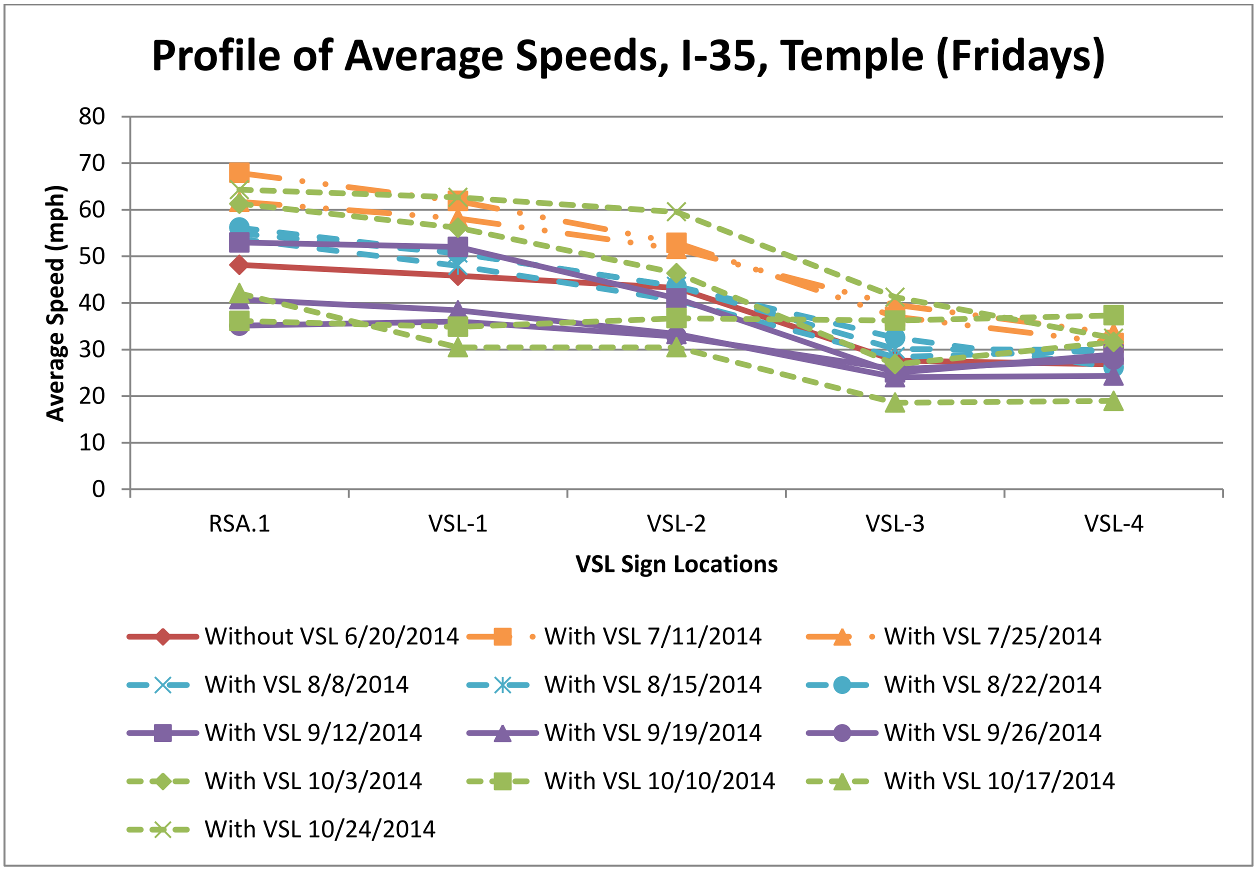


Figure H-10. Profile of Average Speeds in Temple VSL Deployment.

Table H-14. Statistical Comparison of Average Speeds With and Without VSL Active – Temple Deployment.

VSL Status	Average Measured Speed (mph) at Each Sign Location					
	Date	**RSA-1**	**VSL-1**	**VSL-2**	**VSL-3**	**VSL-4**
Without VSL	6/20	48.1	45.8	43.2	27.7	26.8
With VSL-	7/11	**67.9**	**61.9**	**52.9**	**37.0**	**31.4**
	7/25	**61.7**	**58.1**	**51.6**	**39.6**	**33.5**
	8/8	**54.9**	**50.7**	43.6	**30.1**	**29.9**
	8/15	**53.7**	**48.0**	40.6	28.4	**29.9**
	8/22	**56.2**	**50.7**	43.5	**32.5**	26.2
	9/12	**53.0**	**52.0**	41.0	**25.0**	**28.9**
	9/19	**40.8**	**38.4**	**33.3**	**24.0**	**24.3**
	9/26	**35.1**	**36.0**	**32.8**	**25.8**	**27.8**
	10/3	**61.3**	**56.1**	**46.4**	26.8	**31.6**
	10/10	**36.1**	**34.9**	**36.7**	**36.2**	**37.3**
	10/17	**42.1**	**30.5**	**30.5**	**18.6**	**19.0**
	10/24	**64.3**	**62.7**	**59.5**	**41.2**	**32.4**

Note: values shown in bold red are statistically significant at a 95 percent confidence interval. These values are compared to the average speed without VSL active observed on 6/20.

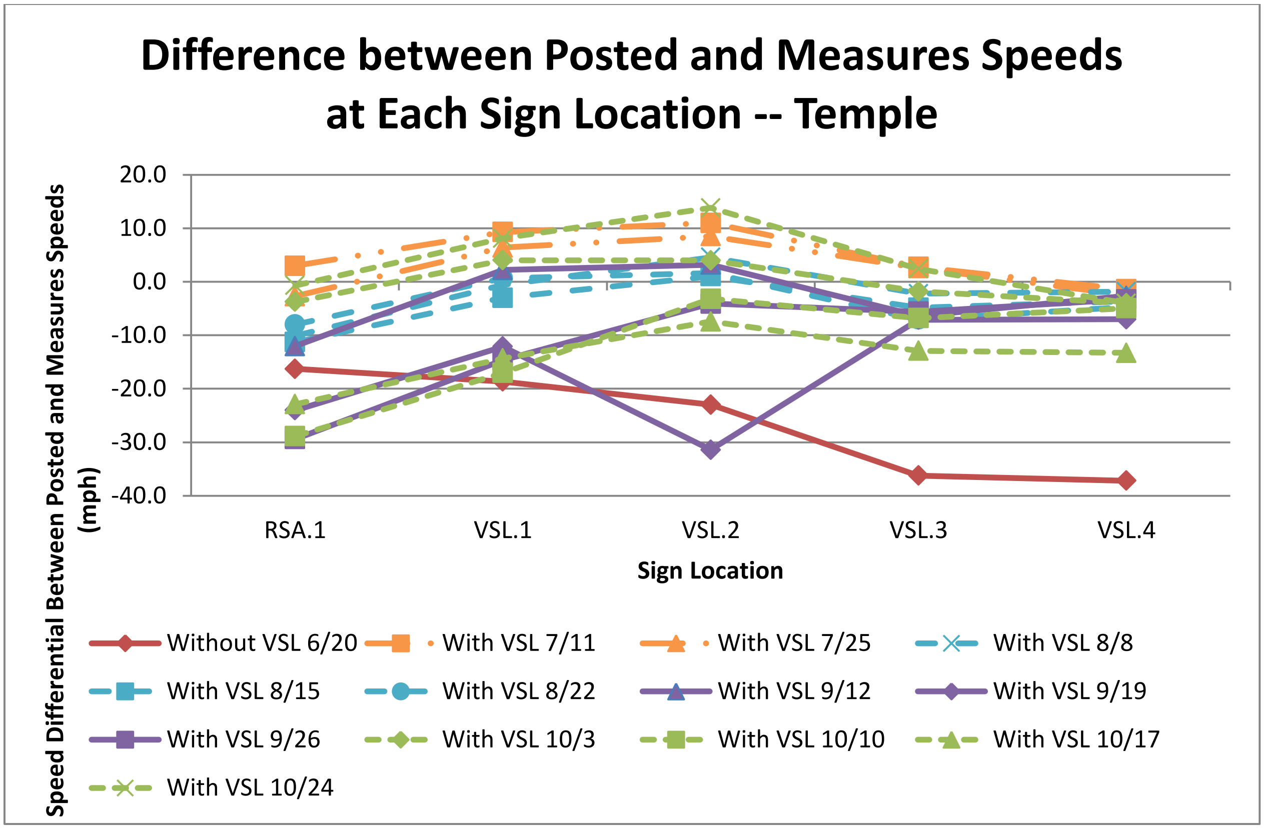


Figure H-11. Difference between Posted and Measures Speeds (mph) –Temple VSL Deployment

Table H-15. Statistical Analysis of Speed Differential – Temple VSL Deployment

VSL Status	Average Differnential between Measured and PostedSpeed (mph) at Each Sign Location					
	Date	**RSA-1**	**VSL-1**	**VSL-2**	**VSL-3**	**VSL-4**
Without VSL	6/20	-16.3	-18.6	-23.0	-36.2	-37.2
With VSL-	7/11	**3.0**	**9.3**	**11.0**	**2.8**	**-1.4**
	7/25	**-2.7**	**6.4**	**8.5**	**2.6**	**-2.5**
	8/8	**-10.1**	**-0.6**	**4.6**	**-2.2**	**-1.8**
	8/15	**-11.3**	**-3.0**	**1.0**	**-4.8**	**-3.7**
	8/22	**-8.0**	**0.7**	**1.6**	**-7.1**	**-4.7**
	9/12	**-12.0**	**2.2**	**3.2**	**-6.4**	**-2.6**
	9/19	**-24.0**	**-12.1**	**-31.4***	**-7.1**	**-7.0**
	9/26	**-29.4**	**-14.7**	**-4.1**	**-5.6**	**-3.3**
	10/3	**-3.7**	**4.0**	**4.0**	**-1.8**	**-4.0**
	10/10	**-28.9**	**-17.0**	**-3.2**	**-6.8**	**-4.9**
	10/17	**-22.9**	**-14.3**	**-7.4**	**-12.9**	**-13.3**
	10/24	**-0.7**	**8.1**	**13.8**	**2.4**	**-4.0**

Note: values shown in bold are statistically significant at a 95 percent confidence interval. These values are compared to the average speed without VSL active observed on 6/20. Negative values imply that measured speed were lower than posted speed limits, while positive values imply that measured speeds were higher than posted speed limits.

* Error in communicating with sign. Sign posted at 65 mph during activation.

Table H-16 shows the average per lane flow rate at each sign location for the Temple deployment. The data show that beginning with the activations in August, the average per lane flow rate has increased over that generated before the VSL was active. These increases in average per lane flow rate were determined to be statistically significant at a 95 percentile confidence level. The increase in flow rate may be a result of increased efficiencies generated by the VSL deployment or signify an increase in traffic demands toward the end of summer.

Table H-16. Average Per Lane Flow Rate at Each Sign Location–Temple VSL Deployment

VSL Status	Average Per Lane Flow Rate (VPHPL) at Each Sign Location					
	Date	**RSA-1**	**VSL-1**	**VSL-2**	**VSL-3**	**VSL-4**
Without VSL	6/20	717	733	644	635	763
With VSL-	7/11	720	712	612	612	732
	7/25	724	725	628	642	726
	8/8	**1169**	**1154**	**988**	**1013**	**1191**
	8/15	**1168**	**1161**	**1000**	**1068**	**1189**
	8/22	**1103**	**1093**	**925**	**958**	**1058**
	9/12	**1146**	**1113**	**1014**	**1016**	**1207**
	9/19	**1106**	**1101**	**922**	**968**	**1055**
	9/26	**1098**	**1067**	**956**	**973**	**1151**
	10/3	**1228**	**1212**	**1030**	**1055**	**846**
	10/10	**1092**	**1133**	**984**	**976**	**822**
	10/17	**1018**	**1013**	**793**	**810**	**593**
	10/24	**1235**	**1244**	**1106**	**1124**	**846**

Note: values shown in bold are statistically significant at a 95 percent confidence interval. These values are compared to the average speed without VSL active observed on 6/20.

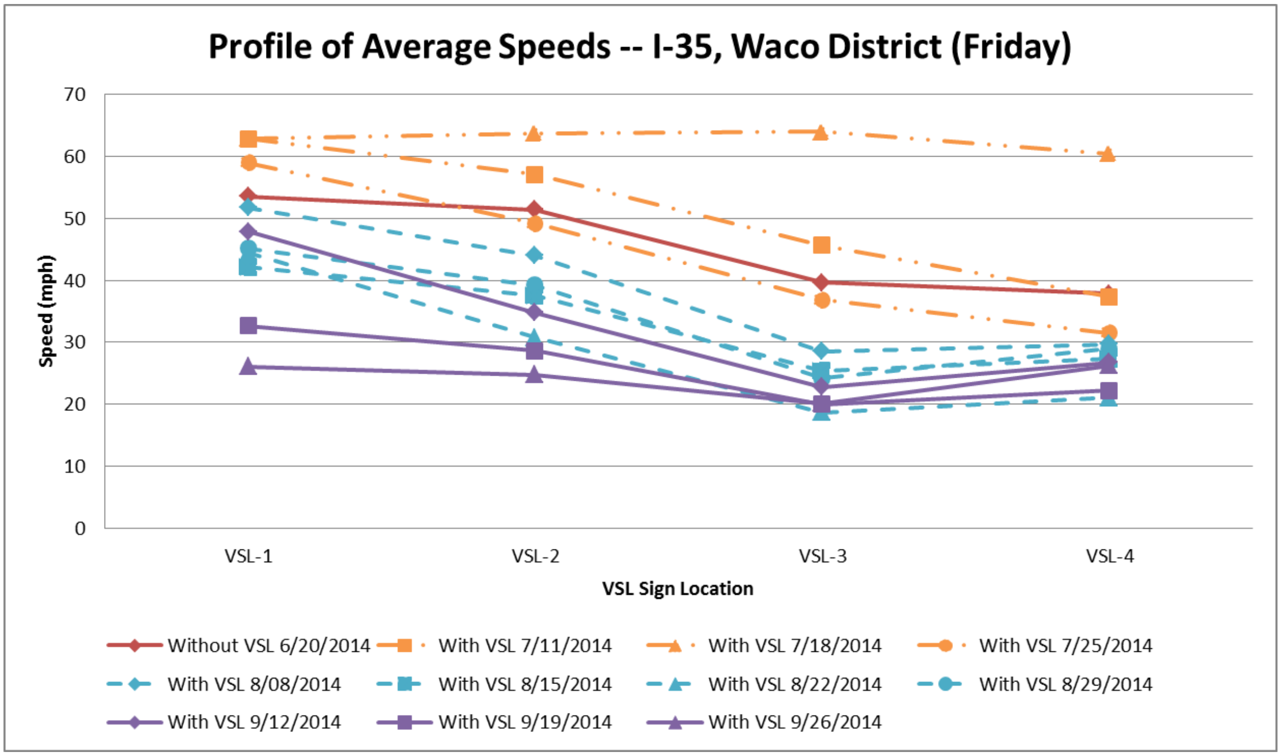


Figure H-12. Comparison of Friday's Average Speeds (mph) at Each VSL Sign Location, Temple.

Ranger Hill, Eastland County

The project team reviewed the data from Ranger Hill, Eastland County to determine the best approach to analyze the operational performance of the VSL. Once the VSL system in Ranger Hill, Eastland County was operational, reduced speed limits were actually posted on signs in the field on only four days though were more potential activations. Six days saw activations that were for weather events (8/29; 9/12; 9/17), and one was a congestion event (8/7).

Table H-17. Average Measured Speed during Weather Events at Each Sign Location.

Date of Weather Event	Eastbound				Westbound			
	RSA.1	VSL-1	VSL-2	VSL-3	RSA.1	VSL-1	VSL-2	VSL-3
Event Speed Limit	65	55	55	55	75	60	55	55
8/29	64.5	64.1	63.9	64.3	71.8	69.4	63.9	64.5
9/12	64.7	64.3	64.1	64.9	72.0	72.2	64.8	64.8
9/17	64.6	64.1	64.1	63.7	70.1	69.0	63.6	62.1
10/12	54.6	64.3	64.1	64.9	73.6	72.2	64.8	64.8
11/14	64.3	63.9	63.3	62.9	69.4	68.0	63.3	62.2
11/22	64.2	63.9	63.3	62.9	69.4	68.0	63.3	62.2

For the weather events, the VSL had very little impact with the VSL posted speed of 55 mph. Average travel speeds were between 60 and 65 mph. For the congestion event, the data suggests that an incident occurred where the freeway may have actually been blocked. For this event, the posted speeds were initially close to measured speeds. Once the freeway stopped moving altogether, the system registered that no cars were passing in front of the sensor and displayed 65 mph when in fact, no vehicles were moving. The system did not recover until vehicles started moving again.

As indicated by the heat maps shown in the following figures for these events, no routine congestion forms along the facility, offering no true baseline data for comparison. Furthermore, the weather events that did occur were fairly minor. More significant weather events may yield more telling results.

VSL Deployment -- Brownwood District - Weather Activation 8/29/2014

	Eastbound								Westbound								
	Posted Speed Limit				Measured Speeds				Posted Speed Limit				Measured Speeds				
	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	
1:00:00 AM	65	65	65	65	65.0	64.4	62.7	64.0	75	75	65	65	71.6	70.4	65.0	64.2	1:00:00 AM
1:01:00 AM	65	65	65	65	64.6	65.0	65.0	65.0	75	75	65	65	72.8	69.3	65.0		1:01:00 AM
1:02:00 AM	65	65	65	65	64.8	65.0	65.0	64.5	75	75	65	65	71.1	68.0	65.0		1:02:00 AM
1:03:00 AM	65	65	65	65	65.0	64.3	65.0	64.7	75	75	65	65	72.3	64.4	65.0	65.0	1:03:00 AM
1:04:00 AM	65	65	65	65	62.1	63.8	64.5	63.9	75	75	65	65	73.6	67.4	64.3	65.0	1:04:00 AM
1:05:00 AM	65	65	65	65	59.9	63.7	64.7	64.4	75	75	65	65	70.4	65.6	63.8	64.2	1:05:00 AM
1:06:00 AM	65	65	65	65	65.0	60.0	65.0	64.7	75	75	65	65	62.5	71.3	62.8	62.4	1:06:00 AM
1:07:00 AM	65	65	65	65	62.8	59.1	59.0	64.0	75	75	65	65	66.2	72.0	65.0	63.3	1:07:00 AM
1:08:00 AM	65	65	65	65	63.1	59.6	61.4	64.3	75	75	65	65	71.5	64.0	64.8	65.0	1:08:00 AM
1:09:00 AM	65	65	65	65	64.9	64.3	62.0	64.3	75	75	65	65	57.6	57.8	63.8	65.0	1:09:00 AM
1:10:00 AM	65	65	65	65	64.3	62.8	64.3	64.8	75	75	65	65	62.8	53.0	56.0	65.0	1:10:00 AM
1:11:00 AM	65	65	65	65	64.0	60.5	61.7	63.4	75	75	65	65	52.3	68.0	49.1	60.5	1:11:00 AM
1:12:00 AM	65	65	65	65	65.0	63.8	62.1	63.1	75	75	65	65	63.5	70.5	64.2	60.3	1:12:00 AM
1:13:00 AM	65	65	65	65	65.0	64.4	65.0	64.9	75	75	65	65	67.0	72.5	64.2	63.7	1:13:00 AM
1:14:00 AM	65	65	65	65	65.0	63.8	65.0	65.0	75	75	65	65	69.3	69.3	65.0	65.0	1:14:00 AM
1:15:00 AM	65	65	65	65			65.0		75	75	65	65	73.7	66.9	63.5	65.0	1:15:00 AM
1:16:00 AM	65	65	65	65	63.3	59.0			75	75	65	65	72.7	68.5	62.8		1:16:00 AM
1:17:00 AM	65	65	65	65	60.7	56.8	61.0		75	75	65	65	71.8	71.9	64.2	61.0	1:17:00 AM
1:18:00 AM	65	65	65	65	61.5	53.3	60.2	64.0	75	75	65	65	72.3	70.8	65.0	60.8	1:18:00 AM
1:19:00 AM	65	65	65	65	63.3	61.5	60.2	60.2	75	75	65	65	72.9	71.9	65.0	64.4	1:19:00 AM
1:20:00 AM	65	55	55	55	61.2	62.1	61.1	60.9	75	60	55	55	72.0	70.0	65.0	65.0	1:20:00 AM
1:21:00 AM	65	55	55	55	57.6	58.8	60.5	61.5	75	60	55	55	74.9	74.4	65.0	65.0	1:21:00 AM
1:22:00 AM	65	55	55	55	56.8	51.0	58.3	61.9	75	60	55	55	73.8	73.4	65.0	64.5	1:22:00 AM
1:23:00 AM	65	55	55	55	53.6	49.2	59.2	60.3	75	60	55	55	73.0	70.4	64.0	64.7	1:23:00 AM
1:24:00 AM	65	55	55	55	49.4	50.8	61.3	60.3	75	60	55	55	64.0	68.4	64.3	65.0	1:24:00 AM
1:25:00 AM	65	55	55	55	56.1	50.8	56.0	57.9	75	60	55	55	64.5	61.7	62.8		1:25:00 AM
1:26:00 AM	65	55	55	55	59.6	59.6	59.3	56.3	75	60	55	55	68.4	64.0	60.9	60.0	1:26:00 AM
1:27:00 AM	65	55	55	55	61.0		61.0		75	60	55	55	66.1	65.5			1:27:00 AM
1:28:00 AM																	1:28:00 AM
1:29:00 AM																	1:29:00 AM
1:30:00 AM																	1:30:00 AM
1:31:00 AM																	1:31:00 AM
1:32:00 AM																	1:32:00 AM
1:33:00 AM																	1:33:00 AM
1:34:00 AM	65	55	55	55	54.0	59.5			75	60	55	55	65.0	54.0	56.0	54.0	1:34:00 AM
1:35:00 AM	65	55	55	55	56.0	60.0		61.7	75	60	55	55	62.7	62.3	60.5	54.3	1:35:00 AM
1:36:00 AM	65	65	65	65	58.3	61.2		61.9	75	75	65	65	62.3	64.6	64.3	56.7	1:36:00 AM
1:37:00 AM	65	65	65	65	55.4	59.5		60.9	75	75	65	65	64.3	64.1	62.5	62.5	1:37:00 AM
1:38:00 AM	65	65	65	65	53.0	55.5	62.8	60.1	75	75	65	65	63.9	58.7	59.3	63.2	1:38:00 AM
1:39:00 AM	65	65	65	65	51.4	53.9	60.9	60.6	75	75	65	65	66.3	65.3	61.3	62.4	1:39:00 AM
1:40:00 AM	65	65	65	65	47.6	49.0	53.4	57.3	75	75	65	65	67.3	63.8	64.4	63.5	1:40:00 AM
1:41:00 AM	65	65	65	65	45.8	46.5	51.2	53.8	75	75	65	65	70.6	69.4	64.6	64.3	1:41:00 AM
1:42:00 AM	65	65	65	65	56.4	48.0	47.6	50.1	75	75	65	65	66.3	71.7	64.3	65.0	1:42:00 AM
1:43:00 AM	65	65	65	65	52.8	51.2	48.3	53.1	75	75	65	65	63.3	60.5	62.5	65.0	1:43:00 AM
1:44:00 AM	65	65	65	65	52.3	44.5	48.0	54.2	75	75	65	65	61.4	63.3	63.1	52.0	1:44:00 AM
1:45:00 AM	65	65	65	65		50.6	46.3	49.6	75	75	65	65	56.9	55.8	63.6	54.8	1:45:00 AM
1:46:00 AM	65	65	65	65	63.5	55.7	47.7	50.1	75	75	65	65	64.8	60.9	54.8	58.3	1:46:00 AM
1:47:00 AM	65	65	65	65	59.6	54.7	54.6	58.3	75	75	65	65	66.8	56.9	57.8	55.7	1:47:00 AM
1:48:00 AM	65	65	65	65	51.9	50.9	57.4	61.8	75	75	65	65	59.7	58.5	57.7	46.9	1:48:00 AM
1:49:00 AM	65	65	65	65	51.2	48.1	52.1	57.0	75	75	65	65	55.8	63.6	56.8	55.5	1:49:00 AM
1:50:00 AM	65	65	65	65	61.9	54.0	37.8	52.3	75	75	65	65	66.0	65.7	61.7	59.8	1:50:00 AM
1:51:00 AM	65	65	65	65	60.0	63.7	54.3	58.4	75	75	65	65	60.3	62.0	64.5	64.0	1:51:00 AM
1:52:00 AM	65	65	65	65	59.7	54.9	60.7	63.1	75	75	65	65	64.8	63.8	64.5		1:52:00 AM
1:53:00 AM	65	65	65	65	59.9	56.7	53.4	60.2	75	75	65	65	62.5	64.6	64.7	61.5	1:53:00 AM
1:54:00 AM	65	65	65	65	60.1	56.8	57.0	57.9	75	75	65	65	63.0	65.3	62.7	61.3	1:54:00 AM
1:55:00 AM	65	65	65	65	54.8	49.9	58.3	58.9	75	75	65	65	61.0	54.0	60.5	61.0	1:55:00 AM
1:56:00 AM	65	65	65	65	48.4	45.7	51.3	57.9	75	75	65	65	62.0	60.7	55.3	51.0	1:56:00 AM
1:57:00 AM	65	65	65	65	50.6	52.2	48.2	47.6	75	75	65	65	68.5	64.0	59.3	54.0	1:57:00 AM
1:58:00 AM	65	65	65	65	56.7	52.1	51.3	48.4	75	75	65	65	73.0	63.3	62.8	61.0	1:58:00 AM
1:59:00 AM	65	65	65	65	59.9	49.0	54.9	54.9	75	75	65	65	63.0	61.7	60.5		1:59:00 AM

Figure H-13. "Heat Map" Speeds for VSL Weather Event – August 29, 2014, Ranger Hill, Eastland County.

VSL Deployment -- Brownwood District - Weather Activation 9/12/2014

	Eastbound								Westbound								
	Posted Speed Limit				Measured Speeds				Posted Speed Limit				Measured Speeds				
	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	VSL.3	VSL.2	VSL.1	RSA.1	
8:00:00 AM	65	65	65	65	64.9	64.1	64.9	64.7	75	75	65	65	64.8	65.0	72.3	72.4	8:00:00 AM
8:01:00 AM	65	65	65	65	65.0	64.9	64.8	64.9	75	75	65	65	63.0	64.6	73.1	73.5	8:01:00 AM
8:02:00 AM	65	65	65	65	65.0	64.2	64.8	65.0	75	75	65	65	61.7	64.1	72.8	74.3	8:02:00 AM
8:03:00 AM	65	65	65	65	65.0	63.4	63.8	64.9	75	75	65	65	64.5	64.8	72.5	72.1	8:03:00 AM
8:04:00 AM	65	65	65	65	64.4	64.6	64.3	64.9	75	75	65	65	32.0	64.6	70.8	72.5	8:04:00 AM
8:05:00 AM	65	65	65	65	64.1	65.0	64.9	65.0	75	75	65	65	64.1	64.9	72.8	74.1	8:05:00 AM
8:06:00 AM	65	65	65	65	64.8	65.0	64.7	64.7	75	75	65	65	64.0	65.0	73.6	72.9	8:06:00 AM
8:07:00 AM	65	65	65	65	64.5	64.7	64.8	64.9	75	75	65	65	65.0	64.9	71.7	72.9	8:07:00 AM
8:08:00 AM	65	65	65	65	63.7	63.8	64.1	65.0	75	75	65	65	65.0	64.9	71.4	73.3	8:08:00 AM
8:09:00 AM	65	65	65	65	64.3	63.7	64.1	65.0	75	75	65	65	65.0	65.0	70.8	72.7	8:09:00 AM
8:10:00 AM	65	65	65	65	64.7	65.0	63.5	65.0	75	75	65	65	64.0	65.0	71.8	49.7	8:10:00 AM
8:11:00 AM	65	65	65	65	64.4	64.7	62.3	65.0	75	75	65	65	64.7	65.0	72.0	73.5	8:11:00 AM
8:12:00 AM	65	65	65	65	64.8	64.2	65.0	65.0	75	75	65	65	64.5	64.6	68.8	71.8	8:12:00 AM
8:13:00 AM	65	65	65	65	64.8	63.8	65.0	65.0	75	75	65	65	63.6	63.9	70.9	73.3	8:13:00 AM
8:14:00 AM	65	65	65	65	64.1	64.7	65.0	65.0	75	75	65	65	64.6	64.5	72.3	71.1	8:14:00 AM
8:15:00 AM	65	55	55	55	64.8	64.3	64.9	65.0	75	60	55	55	62.9	64.9	66.3	68.2	8:15:00 AM
8:16:00 AM	65	55	55	55	64.8	64.1	64.1	65.0	75	60	55	55	64.1	64.7	68.5	71.1	8:16:00 AM
8:17:00 AM	65	55	55	55	65.0	63.8	63.5	63.7	75	60	55	55	64.6	64.4	70.2	72.2	8:17:00 AM
8:18:00 AM	65	55	55	55	65.0	31.4	63.0	61.8	75	60	55	55	64.5	64.6	67.4	70.8	8:18:00 AM
8:19:00 AM	65	55	55	55	65.0	32.5	63.3	63.0	75	60	55	55	63.7	62.4	69.3	73.2	8:19:00 AM
8:20:00 AM	65	55	55	55	65.0	64.9	62.6	62.8	75	60	55	55	62.6	63.5	72.5	73.3	8:20:00 AM
8:21:00 AM	65	55	55	55	65.0	64.9	64.1	64.1	75	60	55	55	62.6	63.8	72.0	73.9	8:21:00 AM
8:22:00 AM	65	55	55	55	64.9	65.0	64.5	64.6	75	60	55	55	62.3	63.9	72.4	72.7	8:22:00 AM
8:23:00 AM	65	55	55	55	64.6	64.4	64.8	65.0	75	60	55	55	64.1	64.1	72.8	71.4	8:23:00 AM
8:24:00 AM	65	55	55	55	64.9	63.7	64.1	64.4	75	60	55	55	65.0	64.5	71.7	70.2	8:24:00 AM
8:25:00 AM	65	55	55	55	65.0	64.9	62.8	61.9	75	60	55	55	64.7	64.4	70.0	72.6	8:25:00 AM
8:26:00 AM	65	55	55	55	64.3	64.2	63.6	59.6	75	60	55	55	61.3	63.1	70.7	72.9	8:26:00 AM
8:27:00 AM	65	55	55	55	64.6	63.4	63.6	64.8	75	60	55	55	61.3	65.0	73.8	73.2	8:27:00 AM
8:28:00 AM	65	55	55	55	65.0	64.6	64.5	64.1	75	60	55	55	64.8	65.0	71.1	69.8	8:28:00 AM
8:29:00 AM	65	55	55	55	64.3	64.8	65.0	63.8	75	60	55	55	62.8	65.0	70.9	72.9	8:29:00 AM
8:30:00 AM	65	55	55	55	64.1	64.2	65.0	64.7	75	60	55	55	61.7	65.0	72.7	73.8	8:30:00 AM
8:31:00 AM	65	65	65	65	63.3	63.1	64.8	65.0	75	75	65	65	63.8	65.0	71.2	73.8	8:31:00 AM
8:32:00 AM	65	55	55	55	64.3	64.4	64.3	65.0	75	60	55	55	65.0	64.9	70.3	70.4	8:32:00 AM
8:33:00 AM	65	55	55	55	65.0	65.0	64.7	65.0	75	60	55	55	65.0	63.2	69.4	71.4	8:33:00 AM
8:34:00 AM	65	55	55	55	65.0	65.0	64.0	63.9	75	60	55	55	65.0	62.2	73.5	74.6	8:34:00 AM
8:35:00 AM	65	55	55	55	64.9	65.0	63.8	62.8	75	60	55	55	65.0	65.0	73.7	74.4	8:35:00 AM
8:36:00 AM	65	55	55	55	64.9	64.9	64.9	64.1	75	60	55	55	65.0	65.0	71.5	70.9	8:36:00 AM
8:37:00 AM	65	55	55	55	64.7	64.5	64.9	64.6	75	60	55	55	65.0	64.2	66.5	67.8	8:37:00 AM
8:38:00 AM	65	55	55	55	65.0	63.7	63.9	64.3	75	60	55	55	65.0	63.7	70.4	73.5	8:38:00 AM
8:39:00 AM	65	55	55	55	64.7	64.0	62.7	61.2	75	60	55	55	64.8	64.5	70.5	71.4	8:39:00 AM
8:40:00 AM	65	55	55	55	64.3	63.8	63.8	63.0	75	60	55	55	64.6	63.5	66.6	69.8	8:40:00 AM
8:41:00 AM	65	55	55	55	63.7	63.4	63.1	61.4	75	60	55	55	64.8	63.8	70.3	73.8	8:41:00 AM
8:42:00 AM	65	55	55	55	64.7	64.3	60.3	60.7	75	60	55	55	65.0	64.3	72.3	70.8	8:42:00 AM
8:43:00 AM	65	55	55	55	65.0	62.6	64.0	63.4	75	60	55	55	63.8	64.3	72.1	69.4	8:43:00 AM
8:44:00 AM	65	55	55	55	65.0	61.7	64.1	64.8	75	60	55	55	62.8	64.8	70.7	69.7	8:44:00 AM
8:45:00 AM	65	55	55	55	65.0	65.0	63.6	65.0	75	60	55	55	64.4	65.0	70.3	72.9	8:45:00 AM
8:46:00 AM	65	55	55	55	48.5	65.0	63.3	62.5	75	60	55	55	61.7	65.0	70.9	71.3	8:46:00 AM
8:47:00 AM	65	55	55	55	65.0	65.0	65.0	62.1	75	60	55	55	21.7	62.3	65.8	69.9	8:47:00 AM
8:48:00 AM	65	55	55	55	64.8	64.6	63.5	63.5	75	60	55	55	59.5	63.3	71.0	71.5	8:48:00 AM
8:49:00 AM	65	55	55	55	64.7	63.3	63.9	64.2	75	60	55	55	61.9	64.3	73.1	73.7	8:49:00 AM
8:50:00 AM	65	55	55	55	65.0	64.1	64.3	64.7	75	60	55	55	64.1	64.1	68.4	72.7	8:50:00 AM
8:51:00 AM	65	55	55	55	63.8	63.5	64.6	64.9	75	60	55	55	64.8	63.3	66.7	72.0	8:51:00 AM
8:52:00 AM	65	55	55	55	64.1	62.7	60.5	64.5	75	60	55	55	64.7	63.2	69.6	71.8	8:52:00 AM
8:53:00 AM	65	65	65	65	65.0	62.9	62.4	62.3	75	75	65	65	63.8	64.0	71.2	74.4	8:53:00 AM
8:54:00 AM	65	65	65	65	65.0	64.4	64.4	64.0	75	75	65	65	63.7	64.7	71.5	72.5	8:54:00 AM
8:55:00 AM	65	65	65	65	65.0	65.0	64.8	64.6	75	75	65	65	64.9	65.0	71.6	73.4	8:55:00 AM
8:56:00 AM	65	65	65	65	65.0	65.0	65.0	65.0	75	75	65	65	64.8	65.0	72.2	74.1	8:56:00 AM
8:57:00 AM	65	65	65	65	64.6	64.4	65.0	65.0	75	75	65	65	64.9	65.0	73.1	73.8	8:57:00 AM
8:58:00 AM	65	65	65	65	64.8	63.3	65.0	65.0	75	75	65	65	64.3	65.0	72.3	71.1	8:58:00 AM
8:59:00 AM	65	65	65	65	65.0	64.7	65.0	65.0	75	75	65	65	64.7	65.0	71.8	72.3	8:59:00 AM

Figure H-14. "Heat Map" Speeds for VSL Weather Event – September 12, 2014, Ranger Hill, Eastland County.

VSL Deployment -- Brownwood District - Weather Activation 9/17/2014

	Eastbound								Westbound								
	Posted Speed Limit				Measured Speeds				Posted Speed Limit				Measured Speeds				
	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	
4:00:00 PM	65	65	65	65	64.4	63.8	62.2	62.0	75	75	65	65	72.5	71.9	65.0	64.6	4:00:00 PM
4:01:00 PM	65	65	65	65	64.9	63.4	64.1	63.3	75	75	65	65	73.3	69.5	65.0	65.0	4:01:00 PM
4:02:00 PM	65	65	65	65	65.0	64.1	64.7	62.9	75	75	65	65	73.8	69.8	64.4	64.5	4:02:00 PM
4:03:00 PM	65	65	65	65	64.3	65.0	64.7	63.4	75	75	65	65	72.1	73.8	64.5	63.8	4:03:00 PM
4:04:00 PM	65	65	65	65	64.2	63.2	65.0	64.5	75	75	65	65	71.8	70.1	64.8	62.5	4:04:00 PM
4:05:00 PM	65	65	65	65	64.9	61.4	65.0	64.5	75	75	65	65	70.9	66.6	64.0	62.3	4:05:00 PM
4:06:00 PM	65	65	65	65	64.6	63.4	64.4	64.1	75	75	65	65	71.2	69.7	63.2	64.6	4:06:00 PM
4:07:00 PM	65	65	65	65	64.3	63.9	63.3	63.8	75	75	65	65	74.0	71.8	62.8	58.5	4:07:00 PM
4:08:00 PM	65	65	65	65	63.6	63.5	63.2	62.7	75	75	65	65	73.5	71.7	64.9	58.2	4:08:00 PM
4:09:00 PM	65	65	65	65	63.3	62.0	62.0	57.9	75	75	65	65	72.6	71.4	64.7	64.9	4:09:00 PM
4:10:00 PM	65	65	65	65	64.9	64.3	62.1	57.6	75	75	65	65	71.6	70.1	64.8	65.0	4:10:00 PM
4:11:00 PM	65	65	65	65	64.3	63.8	64.2	63.9	75	75	65	65	71.8	71.3	64.8	63.2	4:11:00 PM
4:12:00 PM	65	65	65	65	63.8	62.6	65.0	64.5	75	75	65	65	71.6	53.0	64.7	62.9	4:12:00 PM
4:13:00 PM	65	65	65	65	64.3	63.0	62.0	63.9	75	75	65	65	71.6	70.4	64.0	64.6	4:13:00 PM
4:14:00 PM	65	65	65	65	64.8	62.0	62.0	63.2	75	75	65	65	70.0	69.3	62.9	58.7	4:14:00 PM
4:15:00 PM	65	65	65	65	65.0	63.0	63.1	62.8	75	75	65	65	70.1	69.2	65.0	60.0	4:15:00 PM
4:16:00 PM	65	65	65	65	65.0	65.0	64.1	64.1	75	75	65	65	72.6	70.5	65.0	62.3	4:16:00 PM
4:17:00 PM	65	55	55	55	64.8	63.9	64.8	64.5	75	60	55	55	72.9	71.9	64.7	56.0	4:17:00 PM
4:18:00 PM	65	55	55	55	64.8	62.8	63.7	63.3	75	60	55	55	70.9	69.8	64.1	53.8	4:18:00 PM
4:19:00 PM	65	55	55	55	65.0	64.6	62.0	62.7	75	60	55	55	70.6	68.7	60.3	57.7	4:19:00 PM
4:20:00 PM	65	55	55	55	64.6	62.8	64.6	63.2	75	60	55	55	72.7	65.7	57.1	59.4	4:20:00 PM
4:21:00 PM	65	55	55	55	64.6	63.9	62.2	64.2	75	60	55	55	74.6	67.3	59.0	59.4	4:21:00 PM
4:22:00 PM	65	55	55	55	65.0	64.1	61.9	64.3	75	60	55	55	74.3	65.2	60.9	60.3	4:22:00 PM
4:23:00 PM	65	55	55	55	64.7	63.7	63.4	62.0	75	60	55	55	71.6	59.3	61.9	60.0	4:23:00 PM
4:24:00 PM	65	55	55	55	64.8	62.8	62.9	62.8	75	60	55	55	66.4	59.5	60.4	60.9	4:24:00 PM
4:25:00 PM	65	55	55	55	65.0	64.3	61.9	60.6	75	60	55	55	68.3	61.8	59.0	59.9	4:25:00 PM
4:26:00 PM	65	55	55	55	65.0	65.0	63.2	60.9	75	60	55	55	67.9	64.6	61.1	58.3	4:26:00 PM
4:27:00 PM	65	55	55	55	64.4	64.3	61.5	62.2	75	60	55	55	65.3	61.4	63.8	58.2	4:27:00 PM
4:28:00 PM	65	55	55	55	64.6	63.4	61.1	61.2	75	60	55	55	68.7	61.9	63.1	58.8	4:28:00 PM
4:29:00 PM	65	55	55	55	64.6	64.0	62.8	61.7	75	60	55	55	70.2	67.7	62.5	59.3	4:29:00 PM
4:30:00 PM	65	55	55	55	64.9	63.2	63.9	63.5	75	60	55	55	65.5	67.3	61.4	58.5	4:30:00 PM
4:31:00 PM	65	55	55	55	64.9	64.2	62.9	62.6	75	60	55	55	63.2	64.6	62.4	61.0	4:31:00 PM
4:32:00 PM	65	55	55	55	65.0	64.8	63.8	62.2	75	60	55	55	69.4	68.2	63.1	63.3	4:32:00 PM
4:33:00 PM	65	55	55	55	65.0	64.6	65.0	63.9	75	60	55	55	69.3	67.4	64.8	30.3	4:33:00 PM
4:34:00 PM	65	55	55	55	65.0	64.3	64.8	62.4	75	60	55	55	68.3	67.5	61.8	32.5	4:34:00 PM
4:35:00 PM	65	55	55	55	65.0	64.8	64.6	61.7	75	60	55	55	69.8	68.6	63.1	64.5	4:35:00 PM
4:36:00 PM	65	55	55	55	65.0	64.3	64.8	64.0	75	60	55	55	69.6	67.0	64.5	63.5	4:36:00 PM
4:37:00 PM	65	55	55	55	65.0	64.4	64.9	63.7	75	60	55	55	68.3	67.5	64.0	63.2	4:37:00 PM
4:38:00 PM	65	55	55	55	65.0	64.8	64.4	62.7	75	60	55	55	65.7	68.9	64.4	59.9	4:38:00 PM
4:39:00 PM	65	55	55	55	65.0	65.0	64.4	63.3	75	60	55	55	67.4	68.7	64.9	61.6	4:39:00 PM
4:40:00 PM	65	55	55	55	65.0	65.0	64.8	62.4	75	60	55	55	67.0	67.8	31.8	63.2	4:40:00 PM
4:41:00 PM	65	55	55	55	65.0	65.0	64.9	64.2	75	60	55	55	50.8	67.1	64.5	62.3	4:41:00 PM
4:42:00 PM	65	65	65	65	48.5	65.0	64.9	64.8	75	75	65	65	67.5	69.5	63.9	60.9	4:42:00 PM
4:43:00 PM	65	65	65	65	64.9	64.9	64.9	64.8	75	75	65	65	54.2	67.6	63.6	63.1	4:43:00 PM
4:44:00 PM	65	65	65	65	64.7	64.6	64.9	64.9	75	75	65	65	74.3	72.2	64.3	64.6	4:44:00 PM
4:45:00 PM	65	65	65	65	64.9	64.5	64.9	64.9	75	75	65	65	72.3	70.5	64.9	64.7	4:45:00 PM
4:46:00 PM	65	65	65	65	64.3	64.8	64.9	65.0	75	75	65	65	68.9	69.2	64.9	65.0	4:46:00 PM
4:47:00 PM	65	65	65	65	64.5	64.6	64.9	64.4	75	75	65	65	67.0	69.5	65.0	64.9	4:47:00 PM
4:48:00 PM	65	65	65	65	65.0	64.9	64.9	64.3	75	75	65	65	70.2	69.6	64.5	64.7	4:48:00 PM
4:49:00 PM	65	65	65	65	64.8	64.8	64.8	64.9	75	75	65	65	69.7	69.6	64.5	64.1	4:49:00 PM
4:50:00 PM	65	65	65	65	64.8	64.8	64.6	64.4	75	75	65	65	70.1	67.6	62.8	62.2	4:50:00 PM
4:51:00 PM	65	65	65	65	65.0	64.6	64.5	64.4	75	75	65	65	71.4	70.1	63.6	63.8	4:51:00 PM
4:52:00 PM	65	65	65	65	64.9	64.7	64.9	64.8	75	75	65	65	71.8	71.1	64.9	63.8	4:52:00 PM
4:53:00 PM	65	65	65	65	64.7	64.9	65.0	64.7	75	75	65	65	69.7	68.8	64.8	62.7	4:53:00 PM
4:54:00 PM	65	65	65	65	64.1	65.0	65.0	65.0	75	75	65	65	53.0	70.8	64.9	61.5	4:54:00 PM
4:55:00 PM	65	65	65	65	64.4	65.0	64.1	64.9	75	75	65	65	71.3	71.6	65.0	65.0	4:55:00 PM
4:56:00 PM	65	55	55	55	64.6	65.0	63.6	63.7	75	60	55	55	68.9	67.7	65.0	65.0	4:56:00 PM
4:57:00 PM	65	55	55	55	64.8	64.2	64.3	63.9	75	60	55	55	69.4	71.2	65.0	64.9	4:57:00 PM
4:58:00 PM	65	55	55	55	65.0	63.9	62.9	62.4	75	60	55	55	68.1	67.8	64.6	62.2	4:58:00 PM
4:59:00 PM	65	55	55	55	65.0	64.8	62.4	62.8	75	60	55	55	67.9	67.0	63.6	62.2	4:59:00 PM
5:00:00 PM	65	55	55	55	65.0	64.9	64.0	62.8	75	60	55	55	55.3	68.7	61.1	62.7	5:00:00 PM
5:01:00 PM	65	55	55	55	64.8	65.0	63.6	61.7	75	60	55	55	73.9	72.4	59.3	56.3	5:01:00 PM
5:02:00 PM	65	65	65	65	64.5	64.4	31.3	63.8	75	75	65	65	70.3	71.3	62.5	62.2	5:02:00 PM
5:03:00 PM	65	65	65	65	64.5	62.9	65.0	64.3	75	75	65	65	71.5	67.0	63.7	63.5	5:03:00 PM
5:04:00 PM	65	65	65	65	64.9	64.3	65.0	63.8	75	75	65	65	72.5	69.9	64.1	62.4	5:04:00 PM
5:05:00 PM	65	65	65	65	65.0	65.0	65.0	63.8	75	75	65	65	71.6	69.3	65.0	64.4	5:05:00 PM
5:06:00 PM	65	65	65	65	64.9	64.8	65.0	65.0	75	75	65	65	70.7	68.8	65.0	64.7	5:06:00 PM
5:07:00 PM	65	65	65	65	64.9	64.6	64.8	64.8	75	75	65	65	73.2	69.2	63.7	64.6	5:07:00 PM
5:08:00 PM	65	65	65	65	64.8	65.0	64.8	64.8	75	75	65	65	72.0	69.1	63.7	65.0	5:08:00 PM
5:09:00 PM	65	65	65	65	64.1	64.8	65.0	65.0	75	75	65	65	70.3	68.1	64.8	65.0	5:09:00 PM
5:10:00 PM	65	65	65	65	64.5	64.9	65.0	65.0	75	75	65	65	71.0	71.4	64.9	65.0	5:10:00 PM
5:11:00 PM	65	65	65	65	65.0	65.0	65.0	64.8	75	75	65	65	69.1	71.1	65.0	65.0	5:11:00 PM
5:12:00 PM	65	65	65	65	64.4	65.0	64.7	64.8	75	75	65	65	69.3	69.0	63.1	63.3	5:12:00 PM
5:13:00 PM	65	65	65	65	64.7	65.0	64.4	64.3	75	75	65	65	72.9	70.0	63.1	60.8	5:13:00 PM
5:14:00 PM	65	65	65	65	64.7	65.0	64.9	64.7	75	75	65	65	73.6	71.1	64.6	63.5	5:14:00 PM
5:15:00 PM	65	65	65	65	64.6	64.5	64.3	63.9	75	75	65	65	74.1	71.3	65.0	64.5	5:15:00 PM
5:16:00 PM	65	65	65	65	65.0	64.1	63.2	63.0	75	75	65	65	73.2	71.6	65.0	64.3	5:16:00 PM
5:17:00 PM	65	65	65	65	65.0	65.0	64.4	64.1	75	75	65	65	69.4	68.7	64.5	63.3	5:17:00 PM
5:18:00 PM	65	65	65	65	65.0	65.0	65.0	64.5	75	75	65	65	67.2	68.7	62.8	63.3	5:18:00 PM
5:19:00 PM	65	65	65	65	64.6	64.4	65.0	65.0	75	75	65	65	72.3	72.4	65.0	62.7	5:19:00 PM
5:20:00 PM	65	65	65	65	64.7	64.4	65.0	64.9	75	75	65	65	72.3	55.3	65.0	64.6	5:20:00 PM
5:21:00 PM	65	65	65	65	65.0	64.8	65.0	64.7	75	75	65	65	72.4	74.5	64.2	63.9	5:21:00 PM
5:22:00 PM	65	65	65	65	64.9	64.6	65.0	64.7	75	75	65	65	71.1	73.2	64.5	63.4	5:22:00 PM
5:23:00 PM	65	65	65	65	64.9	64.7	64.7	64.4	75	75	65	65	70.8	71.3	64.8	64.0	5:23:00 PM

Figure H-15. "Heat Map" Speeds for VSL Weather Event – September 17, 2014, Ranger Hill, Eastland County.

VSL Deployment -- Brownwood District - Weather Activation 9/17/2014

	Eastbound								Westbound								
	Posted Speed Limit				Measured Speeds				Posted Speed Limit				Measured Speeds				
	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	
5:24:00 PM	65	65	65	65	65.0	64.9	64.4	63.7	75	75	65	65	73.2	70.1	64.4	64.8	5:24:00 PM
5:25:00 PM	65	65	65	65	64.8	65.0	64.9	64.5	75	75	65	65	74.5	72.1	64.1	64.8	5:25:00 PM
5:26:00 PM	65	65	65	65	64.5	65.0	64.8	64.8	75	75	65	65	74.5	74.2	64.3	64.9	5:26:00 PM
5:27:00 PM	65	65	65	65	64.8	65.0	64.8	64.9	75	75	65	65	72.0	73.6	65.0	65.0	5:27:00 PM
5:28:00 PM	65	65	65	65	64.6	62.8	64.9	65.0	75	75	65	65	69.7	35.5	65.0	65.0	5:28:00 PM
5:29:00 PM	65	65	65	65	63.6	63.8	62.2	64.2	75	75	65	65	70.8	71.7	65.0	62.8	5:29:00 PM
5:30:00 PM	65	65	65	65	63.6	63.8	62.1	62.4	75	75	65	65	70.2	68.3	64.8	63.8	5:30:00 PM
5:31:00 PM	65	65	65	65	64.9	63.8	59.9	63.4	75	75	65	65	71.1	68.1	64.2	65.0	5:31:00 PM
5:32:00 PM	65	65	65	65	65.0	64.9	62.3	61.1	75	75	65	65	69.8	68.4	64.8	65.0	5:32:00 PM
5:33:00 PM	65	65	65	65	65.0	64.7	64.8	63.3	75	75	65	65	68.6	67.9	64.6	65.0	5:33:00 PM
5:34:00 PM	65	55	55	55	65.0	63.8	64.8	65.0	75	60	55	55	70.9	69.3	65.0	63.5	5:34:00 PM
5:35:00 PM	65	55	55	55	65.0	64.3	63.9	64.6	75	60	55	55	72.1	71.8	64.1	64.3	5:35:00 PM
5:36:00 PM	65	55	55	55	64.9	64.6	63.6	63.9	75	60	55	55	72.9	72.8	62.6	61.1	5:36:00 PM
5:37:00 PM	65	55	55	55	64.9	64.9	63.9	63.8	75	60	55	55	70.9	70.8	64.6	59.2	5:37:00 PM
5:38:00 PM	65	55	55	55	65.0	65.0	63.9	63.6	75	60	55	55	70.9	69.2	64.3	63.5	5:38:00 PM
5:39:00 PM	65	65	65	65	65.0	65.0	65.0	64.2	75	75	65	65	71.2	68.5	64.8	64.2	5:39:00 PM
5:40:00 PM	65	65	65	65	64.8	64.9	65.0	64.6	75	75	65	65	71.0	66.9	64.9	64.7	5:40:00 PM
5:41:00 PM	65	65	65	65	64.9	64.9	65.0	64.9	75	75	65	65	70.3	67.4	64.8	63.5	5:41:00 PM
5:42:00 PM	65	65	65	65	64.5	65.0	65.0	65.0	75	75	65	65	69.4	66.9	64.3	61.9	5:42:00 PM
5:43:00 PM	65	65	65	65	64.4	65.0	64.8	64.5	75	75	65	65	71.1	66.9	63.6	63.9	5:43:00 PM
5:44:00 PM	65	65	65	65	65.0	65.0	64.0	64.4	75	75	65	65	71.6	70.6	64.8	63.4	5:44:00 PM
5:45:00 PM	65	65	65	65	65.0	65.0	63.4	63.9	75	75	65	65	73.6	70.7	65.0	62.8	5:45:00 PM
5:46:00 PM	65	65	65	65	65.0	65.0	65.0	64.6	75	75	65	65	71.5	67.8	64.8	64.7	5:46:00 PM
5:47:00 PM	65	55	55	55	65.0	65.0	65.0	64.4	75	60	55	55	69.8	70.1	64.5	65.0	5:47:00 PM
5:48:00 PM	65	55	55	55	64.5	64.8	64.7	64.7	75	60	55	55	69.5	71.5	64.3	63.3	5:48:00 PM
5:49:00 PM	65	55	55	55	64.5	64.4	64.1	64.3	75	60	55	55	67.9	67.9	64.1	63.6	5:49:00 PM
5:50:00 PM	65	55	55	55	64.9	64.2	63.5	64.3	75	60	55	55	67.6	66.3	62.7	63.6	5:50:00 PM
5:51:00 PM	65	55	55	55	64.9	63.6	62.8	63.6	75	60	55	55	72.5	66.8	61.6	63.5	5:51:00 PM
5:52:00 PM	65	65	65	65	64.8	64.3	64.2	60.8	75	75	65	65	73.4	72.5	64.2	63.4	5:52:00 PM
5:53:00 PM	65	65	65	65	64.9	64.8	65.0	63.1	75	75	65	65	72.3	72.0	65.0	62.3	5:53:00 PM
5:54:00 PM	65	65	65	65	64.7	64.8	65.0	64.8	75	75	65	65	72.8	69.7	64.9	64.0	5:54:00 PM
5:55:00 PM	65	65	65	65	64.0	64.9	65.0	64.5	75	75	65	65	73.4	72.6	64.9	64.3	5:55:00 PM
5:56:00 PM	65	65	65	65	64.5	65.0	64.8	64.2	75	75	65	65	74.4	71.5	65.0	64.2	5:56:00 PM
5:57:00 PM	65	65	65	65	64.5	64.9	64.5	64.6	75	75	65	65	73.4	73.3	65.0	62.8	5:57:00 PM
5:58:00 PM	65	65	65	65	64.3	64.3	64.6	65.0	75	75	65	65	72.9	72.6	43.0	64.1	5:58:00 PM
5:59:00 PM	65	65	65	65	64.2	64.7	64.8	64.9	75	75	65	65	73.0	71.5	64.7	65.0	5:59:00 PM
6:00:00 PM	65	65	65	65	64.4	64.2	64.8	64.7	75	75	65	65	73.9	70.4	63.3	65.0	6:00:00 PM
6:01:00 PM	65	65	65	65	65.0	63.2	64.7	59.3	75	75	65	65	74.3	48.6	64.2	21.7	6:01:00 PM
6:02:00 PM	65	65	65	65	65.0	64.3	64.6	60.6	75	75	65	65	71.3	74.5	65.0	65.0	6:02:00 PM
6:03:00 PM	65	65	65	65	65.0	64.7	43.0	63.2	75	75	65	65	65.8	68.6	64.9	65.0	6:03:00 PM
6:04:00 PM	65	65	65	65	65.0	64.9	64.9	64.9	75	75	65	65	69.9	54.0	64.6	65.0	6:04:00 PM
6:05:00 PM	65	65	65	65	65.0	64.8	64.9	64.7	75	75	65	65	71.3	73.4	65.0	65.0	6:05:00 PM
6:06:00 PM	65	65	65	65	64.6	64.4	65.0	64.4	75	75	65	65	69.9	70.4	64.7	65.0	6:06:00 PM
6:07:00 PM	65	65	65	65	64.4	64.1	64.3	64.5	75	75	65	65	70.8	69.7	64.5	65.0	6:07:00 PM
6:08:00 PM	65	65	65	65	64.4	64.6	64.0	64.4	75	75	65	65	67.8	69.2	64.9	65.0	6:08:00 PM
6:09:00 PM	65	65	65	65	64.4	64.1	64.8	63.3	75	75	65	65	66.9	65.4	63.9	64.0	6:09:00 PM
6:10:00 PM	65	65	65	65	65.0	64.8	64.9	63.3	75	75	65	65	69.3	68.5	62.1	62.9	6:10:00 PM
6:11:00 PM	65	65	65	65	65.0	65.0	65.0	64.9	75	75	65	65	71.9	71.7	63.4	60.6	6:11:00 PM
6:12:00 PM	65	65	65	65	65.0	64.8	65.0	65.0	75	75	65	65	68.8	68.2	64.9	63.7	6:12:00 PM
6:13:00 PM	65	65	65	65	64.6	64.8	65.0	65.0	75	75	65	65	68.3	65.6	64.3	64.8	6:13:00 PM
6:14:00 PM	65	65	65	65	62.6	64.1	64.3	64.9	75	75	65	65	69.0	67.1	64.3	62.1	6:14:00 PM
6:15:00 PM	65	65	65	65	62.7	62.3	62.5	64.3	75	75	65	65	68.9	70.8	64.8	58.4	6:15:00 PM
6:16:00 PM	65	65	65	65	64.5	64.2	63.0	63.9	75	75	65	65	70.7	70.2	64.4	62.8	6:16:00 PM
6:17:00 PM	65	65	65	65	64.3	64.3	64.5	64.8	75	75	65	65	70.2	69.2	64.3	64.5	6:17:00 PM
6:18:00 PM	65	65	65	65	65.0	64.5	63.3	64.3	75	75	65	65	70.5	68.7	64.7	63.9	6:18:00 PM
6:19:00 PM	65	65	65	65	64.9	65.0	64.9	64.8	75	75	65	65	72.7	68.8	65.0	63.8	6:19:00 PM
6:20:00 PM	65	65	65	65	64.6	64.5	65.0	65.0	75	75	65	65	72.2	70.6	64.5	62.5	6:20:00 PM
6:21:00 PM	65	65	65	65	64.4	63.8	64.9	64.1	75	75	65	65	72.2	69.8	64.8	63.0	6:21:00 PM
6:22:00 PM	65	65	65	65	64.4	64.9	64.5	64.0	75	75	65	65	73.2	72.1	65.0	64.5	6:22:00 PM
6:23:00 PM	65	65	65	65	65.0	65.0	64.6	64.7	75	75	65	65	73.1	73.6	65.0	65.0	6:23:00 PM
6:24:00 PM	65	65	65	65	64.4	65.0	65.0	64.7	75	75	65	65	71.5	69.7	65.0	65.0	6:24:00 PM
6:25:00 PM	65	65	65	65	63.8	64.8	64.9	64.7	75	75	65	65	69.9	69.3	65.0	65.0	6:25:00 PM
6:26:00 PM	65	65	65	65	63.8	64.0	64.9	64.4	75	75	65	65	70.4	66.7	64.7	65.0	6:26:00 PM
6:27:00 PM	65	65	65	65	64.5	64.5	64.8	63.8	75	75	65	65	71.3	68.5	64.4	65.0	6:27:00 PM
6:28:00 PM	65	65	65	65	64.9	64.7	64.9	64.3	75	75	65	65	72.4	70.0	64.1	65.0	6:28:00 PM
6:29:00 PM	65	65	65	65	64.9	64.9	65.0	63.6	75	75	65	65	72.4	71.2	64.8	64.8	6:29:00 PM
6:30:00 PM	65	65	65	65	64.9	64.7	64.9	63.5	75	75	65	65	71.4	70.2	65.0	64.7	6:30:00 PM
6:31:00 PM	65	65	65	65	64.8	64.8	65.0	64.4	75	75	65	65	69.0	71.1	65.0	64.9	6:31:00 PM
6:32:00 PM	65	65	65	65	64.8	32.0	65.0	64.8	75	75	65	65	67.9	70.5	65.0	64.5	6:32:00 PM
6:33:00 PM	65	65	65	65	64.8	64.0	64.8	64.9	75	75	65	65	73.4	71.7	65.0	64.0	6:33:00 PM
6:34:00 PM	65	65	65	65	64.9	64.2	64.8	64.2	75	75	65	65	73.4	72.5	64.9	63.7	6:34:00 PM
6:35:00 PM	65	65	65	65	65.0	64.6	65.0	64.7	75	75	65	65	72.6	73.2	64.8	64.9	6:35:00 PM
6:36:00 PM	65	65	65	65	65.0	64.4	65.0	65.0	75	75	65	65	72.4	72.5	65.0	64.9	6:36:00 PM
6:37:00 PM	65	65	65	65	65.0	64.3	65.0	64.6	75	75	65	65	71.8	72.2	65.0	65.0	6:37:00 PM
6:38:00 PM	65	65	65	65	64.3	63.5	65.0	64.8	75	75	65	65	72.5	69.6	64.8	65.0	6:38:00 PM
6:39:00 PM	65	65	65	65	63.6	62.7	63.9	65.0	75	75	65	65	73.9	69.7	64.6	64.8	6:39:00 PM
6:40:00 PM	65	65	65	65	64.7	64.0	63.3	63.6	75	75	65	65	71.6	72.7	65.0	64.7	6:40:00 PM
6:41:00 PM	65	65	65	65	63.8	64.1	64.9	64.0	75	75	65	65	69.8	69.3	65.0	64.5	6:41:00 PM
6:42:00 PM	65	65	65	65	64.2	64.1	64.8	64.8	75	75	65	65	70.8	69.4	64.6	63.9	6:42:00 PM
6:43:00 PM	65	65	65	65	64.7	65.0	64.9	64.1	75	75	65	65	69.9	69.5	64.9	63.8	6:43:00 PM
6:44:00 PM	65	65	65	65	64.0	64.5	65.0	64.3	75	75	65	65	71.3	70.6	65.0	63.7	6:44:00 PM
6:45:00 PM	65	65	65	65	63.9	64.2	64.9	64.8	75	75	65	65	71.1	68.9	64.3	64.5	6:45:00 PM
6:46:00 PM	65	65	65	65	64.6	64.3	64.9	63.3	75	75	65	65	72.3	70.2	64.8	63.1	6:46:00 PM
6:47:00 PM	65	65	65	65	64.0	64.6	64.8	47.8	75	75	65	65	70.2	70.8	65.0	64.3	6:47:00 PM
6:48:00 PM	65	65	65	65	64.6	64.3	64.3	64.4	75	75	65	65	67.1	67.2	63.3	64.2	6:48:00 PM
6:49:00 PM	65	65	65	65	64.1	63.8	64.6	64.8	75	75	65	65	70.6	68.0	60.0	63.4	6:49:00 PM
6:50:00 PM	65	65	65	65	62.7	62.4	64.8	64.9	75	75	65	65	68.7	69.0	65.0	62.1	6:50:00 PM
6:51:00 PM	65	65	65	65	63.6	62.8	62.9	62.6	75	75	65	65	71.3	65.5	64.1	63.4	6:51:00 PM
6:52:00 PM	65	65	65	65	64.6	65.0	64.3	61.6	75	75	65	65	68.2	68.1	64.3	61.3	6:52:00 PM
6:53:00 PM	65	65	65	65	64.3	64.3	64.8	64.9	75	75	65	65	69.6	69.4	65.0	64.0	6:53:00 PM
6:54:00 PM	65	65	65	65	62.6	63.3	64.2	64.1	75	75	65	65	68.9	69.5	65.0	64.0	6:54:00 PM
6:55:00 PM	65	65	65	65	61.7	61.2	61.0	62.5	75	75	65	65	68.2	67.0	65.0	64.0	6:55:00 PM

Figure H-15 (continued). "Heat Map" Speeds for VSL Weather Event – September 17, 2014, Ranger Hill, Eastland County.

VSL Deployment -- Brownwood District - Congestion Activation 8/7/2014

	Eastbound								Westbound								
	Posted Speed Limit				Measured Speeds				Posted Speed Limit				Measured Speeds				
	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	
4:30:00 PM	65	65	65	65	64.9	64.8	65.0	65.0	75	75	65	65	73.7	72.6	65.0	64.8	4:30:00 PM
4:31:00 PM	65	65	65	65	64.9	64.8	43.0	65.0	75	75	65	65	72.8	71.8	65.0	64.8	4:31:00 PM
4:32:00 PM	65	65	65	65	65.0	65.0	65.0	65.0	75	75	65	65	72.8	70.7	64.7	64.9	4:32:00 PM
4:33:00 PM	65	65	65	65	64.6	64.8	65.0	65.0	75	75	65	65	74.6	71.8	64.0	64.2	4:33:00 PM
4:34:00 PM	65	65	65	65	64.4	60.9	64.7	65.0	75	75	65	65	74.7	68.7	64.7	64.5	4:34:00 PM
4:35:00 PM	65	65	65	65	65.0	62.5	63.8	64.3	75	75	65	65	68.6	53.7	64.6	65.0	4:35:00 PM
4:36:00 PM	65	65	65	65	65.0	64.5	63.4	63.6	75	75	65	65	65.7	46.1	59.6	65.0	4:36:00 PM
4:37:00 PM	65	65	65	65	65.0	64.8	65.0	64.1	75	75	65	65	63.3	38.1	52.8	61.0	4:37:00 PM
4:38:00 PM	65	65	65	65	65.0	65.0	65.0	64.9	75	75	65	65	58.7	54.5	55.2	57.8	4:38:00 PM
4:39:00 PM	65	65	65	65	65.0	65.0	64.9	64.3	75	75	65	65	54.7	56.0	59.5	59.8	4:39:00 PM
4:40:00 PM	65	65	65	65	65.0	64.9	64.6	63.3	75	75	65	65	57.3	53.2	56.9	50.1	4:40:00 PM
4:41:00 PM	65	65	65	65	64.9	64.6	64.4	58.3	75	75	65	65	66.7	60.6	51.2	37.5	4:41:00 PM
4:42:00 PM	65	65	65	65	64.9	64.6	60.3	54.2	75	75	65	65	65.6	62.6	56.7	35.8	4:42:00 PM
4:43:00 PM	65	65	65	65	65.0	64.7	59.6	52.6	75	75	65	65	64.3	62.7	61.1	40.1	4:43:00 PM
4:44:00 PM	65	65	65	65	65.0	64.0	62.4	58.4	75	75	65	65	66.4	66.5	61.1	41.4	4:44:00 PM
4:45:00 PM	65	65	65	65	64.4	61.9	62.6	62.9	75	75	65	65	66.6	67.6	63.4	40.0	4:45:00 PM
4:46:00 PM	65	65	65	65	64.5	60.9	63.0	61.8	75	75	65	65	66.2	68.0	63.5	40.1	4:46:00 PM
4:47:00 PM	65	65	65	65	64.8	63.0	63.6	61.2	75	75	65	65	68.1	46.3	63.6	47.9	4:47:00 PM
4:48:00 PM	65	65	65	65	64.9	64.5	64.6	62.8	75	75	65	65	68.8	70.3	64.5	55.4	4:48:00 PM
4:49:00 PM	65	65	65	65	64.4	64.8	64.2	64.1	75	75	65	65	68.2	69.0	65.0	61.8	4:49:00 PM
4:50:00 PM	65	65	65	65	64.2	63.9	62.8	64.3	75	75	65	65	69.9	68.8	64.9	59.7	4:50:00 PM
4:51:00 PM	65	65	65	65	64.5	63.9	61.9	61.3	75	75	65	65	69.3	66.7	64.6	61.4	4:51:00 PM
4:52:00 PM	65	65	65	65	64.4	64.7	64.4	60.2	75	75	65	65	70.1	67.7	64.3	60.1	4:52:00 PM
4:53:00 PM	65	65	65	65	64.2	63.8	64.4	62.8	75	75	65	65	70.9	67.1	64.3	61.4	4:53:00 PM
4:54:00 PM	65	65	65	65	64.1	64.2	64.0	63.9	75	75	65	65	71.1	32.2	62.5	62.3	4:54:00 PM
4:55:00 PM	65	65	65	65	64.0	64.1	63.2	64.6	75	75	65	65	72.2	62.2	62.5	53.6	4:55:00 PM
4:56:00 PM	65	65	65	65	64.4	63.4	60.8	55.8	75	75	65	65	72.1	68.1	64.4	44.8	4:56:00 PM
4:57:00 PM	65	65	65	65	64.5	64.0	61.3	45.8	75	75	65	65	71.3	71.6	64.8	53.4	4:57:00 PM
4:58:00 PM	65	65	65	65	64.9	64.6	62.4	50.6	75	75	65	65	72.7	71.0	64.9	58.0	4:58:00 PM
4:59:00 PM	65	65	65	65	65.0	65.0	64.8	48.1	75	75	65	65	73.3	68.4	64.9	62.3	4:59:00 PM
5:00:00 PM	65	65	65	65	65.0	64.9	47.3	50.9	75	75	65	65	72.7	65.5	64.4	59.6	5:00:00 PM
5:01:00 PM	65	65	65	65	65.0	64.5	63.9	52.8	75	75	65	65	72.4	69.5	63.8	61.8	5:01:00 PM
5:02:00 PM	65	65	65	65	64.9	64.4	64.8	55.7	75	75	65	65	72.3	70.6	64.4	64.5	5:02:00 PM
5:03:00 PM	65	65	65	65	65.0	64.5	64.6	36.2	75	75	65	65	72.5	72.8	64.3	62.1	5:03:00 PM
5:04:00 PM	65	65	65	65	64.9	64.7	63.7	37.7	75	75	65	65	73.4	72.7	64.3	61.4	5:04:00 PM
5:05:00 PM	65	65	65	65	64.9	64.5	63.2	43.5	75	75	65	65	73.2	72.6	62.5	62.9	5:05:00 PM
5:06:00 PM	65	65	65	65	65.0	64.6	64.0	40.5	75	75	65	65	72.6	71.0	62.9	62.3	5:06:00 PM
5:07:00 PM	65	55	50	45	65.0	64.9	65.0	48.3	75	75	65	65	74.3	71.7	64.8	62.9	5:07:00 PM
5:08:00 PM	65	55	50	45	65.0	65.0	63.2	32.0	75	75	65	65	74.8	-1.0	65.0	63.4	5:08:00 PM
5:09:00 PM	65	55	50	45	65.0	64.9	63.1	20.1	75	75	65	65	74.1	73.7	65.0	63.9	5:09:00 PM
5:10:00 PM	65	65	65	65	65.0	64.9	64.7	15.6	75	75	65	65	73.3	36.0	65.0	64.9	5:10:00 PM
5:11:00 PM	65	50	40	30	65.0	65.0	64.6	9.0	75	75	65	65	73.4	72.3	65.0	64.8	5:11:00 PM
5:12:00 PM	65	50	40	30	65.0	64.9	63.4	3.8	75	75	65	65	74.4	73.5	65.0	64.0	5:12:00 PM
5:13:00 PM	65	50	40	30	64.3	64.6	58.0	3.2	75	75	65	65	72.1	72.8	65.0	63.4	5:13:00 PM
5:14:00 PM	65	50	40	30	64.5	64.4	48.0	3.3	75	75	65	65	69.7	70.1	65.0	64.0	5:14:00 PM
5:15:00 PM	65	50	40	30	65.0	64.5	29.7	7.0	75	75	65	65	72.3	69.8	64.5	61.4	5:15:00 PM
5:16:00 PM	65	50	40	30	65.0	64.4	14.9	8.0	75	75	65	65	71.9	70.5	64.7	60.9	5:16:00 PM
5:17:00 PM	65	50	40	30	64.3	64.4	12.2	9.0	75	75	65	65	72.3	71.9	65.0	61.5	5:17:00 PM
5:18:00 PM	65	50	35	30	64.5	63.9	9.4	10.3	75	75	65	65	73.7	73.1	65.0	62.8	5:18:00 PM
5:19:00 PM	65	50	35	30	65.0	64.3	16.5	10.0	75	75	65	65	72.1	72.4	65.0	62.9	5:19:00 PM
5:20:00 PM	65	50	35	30	65.0	64.9	23.5	9.6	75	75	65	65	72.3	72.9	65.0	62.6	5:20:00 PM
5:21:00 PM	65	50	35	30	65.0	64.9	22.7	8.2	75	75	65	65	73.2	71.2	64.0	63.7	5:21:00 PM
5:22:00 PM	65	50	35	30	65.0	65.0	32.4	7.5	75	75	65	65	73.3	70.7	63.1	63.3	5:22:00 PM
5:23:00 PM	65	50	35	30	64.9	65.0	41.3	6.8	75	75	65	65	73.9	71.2	64.7	63.2	5:23:00 PM
5:24:00 PM	65	50	35	30	64.6	64.1	31.1	9.7	75	75	65	65	74.4	73.1	65.0	63.9	5:24:00 PM
5:25:00 PM	65	50	35	30	64.8	63.7	32.0	10.9	75	75	65	65	73.9	73.6	65.0	64.6	5:25:00 PM
5:26:00 PM	65	50	40	30	65.0	64.8	62.9	8.0	75	75	65	65	73.5	73.6	65.0	64.4	5:26:00 PM
5:27:00 PM	65	50	40	30	64.9	65.0	59.1	7.3	75	75	65	65	74.5	73.7	65.0	64.7	5:27:00 PM
5:28:00 PM	65	50	40	30	64.9	65.0	37.0	12.0	75	75	65	65	73.3	71.0	63.1	63.2	5:28:00 PM
5:29:00 PM	65	50	40	30	65.0	64.5	11.4	11.2	75	75	65	65	73.4	70.3	64.2	62.9	5:29:00 PM
5:30:00 PM	65	50	40	30	64.9	64.1	6.5	16.0	75	75	65	65	74.6	72.8	65.0	63.2	5:30:00 PM
5:31:00 PM	65	50	35	30	64.7	64.2	9.2	15.0	75	75	65	65	74.6	74.0	65.0	62.9	5:31:00 PM
5:32:00 PM	65	50	35	30	64.9	64.2	14.1	13.6	75	75	65	65	73.9	74.5	65.0	63.9	5:32:00 PM
5:33:00 PM	65	50	35	30	65.0	64.5	14.0	16.9	75	75	65	65	72.6	72.4	65.0	64.6	5:33:00 PM
5:34:00 PM	65	50	35	30	64.8	63.7	12.4	16.4	75	75	65	65	71.8	71.9	64.9	65.0	5:34:00 PM
5:35:00 PM	65	50	35	30	63.9	63.2	10.9	15.1	75	75	65	65	71.6	70.4	64.9	64.8	5:35:00 PM
5:36:00 PM	65	50	35	30	63.7	62.9	14.3	18.2	75	75	65	65	72.1	70.5	65.0	63.1	5:36:00 PM
5:37:00 PM	65	50	35	30	64.9	63.8	14.9	22.9	75	75	65	65	73.8	71.6	64.6	62.7	5:37:00 PM
5:38:00 PM	65	50	35	30	65.0	64.8	10.9	14.0	75	75	65	65	74.5	72.5	64.8	62.5	5:38:00 PM
5:39:00 PM	65	50	35	30	64.6	64.7	7.8	13.0	75	75	65	65	74.1	73.7	65.0	62.8	5:39:00 PM
5:40:00 PM	65	50	35	30	64.7	63.7	7.3	13.4	75	75	65	65	73.9	72.4	65.0	62.1	5:40:00 PM
5:41:00 PM	65	50	35	30	64.0	63.7	8.7	13.1	75	75	65	65	71.8	71.3	65.0	63.7	5:41:00 PM
5:42:00 PM	65	50	35	30	63.9	61.8	11.9	9.1	75	75	65	65	70.8	54.8	65.0	62.9	5:42:00 PM
5:43:00 PM	65	50	35	30	64.6	61.4	12.1	5.6	75	75	65	65	73.5	73.0	65.0	62.7	5:43:00 PM
5:44:00 PM	65	50	35	30	65.0	64.5	5.6	6.2	75	75	65	65	72.9	71.4	64.9	63.1	5:44:00 PM
5:45:00 PM	65	50	35	30	65.0	63.7	5.4	10.3	75	75	65	65	72.3	71.2	64.9	64.5	5:45:00 PM
5:46:00 PM	65	50	35	30	65.0	63.7	6.8	9.0	75	75	65	65	71.6	70.4	65.0	64.1	5:46:00 PM
5:47:00 PM	65	50	35	30	64.5	64.8	7.4	5.7	75	75	65	65	71.9	72.8	65.0	62.5	5:47:00 PM
5:48:00 PM	65	50	35	30	63.6	61.6	5.9	6.1	75	75	65	65	72.8	73.5	65.0	64.4	5:48:00 PM
5:49:00 PM	65	50	35	30	64.6	57.7	5.7	6.8	75	75	65	65	73.7	73.2	65.0	63.0	5:49:00 PM
5:50:00 PM	65	50	35	30	65.0	63.0	6.4	9.6	75	75	65	65	74.0	73.0	65.0	63.8	5:50:00 PM
5:51:00 PM	65	50	35	30	64.9	64.1	6.0	14.0	75	75	65	65	73.3	70.6	65.0	63.4	5:51:00 PM
5:52:00 PM	65	50	35	30	63.6	62.7	8.7	16.5	75	75	65	65	72.6	69.8	64.7	63.6	5:52:00 PM
5:53:00 PM	65	50	35	30	61.8	62.2	14.8	17.6	75	75	65	65	72.3	71.0	64.8	64.7	5:53:00 PM

Figure H-16. "Heat Map" Speeds for VSL Congestion Event, August 7, 2014, Ranger Hill, Eastland County.

VSL Deployment -- Brownwood District - Congestion Activation 8/7/2014

	Eastbound								Westbound								
	Posted Speed Limit				Measured Speeds				Posted Speed Limit				Measured Speeds				
	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	
5:54:00 PM	65	50	35	30	62.7	62.3	4.4	22.6	75	75	65	65	72.3	70.9	65.0	64.9	5:54:00 PM
	65	50	35	30	64.4	62.6	8.1	16.4	75	75	65	65	73.7	71.6	65.0	64.8	5:55:00 PM
5:56:00 PM	65	50	35	30	64.4	62.1	10.4	14.9	75	75	65	65	71.1	72.2	65.0	64.0	5:56:00 PM
	65	50	35	30	62.0	60.8	12.0	25.8	75	75	65	65	71.2	48.0	64.8	63.0	5:57:00 PM
5:58:00 PM	65	50	35	30	60.2	56.7	15.9	-1.0	75	75	65	65	74.5	73.4	64.2	63.3	5:58:00 PM
	65	50	35	30	62.3	62.9	18.4	28.7	75	75	65	65	73.7	74.2	64.8	64.1	5:59:00 PM
6:00:00 PM	65	50	35	30	61.2	61.4	16.4	21.5	75	75	65	65	71.9	71.8	64.9	62.1	6:00:00 PM
	65	50	35	30	62.8	61.7	11.9	15.9	75	75	65	65	71.0	70.1	63.7	58.9	6:01:00 PM
6:02:00 PM	65	50	35	30	64.7	63.9	12.0	13.0	75	75	65	65	71.3	70.4	64.1	60.3	6:02:00 PM
	65	50	35	30	64.1	62.4	11.8	9.0	75	75	65	65	73.0	72.2	64.9	62.0	6:03:00 PM
6:04:00 PM	65	50	35	30	62.8	61.4	10.2	8.5	75	75	65	65	72.5	72.1	65.0	63.2	6:04:00 PM
	65	50	35	30	63.1	63.2	7.1	13.5	75	75	65	65	71.7	71.7	64.9	64.9	6:05:00 PM
6:06:00 PM	65	50	35	30	63.9	63.7	4.8	14.5	75	75	65	65	70.2	70.4	64.9	64.8	6:06:00 PM
	65	50	35	30	62.9	62.3	10.3	13.5	75	75	65	65	72.7	72.2	64.7	64.8	6:07:00 PM
6:08:00 PM	65	50	35	30	62.6	61.7	15.9	13.2	75	75	65	65	74.2	69.8	64.9	64.6	6:08:00 PM
	65	50	35	30	63.9	62.8	13.6	13.8	75	75	65	65	74.0	69.8	64.3	64.3	6:09:00 PM
6:10:00 PM	65	50	35	30	64.6	63.6	11.2	15.9	75	75	65	65	74.6	72.7	64.2	62.9	6:10:00 PM
	65	50	35	30	64.0	63.8	15.0	13.3	75	75	65	65	74.8	74.2	65.0	64.1	6:11:00 PM
6:12:00 PM	65	50	35	30	64.0	64.2	30.5	14.4	75	75	65	65	72.6	71.4	65.0	64.9	6:12:00 PM
6:13:00 PM	65	50	35	30	63.2	64.3	39.4	17.5	75	75	65	65	72.2	69.9	64.8	63.5	6:13:00 PM
6:14:00 PM	65	50	35	30	62.6	63.3	14.6	20.6	75	75	65	65	73.3	71.4	64.9	63.3	6:14:00 PM
	65	50	35	30	63.4	63.1	13.5	23.4	75	75	65	65	74.4	73.0	65.0	64.1	6:15:00 PM
6:16:00 PM	65	50	35	30	64.4	63.2	23.3	19.4	75	75	65	65	74.2	73.9	65.0	61.5	6:16:00 PM
	65	50	35	30	64.0	62.1	33.5	12.6	75	75	65	65	73.3	71.0	64.8	62.8	6:17:00 PM
6:18:00 PM	65	50	35	30	63.9	58.6	40.5	10.5	75	75	65	65	73.2	70.4	64.4	63.0	6:18:00 PM
	65	50	35	30	63.5	57.7	40.7	9.9	75	75	65	65	72.1	71.7	64.8	60.7	6:19:00 PM
6:20:00 PM	65	50	35	30	62.6	63.0	46.5	8.4	75	75	65	65	72.3	72.9	65.0	63.4	6:20:00 PM
6:21:00 PM	65	50	35	30	63.1	63.5	39.8	14.2	75	75	65	65	73.0	70.2	65.0	64.8	6:21:00 PM
6:22:00 PM	65	50	40	30	63.5	63.0	28.3	14.5	75	75	65	65	69.4	71.1	64.9	64.5	6:22:00 PM
	65	50	40	30	64.8	63.6	45.0	14.4	75	75	65	65	69.8	69.8	65.0	63.8	6:23:00 PM
6:24:00 PM	65	50	40	30	64.1	64.4	60.4	15.9	75	75	65	65	71.3	67.9	61.8	61.2	6:24:00 PM
	65	50	40	30	63.8	64.1	62.3	25.0	75	75	65	65	72.2	70.1	60.0	58.4	6:25:00 PM
6:26:00 PM	65	50	40	30	63.8	61.0	61.3	44.1	75	75	65	65	71.8	73.4	65.0	58.7	6:26:00 PM
6:27:00 PM	65	55	45	35	63.6	62.4	56.6	49.6	75	75	65	65	70.0	72.6	64.5	60.8	6:27:00 PM
6:28:00 PM	65	65	65	65	63.0	63.4	57.2	45.2	75	75	65	65	72.5	69.2	63.2	63.1	6:28:00 PM
	65	65	65	65	61.9	63.9	61.3	49.2	75	75	65	65	72.3	66.2	62.3	59.0	6:29:00 PM
6:30:00 PM	65	65	65	65	60.8	63.1	62.0	55.6	75	75	65	65	74.6	69.6	64.0	57.4	6:30:00 PM
	65	65	65	65	62.9	62.2	60.5	49.8	75	75	65	65	74.4	70.5	65.0	62.0	6:31:00 PM
6:32:00 PM	65	65	65	65	64.0	64.5	62.5	28.9	75	75	65	65	74.6	73.4	63.8	64.7	6:32:00 PM
	65	65	65	65	64.0	64.4	58.9	5.7	75	75	65	65	74.4	73.5	64.3	64.4	6:33:00 PM
6:34:00 PM	65	65	65	65	64.4	64.2	45.8	0.0	75	75	65	65	72.8	71.5	65.0	63.2	6:34:00 PM
	65	65	65	65	63.8	64.6	31.1	0.0	75	75	65	65	72.4	70.4	65.0	64.1	6:35:00 PM
6:36:00 PM	65	65	65	65	63.1	64.6	17.8	0.0	75	75	65	65	73.2	71.3	65.0	64.9	6:36:00 PM
	65	65	65	65	63.7	64.2	4.2	0.0	75	75	65	65	72.8	70.7	65.0	65.0	6:37:00 PM
6:38:00 PM	65	65	65	65	64.4	64.5	0.0	0.0	75	75	65	65	72.8	71.1	64.9	65.0	6:38:00 PM
	65	65	65	65	64.6	64.4	0.0	0.0	75	75	65	65	70.5	69.3	64.8	65.0	6:39:00 PM
6:40:00 PM	65	65	65	65	63.4	62.8	0.0	2.0	75	75	65	65	70.6	69.7	64.8	64.3	6:40:00 PM
	65	65	65	65	63.0	62.1	0.0	6.0	75	75	65	65	73.6	73.2	64.9	63.3	6:41:00 PM
6:42:00 PM	65	65	65	65	62.6	57.9	0.0	2.0	75	75	65	65	72.1	73.1	65.0	64.1	6:42:00 PM
	65	65	65	65	62.4	50.2	0.0	0.0	75	75	65	65	71.2	71.5	65.0	65.0	6:43:00 PM
6:44:00 PM	65	50	40	30	61.1	39.3	0.0	2.7	75	75	65	65	74.4	72.8	65.0	65.0	6:44:00 PM
6:45:00 PM	65	50	40	30	64.5	24.4	0.0	4.0	75	75	65	65	74.4	73.9	65.0	64.9	6:45:00 PM
6:46:00 PM	65	50	40	30	61.7	8.7	0.0	0.0	75	75	65	65	72.1	73.7	65.0	64.0	6:46:00 PM
6:47:00 PM	65	50	40	30	60.2	3.8	7.7	0.0	75	75	65	65	70.4	69.1	65.0	61.3	6:47:00 PM
6:48:00 PM	65	50	35	30	62.6	4.0	7.0	1.0	75	75	65	65	72.4	67.1	64.9	59.6	6:48:00 PM
6:49:00 PM	65	50	35	30	57.8	1.8	3.9	0.8	75	75	65	65	73.1	70.0	64.7	61.4	6:49:00 PM
6:50:00 PM	65	50	35	30	54.7	0.0	4.8	0.0	75	75	65	65	73.2	73.4	64.7	63.9	6:50:00 PM
6:51:00 PM	65	50	35	30	52.2	0.0	4.2	0.0	75	75	65	65	70.9	46.4	64.3	64.2	6:51:00 PM
6:52:00 PM	65	50	35	30	44.5	0.0	3.8	0.0	75	75	65	65	71.5	68.6	64.4	63.9	6:52:00 PM
6:53:00 PM	65	50	35	30	38.6	1.7	5.3	0.0	75	75	65	65	73.4	71.3	64.5	60.9	6:53:00 PM
6:54:00 PM	65	50	35	30	29.4	4.1	0.0	0.0	75	75	65	65	73.7	72.7	65.0	58.4	6:54:00 PM
	65	50	35	30	13.3	5.0	0.0	-0.3	75	75	65	65	73.6	-0.3	64.4	60.3	6:55:00 PM
6:56:00 PM	65	50	35	30	7.5	6.3	0.0	0.0	75	75	65	65	73.5	72.6	31.6	59.4	6:56:00 PM
	65	50	35	30	3.2	4.9	0.0	0.0	75	75	65	65	72.8	71.4	65.0	58.9	6:57:00 PM
6:58:00 PM	65	50	35	30	5.7	4.8	0.0	0.0	75	75	65	65	71.8	72.1	36.6	60.4	6:58:00 PM
	65	50	35	30	8.4	4.0	0.0	0.0	75	75	65	65	47.8	72.1	63.3	60.5	6:59:00 PM
7:00:00 PM	65	50	35	30	7.8	1.0	0.0	0.0	75	75	65	65	73.5	72.3	64.0	54.8	7:00:00 PM
	65	50	35	30	7.0	0.0	0.0	0.0	75	75	65	65	73.6	72.2	63.9	55.5	7:01:00 PM
7:02:00 PM	65	50	35	65	6.2	0.0	0.0	0.0	75	75	65	65	73.4	47.7	64.0	59.3	7:02:00 PM
	65	50	35	65	4.5	0.0	0.0	0.0	75	75	65	65	72.0	69.1	64.0	63.6	7:03:00 PM
7:04:00 PM	65	50	35	65	0.0	0.0	0.0	0.0	75	75	65	65	73.0	70.7	64.1	59.9	7:04:00 PM
	65	50	35	65	1.0	0.0	0.0	0.0	75	75	65	65	74.5	72.4	64.7	59.7	7:05:00 PM
7:06:00 PM	65	50	65	65	4.3	0.0	0.0	0.0	75	75	65	65	73.0	72.2	64.2	60.4	7:06:00 PM
	65	50	65	65	6.3	0.0	0.0	0.0	75	75	65	65	71.1	68.7	63.3	55.2	7:07:00 PM
7:08:00 PM	65	50	65	65	0.0	6.7	0.0	0.0	75	75	65	65	71.6	69.3	64.6	56.0	7:08:00 PM
	65	50	65	65	0.0	10.0	0.0	0.0	75	75	65	65	72.8	70.8	64.0	60.3	7:09:00 PM
7:10:00 PM	65	50	65	65	0.0	0.0	0.0	0.0	75	75	65	65	74.8	74.7	64.3	61.5	7:10:00 PM
	65	50	65	65	0.0	0.0	0.0	0.0	75	75	65	65	72.3	72.9	65.0	62.9	7:11:00 PM
7:12:00 PM	65	50	65	65	0.0	0.0	0.0	0.0	75	75	65	65	72.1	70.8	65.0	64.8	7:12:00 PM
	65	50	65	65	5.0	0.0	0.0	0.0	75	75	65	65	73.9	-1.0	64.9	64.3	7:13:00 PM
7:14:00 PM	65	50	65	65	3.3	0.0	0.7	0.0	75	75	65	65	71.4	55.6	64.7	63.6	7:14:00 PM
7:15:00 PM	65	50	35	65	0.0	0.0	0.3	0.0	75	75	65	65	69.9	63.5	63.0	62.0	7:15:00 PM
7:16:00 PM	65	50	35	65	0.0	0.7	0.0	13.3	75	75	65	65	72.9	70.2	63.0	61.7	7:16:00 PM
	65	50	35	65	0.0	1.0	3.0	40.0	75	75	65	65	73.8	72.9	64.3	62.0	7:17:00 PM
7:18:00 PM	65	50	35	65	0.0	0.0	2.0	13.0	75	75	65	65	74.2	73.5	65.0	62.4	7:18:00 PM

Figure H-16 (continued). "Heat Map" Speeds for VSL Congestion Event, August 7, 2014, Ranger Hill, Eastland County.

VSL Deployment -- Brownwood District - Congestion Activation 8/7/2014

Eastbound

	Posted Speed Limit				Measured Speeds			
	RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3
	65	50	35	65	0.0	0.0	0.0	0.0
7:20:00 PM	65	50	35	65	0.0	0.0	0.0	0.0
	65	50	35	65	0.0	0.0	0.0	0.0
7:22:00 PM	65	50	35	65	0.0	10.7	4.3	0.0
7:24:00 PM	65	50	35	65	0.0	12.0	4.7	0.0
7:25:00 PM	65	50	35	65	0.0	4.0	0.0	0.0
	65	50	35	65	0.0	0.0	0.0	0.0
7:26:00 PM	65	50	35	65	0.0	0.0	-0.3	20.0
	65	50	35	65	0.0	0.0	0.0	13.3
7:28:00 PM	65	50	35	65	0.0	0.0	0.0	0.0
	65	50	35	65	0.0	0.0	0.0	0.0
7:30:00 PM	65	50	35	65	0.0	0.0	0.0	18.7
	65	50	35	65	0.0	4.0	0.0	14.3
7:32:00 PM	65	50	35	65	0.0	11.7	0.0	0.0
	65	50	35	65	0.0	8.0	0.0	0.0
7:34:00 PM	65	50	35	65	0.0	1.7	0.0	0.0
	65	50	35	65	2.7	0.0	0.0	0.0
7:36:00 PM	65	50	65	65	9.3	0.0	0.0	0.0
	65	50	65	65	8.0	0.0	0.0	0.0
7:38:00 PM	65	50	65	65	5.5	1.3	0.0	-0.3
	65	50	65	65	10.3	4.0	0.0	0.0
7:40:00 PM	65	50	65	65	7.8	3.7	0.0	1.7
	65	50	65	65	0.0	6.0	0.0	10.4
7:42:00 PM	65	50	40	30	0.0	3.7	1.5	16.6
7:43:00 PM	65	50	35	30	0.0	0.0	4.6	13.7
7:44:00 PM	65	50	35	30	3.3	0.0	17.0	21.6
	65	50	35	30	3.4	0.0	30.5	21.2
7:46:00 PM	65	50	35	30	2.0	2.7	33.2	21.8
	65	50	35	30	0.7	13.2	34.5	23.5
7:48:00 PM	65	50	35	30	0.0	22.7	42.4	36.0
7:49:00 PM	65	50	40	35	7.9	33.6	46.2	45.9
7:50:00 PM	65	50	50	45	17.0	42.0	49.3	51.9
7:51:00 PM	65	50	50	50	30.1	47.0	54.3	56.3
7:52:00 PM	65	50	50	65	37.9	48.8	57.4	58.0
7:53:00 PM	65	50	50	65	42.7	51.9	58.2	60.2
7:54:00 PM	65	50	65	65	41.2	54.2	59.8	61.8
7:55:00 PM	65	65	65	65	40.8	53.5	60.5	63.1
7:56:00 PM	65	65	65	65	47.2	53.3	55.6	61.7
7:57:00 PM	65	65	65	65	52.3	55.0	52.3	56.6
7:58:00 PM	65	65	65	65	55.4	58.5	54.2	57.5
7:59:00 PM	65	65	65	65	58.4	58.7	55.5	59.3
8:00:00 PM	65	65	65	65	59.6	60.1	59.4	59.9

Westbound

Posted Speed Limit				Measured Speeds				
RSA.1	VSL.1	VSL.2	VSL.3	RSA.1	VSL.1	VSL.2	VSL.3	
75	75	65	65	74.5	73.4	65.0	64.4	7:19:00 PM
75	75	65	65	73.7	73.5	65.0	63.3	7:20:00 PM
75	75	65	65	73.2	74.1	65.0	57.9	7:21:00 PM
75	75	65	65	-1.0	73.6	65.0	62.6	7:22:00 PM
75	75	65	65	75.0	69.8	65.0	62.4	7:23:00 PM
75	75	65	65	75.0	70.2	65.0	64.0	7:24:00 PM
75	75	65	65	74.1	73.6	65.0	63.3	7:25:00 PM
75	75	65	65	74.3	73.3	65.0	63.4	7:26:00 PM
75	75	65	65	72.6	71.0	65.0	61.3	7:27:00 PM
75	75	65	65	71.2	69.9	65.0	61.3	7:28:00 PM
75	75	65	65	71.9	69.6	64.6	63.5	7:29:00 PM
75	75	65	65	71.5	71.9	64.4	62.2	7:30:00 PM
75	75	65	65	47.5	72.4	65.0	63.2	7:31:00 PM
75	75	65	65	69.0	73.7	65.0	64.4	7:32:00 PM
75	75	65	65	71.5	48.4	65.0	63.1	7:33:00 PM
75	75	65	65	73.5	73.0	65.0	63.6	7:34:00 PM
75	75	65	65	73.1	72.4	64.8	65.0	7:35:00 PM
75	75	65	65	72.4	70.2	47.8	64.0	7:36:00 PM
75	75	65	65	73.7	69.3	64.2	64.1	7:37:00 PM
75	75	65	65	74.8	72.4	64.4	63.9	7:38:00 PM
75	75	65	65	74.8	74.5	64.8	64.6	7:39:00 PM
75	75	65	65	74.2	74.8	62.9	65.0	7:40:00 PM
75	75	65	65	73.8	73.5	63.7	63.3	7:41:00 PM
75	75	65	65	72.8	72.2	64.6	64.2	7:42:00 PM
75	75	65	65	73.1	34.3	64.9	65.0	7:43:00 PM
75	75	65	65	71.9	71.8	64.1	65.0	7:44:00 PM
75	75	65	65	72.3	68.4	64.0	64.3	7:45:00 PM
75	75	65	65	72.1	70.3	63.8	64.2	7:46:00 PM
75	75	65	65	74.2	72.7	61.8	60.2	7:47:00 PM
75	75	65	65	73.7	73.3	64.2	58.9	7:48:00 PM
75	75	65	65	71.8	69.1	65.0	64.7	7:49:00 PM
75	75	65	65	73.0	68.3	64.9	65.0	7:50:00 PM
75	75	65	65	75.0	72.2	64.9	64.9	7:51:00 PM
75	75	65	65	49.7	73.9	65.0	65.0	7:52:00 PM
75	75	65	65	74.5	73.0	65.0	65.0	7:53:00 PM
75	75	65	65	73.5	71.8	65.0	64.7	7:54:00 PM
75	75	65	65	72.2	71.3	65.0	64.7	7:55:00 PM
75	75	65	65	71.6	70.9	65.0	65.0	7:56:00 PM
75	75	65	65	74.0	71.5	65.0	65.0	7:57:00 PM
75	75	65	65	48.7	71.9	64.1	63.9	7:58:00 PM
75	75	65	65	75.0	72.4	64.4	63.5	7:59:00 PM
75	75	65	65	74.5	73.4	64.9	64.6	8:00:00 PM

Figure H-16 (continued). "Heat Map" Speeds for VSL Congestion Event, August 7, 2014, Ranger Hill, Eastland County.

Safety Analysis

TxDOT's CRIS was used to analyze the safety of the four study sites (two on IH-20). The specific crash data assessed are shown in Table H-18 based on the project's scope of work. Approximately six months within the three years of Before data (2011, 2012, and 2013) and one year of After data (2014) start and end dates (shown in Table 1) were used in the analysis.

Figure H-17, Figure H-18, and Figure H-19 show the limits of each study site. It is important to note that Figure H-19 shows both the eastbound and westbound sections of IH-20. Because the intent of the variable speed limit (VSL) project is to slow traffic down as drivers approach the end of a queue, the analysis limits generally started at the first "Reduced Speed Ahead" sign to one-mile downstream of the last VSL sign. However, the IH-20 sections were extended to the RSA signs in the opposite direction. This extension ensured that crashes related to the horizontal and vertical curves were included in the analysis.

Table H-18. Safety Analysis Approach.

Hypothesis/Question	Measures of Effectiveness	Data
The deployment of VSLs will improve safety within the study site.	• Change in the number of crashes within the VSL site. • Change in the number of crashes during peak/congested periods in the VSL site. • Change in the distribution of severity of all crashes. • Change in the distribution of severity of crashes during peak/congested periods.	• Total number of all crashes. • Total number of crashes during VSL activation. • Severity of all crashes. • Severity of all crashes during VSL activation.

Note: The project team used data during the same period in previous years. The limited timeframe of the evaluation limited the statistical significance of the safety data.

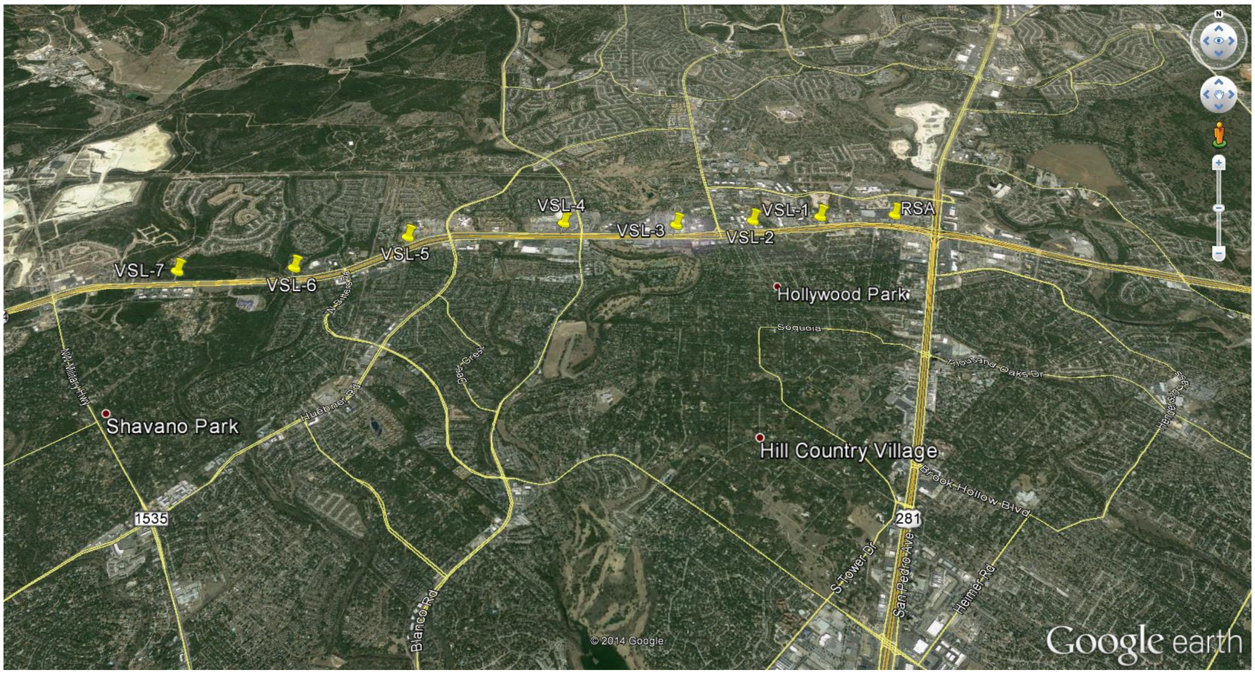


Figure H-17. WB SL 1604, San Antonio.

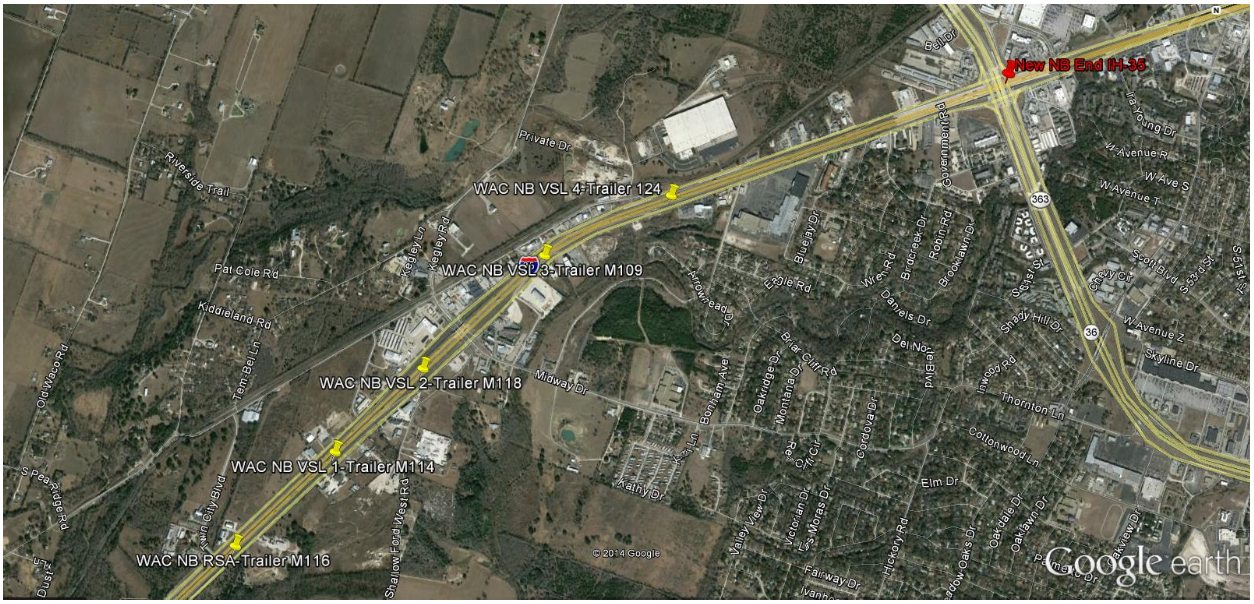


Figure H-18. NB IH-35, MM 297–MM 301, Temple.

Figure H-19. EB and WB IH-20 at Ranger Hill, Ranger Hill, Eastland County.

Table H-19 shows the before and after results. The safety analysis showed that all test sites saw a decrease in the number of crashes and in the crash rate, as presented in Figure H-20, with the exception of San Antonio.

The crash severity and crashes by time-of-day are illustrated in Figure H-21 and Figure H-22, respectively. In general, crash severity decreased after VSL activation with the largest decrease in incapacitating crashes followed by non-incapacitating crashes. Likewise, the largest decrease in crashes occurred in AM peak followed by midday crashes.

The Before and After crashes by 'adverse' surface conditions are illustrated in Figure H-23. In general, the number of crashes with 'adverse' surface conditions (e.g. wet, ice, snow, muddy, etc.) decreased after VSL activation.

No statistical significance test was completed given the short duration of the analysis period. Robust safety analyses involve multiple years of before and after data, and this analysis period was only a few months. Researchers recommend that future assessments utilize at least three years of after data for each site.

Table H-19. Before and After Results: Crashes and Crash Rate.

Site	MI	AADT*	Before	After	Analysis Period	Before		After	
						Crashes	Crash Rate (per MVMT)	Crashes	Crash Rate (per MVMT)
San Antonio	6.08	127000	6/29/11–12/31/13	6/30/14–12/31/14	182 days	141	0.335	46	0.328
Temple	2.56	108500	6/23/11–11/30/13	6/23/14–11/30/14	158 days	51	0.387	8	0.182
Ranger Hill, Eastland County	4.56	18900	7/21/11–1/30/14	7/21/14–1/30/15	195 days	51	1.011	2	0.119

*2011–2012 AADT from http://www.txdot.gov/apps/statewide_mapping/StatewidePlanningMap.html.
Approximately six months within the three years of Before data (2011, 2012, and 2013) and one year of After data (2014) start and end dates were used in the analysis.

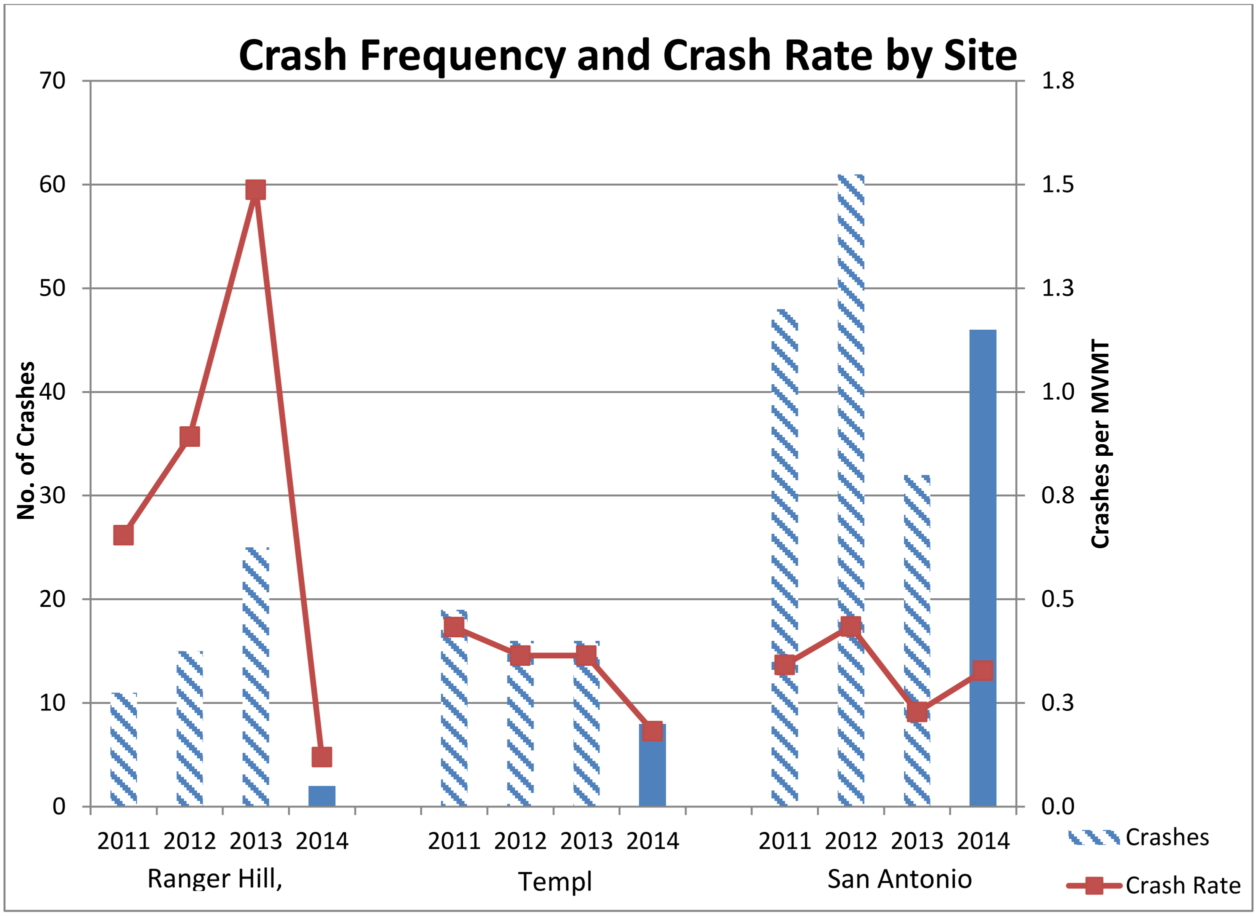


Figure H-20. Crashes and Crash Rates for VSL Sites, Before and After Activation.

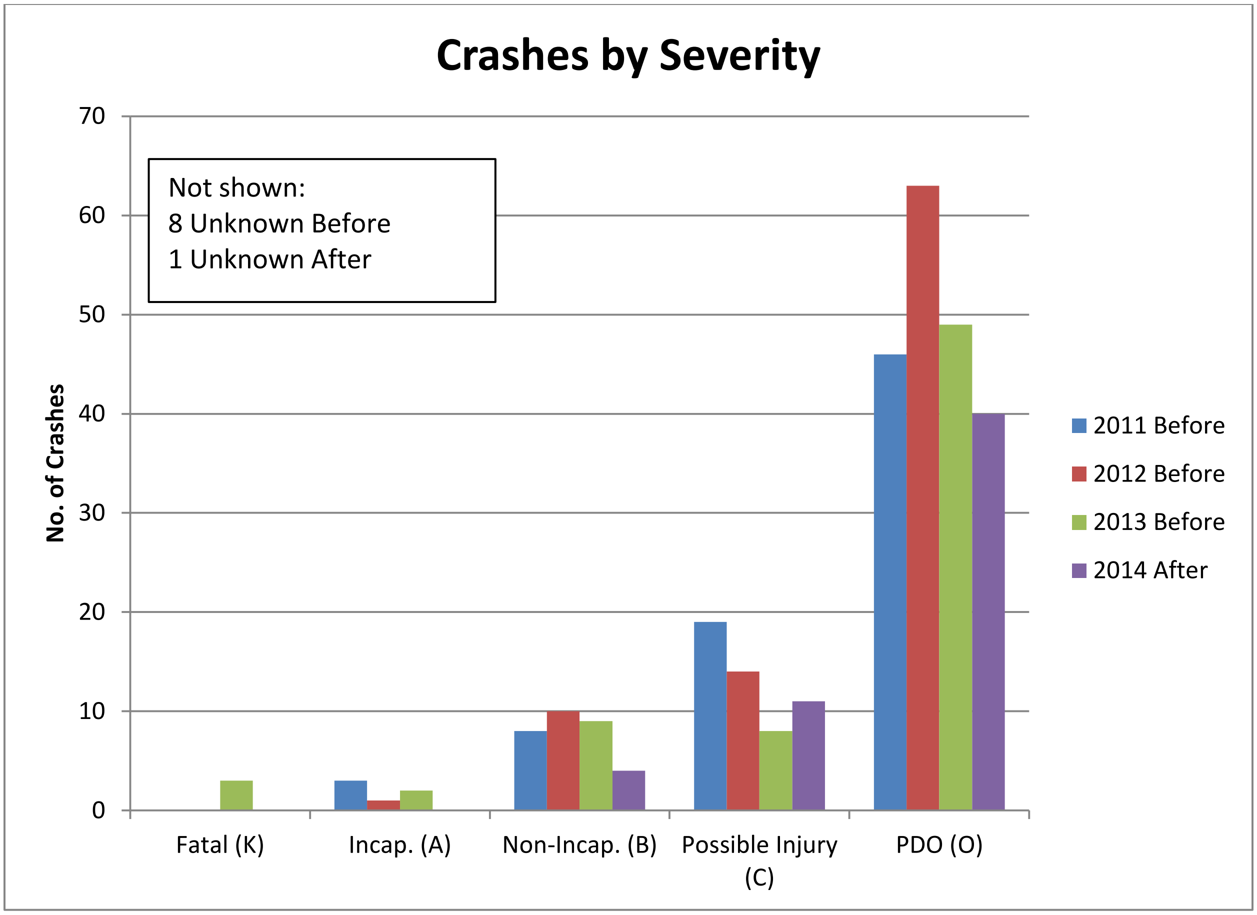


Figure H-21. Crash Severity for VSL Sites, Before and After Activation.

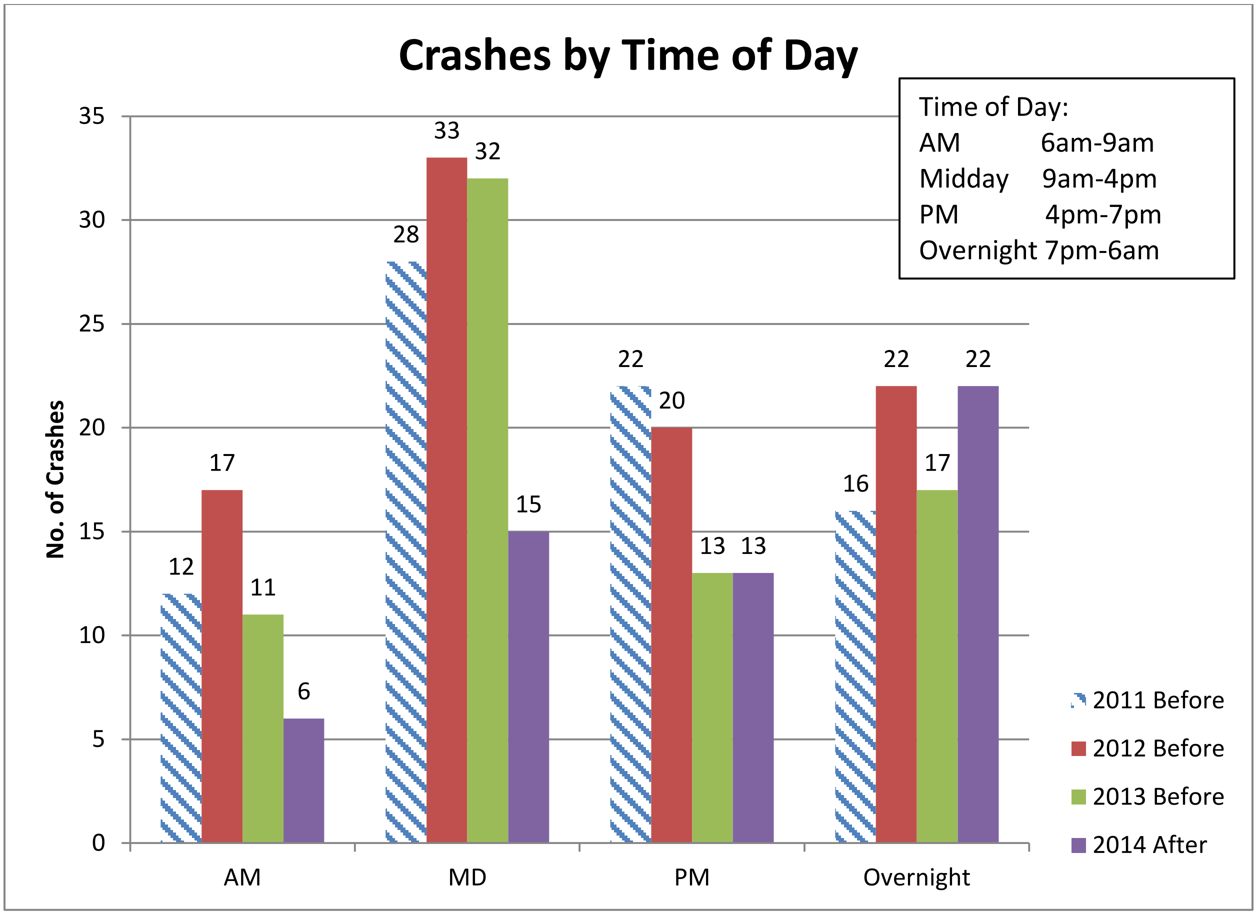


Figure H-22. Crashes by Time of Day for VSL Sites, Before and After Activation.

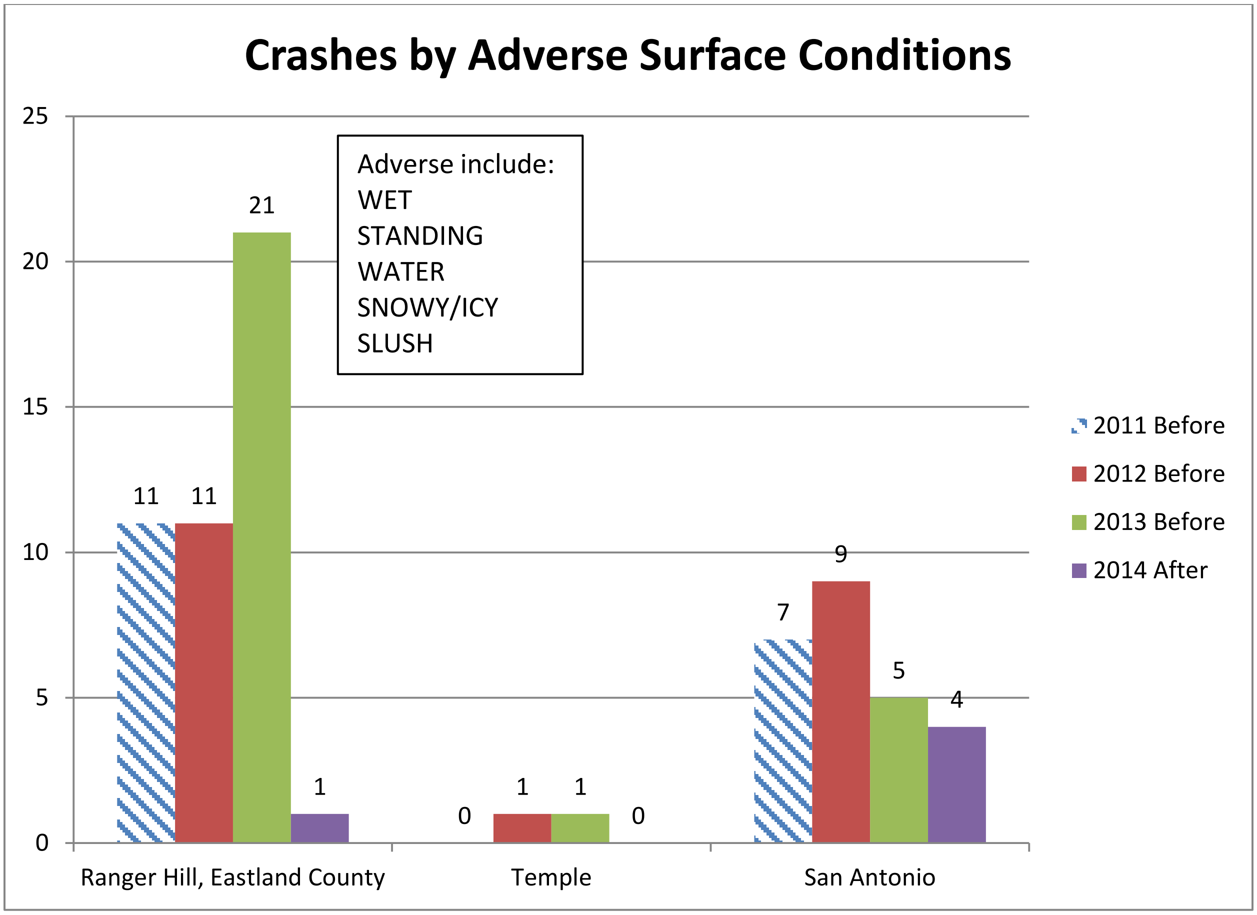


Figure H-23. Crashes by Adverse Surface Conditions for VSL Sites, Before and After Activation.

Users' Perceptions of VSL

Users' perceptions of the VSL project were a key factor in overall success. To assess user understanding of the VSL sign systems, the TTI project team conducted 300 surveys during the VSL deployment period in the San Antonio and Ranger Hill, Eastland County sites.

San Antonio District Surveys

In the San Antonio District, 200 surveys were conducted during the month of August at the Leon Valley Driver License Office located at 7410 Huebner Road, approximately 7 mi from the VSL deployment site. This was the closest public venue for which the project team was able to obtain consent to conduct the surveys.

The survey consisted of questions aimed at assessing the respondents' awareness and understanding of the VSL system, along with their opinions of the signs themselves. These questions included:

- When was the last time you traveled through [the study area]?
- How often do you travel through that area?
- Can you describe the speed limit signs that you saw while driving through that area? If so, what did you notice about them?
- What do you think the signs were telling you?
- How many signs did you see?
- Was the speed limit the same on all of those signs?

The results of the awareness questions were recorded, tabulated, and analyzed. The results are shown in Figure H-24 and indicate that 20 percent of the respondents had driven through the VSL site on SL 1604 on the same day they took the survey. Another 25 percent had driven through the VSL site the day before they took the survey. One-third had been at the VSL site during the previous week, while the remaining respondents had not been there recently.

Figure H-25 shows the results of the question regarding how often the respondents traveled through that area. Twenty-one percent indicated a daily trip through the VSL deployment area, while another 22 percent recalled driving through there several times per week. Eighteen percent made weekly trips through the VSL deployment, while the remaining respondents reported frequenting the area a few times per month or less.

The combined results of these questions indicate that about 40 to 45 percent of the survey respondents had exposure to the signs on a regular basis.

When asked if they could describe the speed limit signs, 79 of the 200 respondents (about 40 percent) in San Antonio said they could and proceeded to explain the speed limit sign attributes that they recalled. The descriptions included terms such as *digital*, *electronic*, *adjustable*, or *changeable*. About 90 percent of these affirmative responses came from the more frequent travelers in the corridor (i.e., those who traveled within the last week and/or claimed to make routine trips in the corridor). There were 121 respondents who were not able to describe the speed limit signs.

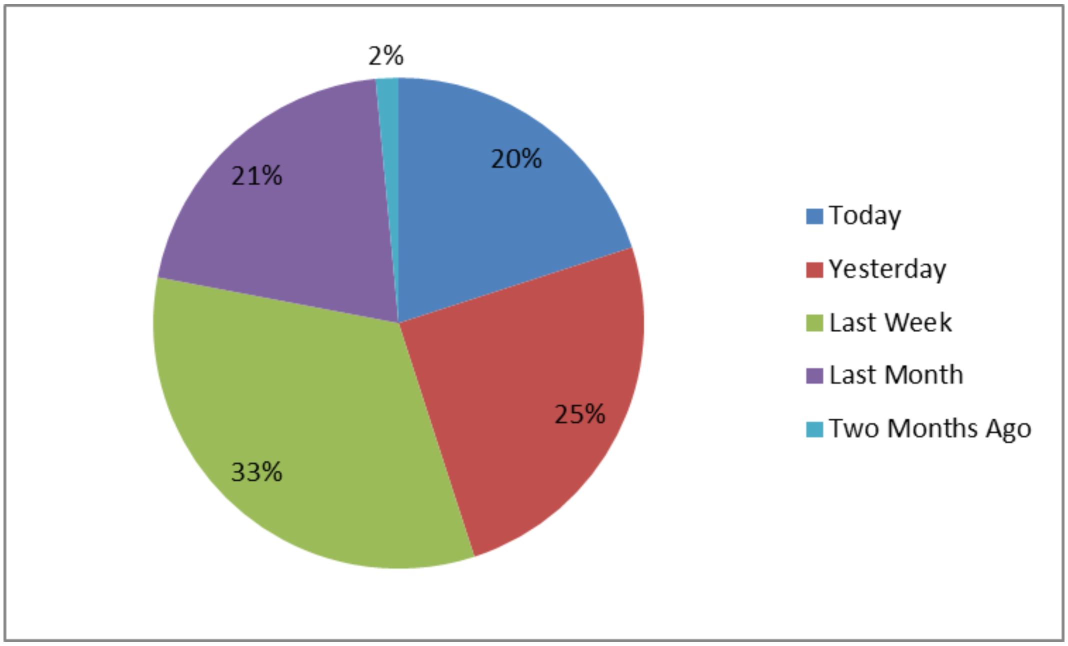


Figure H-24. Last Time Respondents Drove through the VSL Deployment Area on SL 1604, San Antonio.

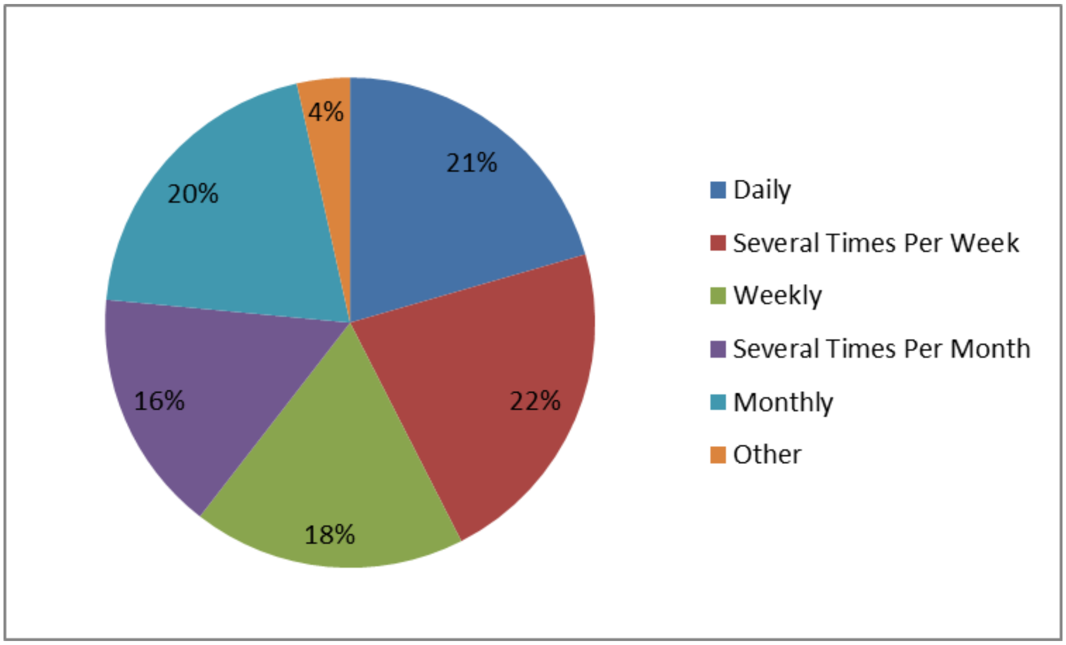


Figure H-25. Frequency of Respondent Trips through the VSL Deployment Area on SL 1604, San Antonio.

The subsequent question asked what the sign was telling the respondent. All 79 respondents who described the signs said that it was the posted speed limit. Twenty-four percent volunteered additional information, indicating that the speed limit was for a certain traffic condition, while another 16 percent added that it was for a certain time period. Several of these respondents mentioned that they had seen or heard something on the local news about the purpose of the signs. Over one-half (54 percent) did not indicate that they knew the reason that the posted speed limit would change, but this question was not directly asked at this point. Four percent thought that the speed limit was for a work zone, although no work zone was present, but it is likely that the safety drums surrounding the VSL trailers might have influenced these responses. One respondent, who was an infrequent traveler in the corridor, thought that the signs were not working.

When asked how many signs each respondent saw, answers varied from one, two, three, or four or more. This is likely due to the fact that many respondents may have entered and exited the corridor within the VSL area and not seen all of the signs.

The 79 respondents who recalled the signs were also asked if the posted speed limit was the same on all of the signs. Forty-one respondents (52 percent) said yes and recalled that the posted speed was 70 mph on all of the signs. Eight others (10 percent) indicated that some other speed was posted (i.e., 60, 55, 50, or 45 mph). Twenty-six respondents (33 percent) said no, the speed limit was not the same on all the signs. The lowest speed that they recalled seeing on any sign varied from 70 down to 25 mph.

The next group of questions was related to assessing driver understanding of the VSL signs. The questions were aimed at getting more information from those 121 respondents who did not initially recall the speed limit signs:

- Is this the sign that you saw?
- Do you think the speed limit shown on the sign changes?
- When do you think there would be a need to change the speed limit?
- Do you think you could get a speeding ticket for going over the speed limits shown on the signs?

The project team showed each of the same 200 respondents a photo of an actual VSL sign taken in San Antonio. When asked if it was the sign that they recalled, 88 (73 percent) of the 121 respondents who initially did not recall the signs then responded affirmatively. The remaining 33 respondents still did not recall the signs but continued to answer the survey questions based on the photo image of the VSL sign.

At this point in the survey, 191 out of 200 respondents understood that the sign was telling them that the speed limit was 70 mph. Nine respondents, all of whom had not seen the sign until shown the photo, thought that the sign was telling them their speed (like a MY SPEED sign).

The respondents were asked when they thought there would be a need to change the speed limit. Many of the respondents gave more than one answer. The most common answer was congestion or peak-hour traffic, followed by accident, work zone or construction, weather, and nighttime conditions. These results are shown in Figure H-26.

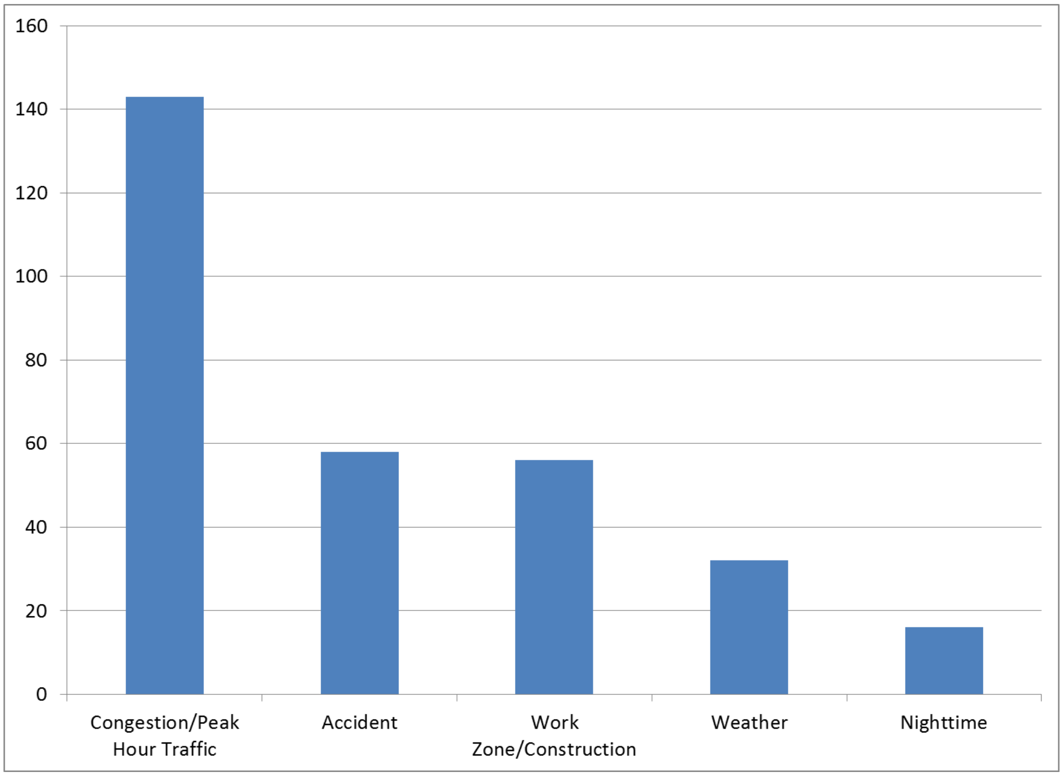


Figure H-26. Conditions under Which San Antonio Respondents Thought a Speed Limit Change May Occur.

When asked if they thought they could get a speeding ticket for exceeding the posted speed, 198 of the 200 respondents said yes. The two dissenters thought that the sign was not legal because it was lighted or represented a suggested speed.

Ranger Hill, Eastland County **Surveys**

In the Brownwood District, 100 surveys were conducted at the Red Star Truck Terminal in Eastland, which was located on rural IH-20 approximately 17 mi west of the VSL deployment site. Consent to conduct surveys closer to the VSL deployment site could not be obtained. The same survey questions were used at this location.

As shown in Figure H-27, the respondents at the Ranger Hill, Eastland County site had approximately the same recent exposure to the VSL system as those in San Antonio. Forty-two percent of respondents had been through the VSL area within one day prior to taking the survey (compared to 45 percent in San Antonio).

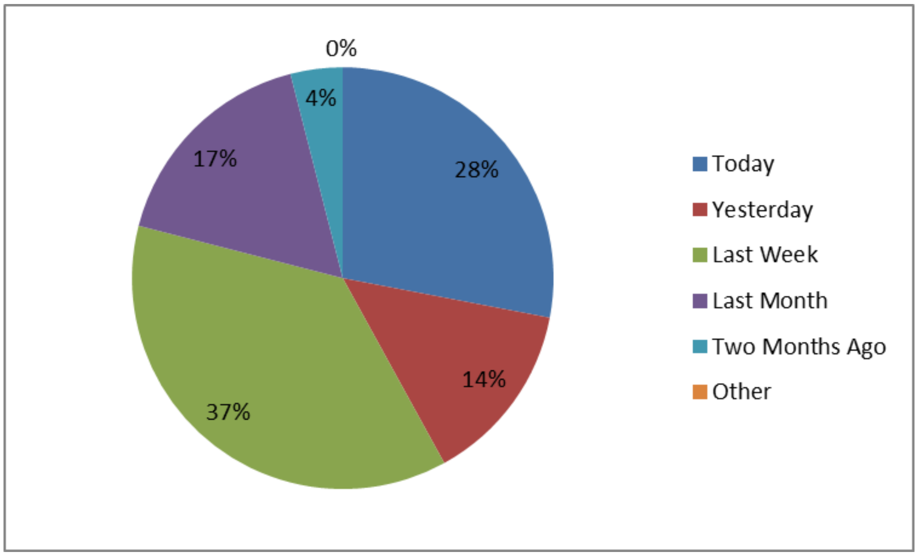


Figure H-27. Last Time Respondents Drove through the VSL Deployment Area on IH-20, Ranger Hill, Eastland County.

Figure H-28 shows the results of the question regarding how often the respondents traveled through the area. Only 9 percent indicated a daily trip through the VSL deployment area, while another 21 percent recalled driving through there several times per week. Fifteen percent made weekly trips through the VSL deployment, while the remaining respondents reported frequenting the area a few times per month or less. The frequency of trips was lower than what was reported in San Antonio, likely due to the long distance of the VSL from the survey location and the rural nature of the area.

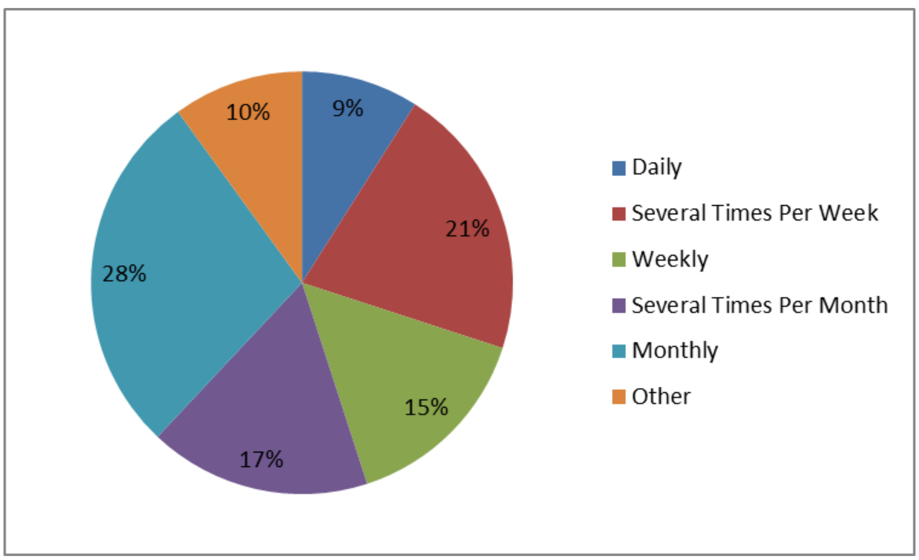


Figure H-28. Frequency of Respondent Trips through the VSL Deployment Area on IH-20, Ranger Hill, Eastland County.

The combined results of these questions indicate that while about 40 to 45 percent of the survey respondents had recent exposure to the signs, they did not have the same frequency of exposure to the VSL signs on a regular basis.

When asked if they could describe the speed limit signs, 42 of the 100 respondents at Ranger Hill, Eastland County said they could and proceeded to explain the speed limit sign attributes that they recalled. The descriptions included terms such as *digital*, *LED*, *electronic*, *lighted*, *flashing*, or *changeable*. There were 58 respondents who were not able to describe the speed limit signs because they said they did not remember or were not paying attention.

The subsequent question asked what the sign was telling the respondent. Forty-one of the 42 respondents who described the signs said that it was the posted speed limit. Three of these 41 thought that the speed limit was related to the work zone that was located within the VSL system (where new rest area ramps were under construction). One person thought the signs were displaying his/her speed (like a MY SPEED sign).

The 42 respondents who recalled the signs were also asked if the posted speed limit was the same on all of the signs. Sixty percent said yes and recalled that the posted speed was 65 mph on all of the signs. Thirty-eight percent said no and recalled seeing speeds of 65, 55, and 25 mph on the signs. These results were not surprising given the infrequency with which the Ranger Hill, Eastland County VSL system deployed due to weather or crashes. The remaining 2 percent were not sure if all the signs were the same.

The project team showed all 100 respondents a photo of an actual VSL sign taken at the IH-20 VSL system site. When asked if it was the sign that they recalled, 80 percent said yes. The remaining 20 respondents still did not recall the signs but continued to answer the survey questions based on the photo image of the VSL sign.

At this point in the survey, 97 out of 100 respondents understood that the sign was telling them that the speed limit was 65 mph. Of this group, five indicated that the posted speed was due to a nearby work zone. Three respondents thought that the sign was telling them their speed (like a MY SPEED sign).

The respondents were asked when they thought there would be a need to change the speed limit. Many of the respondents gave more than one answer. The most common answer was weather, followed by work zone or construction, accident, road conditions, traffic, and nighttime conditions. These results are shown in Figure H-29.

When asked if they thought they could get a speeding ticket for exceeding the posted speed, 98 of the 100 respondents said yes. The two dissenters thought that the sign was not legal because it was a temporary sign or a warning sign.

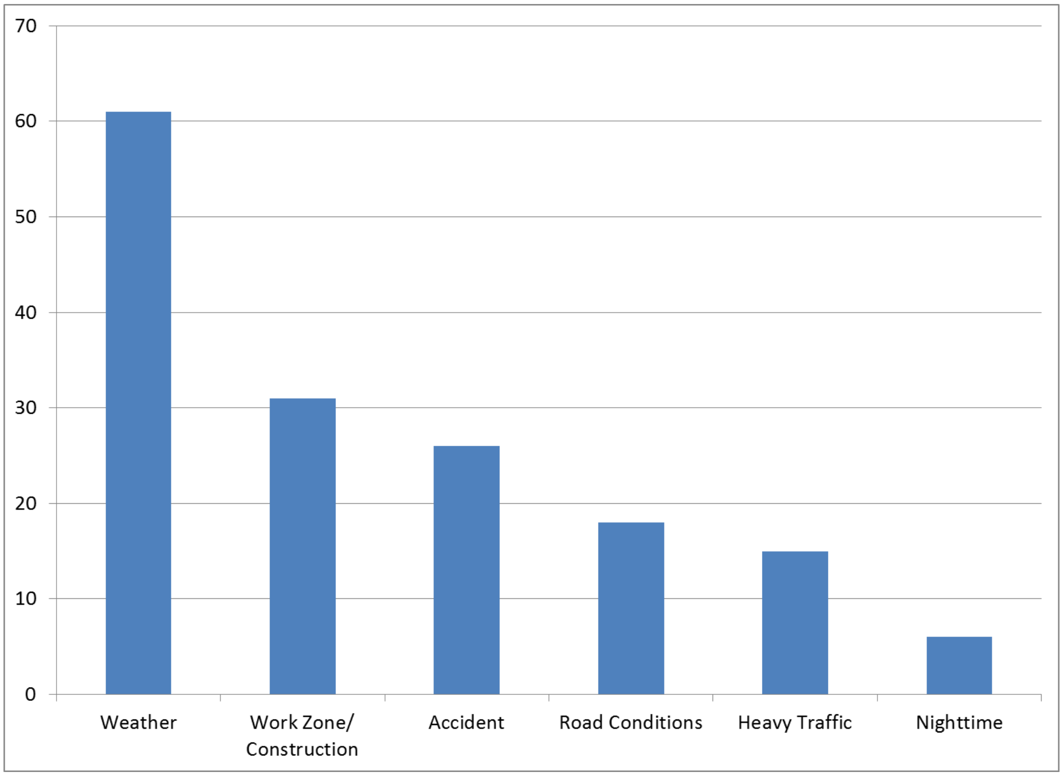


Figure H-29. Conditions Under Which Ranger Hill, Eastland County under which Respondents Thought a Speed Limit Change May Occur.

Summary

Because consent to conduct the surveys closer to the VSL deployment sites could not be obtained, the project team did not expect respondents to be able to recall or accurately compare their speeds with and without the VSL system activated. Thus, the project team focused on other questions that would better ascertain public understanding of the VSL system. The survey results indicate that the respondents understood that the signs displayed a legal, enforceable speed limit. In addition, most respondents at each location were aware of the reasons for activation of the VSL system (i.e., primarily congestion in San Antonio and weather in Ranger Hill, Eastland County).

Violation Analysis

Past research shows that motorists typically drive at a speed they deem comfortable for the given conditions. Thus, posted speed limits that do not appear to be appropriate for the prevailing conditions are less likely to have good compliance rates. Speed limit compliance is a function of many different factors, including road and traffic conditions, weather, and various driver characteristics. In order to determine the impacts of enforcement on VSL speed compliance, the project team performed an enforcement study at the VSL deployment located on SL 1604 in San Antonio.

The study consisted of a comparison of recorded speed data taken from the advance warning PCMS and VSL#1 in the series. These locations were selected because a review of the

San Antonio data revealed that congestion at downstream VSLs (such as #5 and #6) often triggered the system to deploy speed limits of 55 or 60 mph farther upstream. In the upstream area, motorists often could not physically see any apparent need to reduce their speed, despite the "Reduced Speed Ahead" display on the advance warning PCMS and a reduced speed limit on VSL#1.

On September 30 and October 1, 2014, a patrol car was positioned near VSL#1 during the a.m. and p.m. peak periods. At this location, the VSL routinely displayed lowered speed limits during peak periods. Figure H-30 shows the patrol car position and the VSL displaying 55 mph during relatively light traffic conditions. For comparison, the project team used data collected on September 23, 24, and October 7 with the reduced speed limit of 55 mph without the officer present. Control data were collected at the advance warning PCMS while it was displaying "Reduced Speed Ahead" and while the VSL#1 display was 55 mph. Table H-20 shows a summary of these occurrences used for the enforcement study.

Figure H-30. Patrol Car Stationed Near VSL#1 in San Antonio.

Speeds were collected with the Wavetronix sensors, and average speeds were stored every 20 seconds at each data collection point. Individual vehicle speeds were not stored, but the number of vehicles included in the average speed was recorded. For example, the downloaded data could show that the average speed of seven vehicles during a 20-second period was 61.4 mph. Due to this limitation of the data, the project team could not perform traditional analyses on the data. However, the percentage of time that the average speeds exceeded the speed limit (or any particular speed threshold) could still provide valuable information.

Table H-20. Time Ranges Used for 55 mph Speed Comparison.

Date	Begin Time	End Time	Number of Minutes	Enforcement Present? (Y/N)
Tuesday 9/23/14	7:22 a.m.	8:21 a.m.	59	N
Wednesday 9/24/14	7:17 a.m.	7:59 a.m.	42	N
Wednesday 9/24/14	5:19 p.m.	5:30 p.m.	11	N
Tuesday 9/30/14	7:33 a.m.	8:25 a.m.	52	Y
Wednesday 10/01/14	7:28 a.m.	8:07 a.m.	39	Y
Wednesday 10/01/14	5:13 p.m.	5:59 p.m.	46	Y
Tuesday 10/07/14	7:31 a.m.	8:28 a.m.	57	N

The analysis of violation data, presented in Figure H-31, indicate that the VSL system alone without enforcement had an impact on the percentage of time that average speeds exceed specific speed thresholds, more at higher speeds than at lower speeds. When a patrol officer was present, the impact increased, most likely because motorists perceived a need to slow down, albeit to avoid the penalty of receiving a speeding ticket. Thus, VSL compliance increases in the presence of law enforcement.

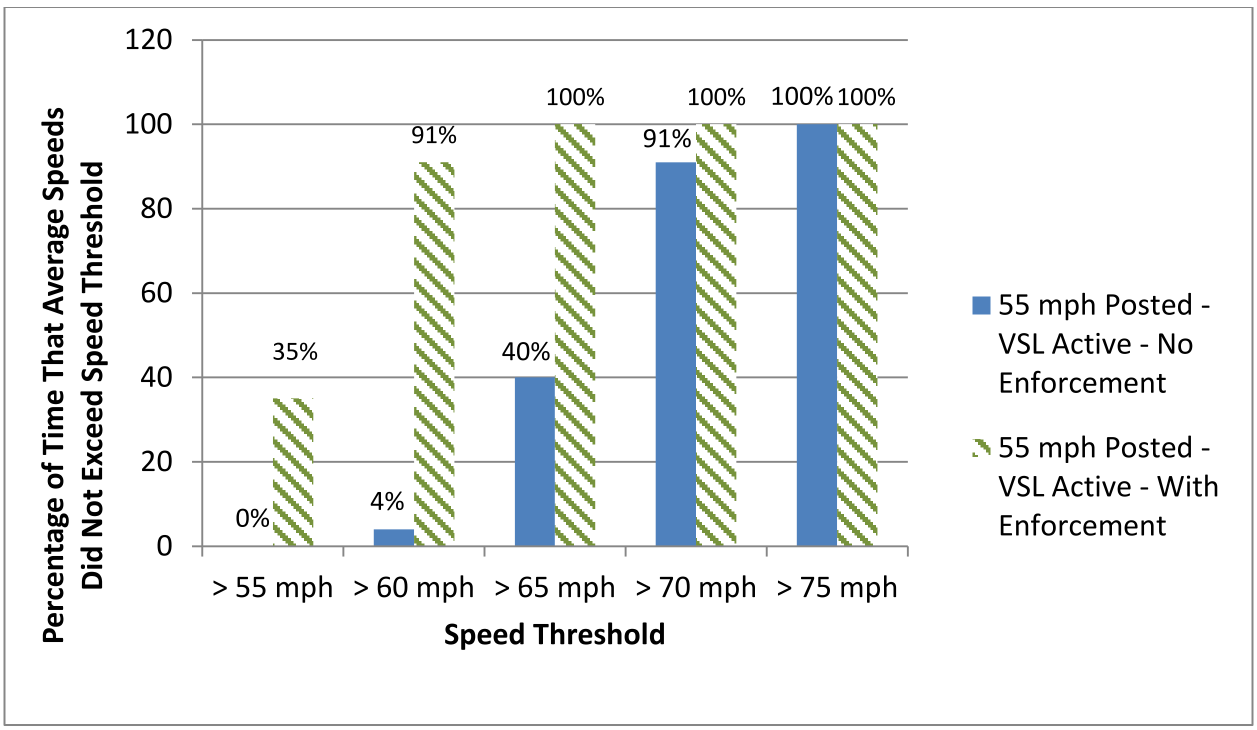


Figure H-31. Impacts of VSL on Average Speeds, With and Without Enforcement.

In summary, there are cases where downstream congestion creates a need to reduce speeds in upstream areas to avoid sudden braking and other erratic maneuvers when vehicles reach the congested area. These data show that the effectiveness of the VSL system was very limited in upstream locations where motorists may not have realized there was a legitimate need to reduce their speed. When a patrol officer was present, motorists perceived a need to slow down, albeit to avoid the penalty of receiving a speeding ticket. Thus, VSL compliance increased in the presence of law enforcement.

Benefit-Cost Analysis

The project team conducted a high-level benefit-cost analysis on potential VSL deployments in Texas as part of this project. Given the short duration of the evaluation period for the pilot deployments and the temporary nature of the installed equipment, the project team determined that an analysis using the specific project costs and benefits may not provide useful information. Thus, the team utilized the FHWA *Operations Benefit/Cost Analysis Desk Reference* to conduct the analysis.[5] As presented by FHWA, speed harmonization—also known as VSL—involves the implementation of VSL to help lessen stop-and-go conditions and lower the speeds of vehicles as they approach downstream bottlenecks. These bottlenecks, as considered throughout the TxDOT VSL pilot deployments, include recurring congestion, work zones, and weather conditions causing slowdowns. The anticipated primary benefit of VSL is improved safety.[5]

The B/C analysis as presented by FHWA is a process by which agencies can calculate and compare benefits and costs of a project to determine (a) if the investment in the project is sound, and (b) how it compares to other alternative projects being considered for the corridor. Typical measures of effectiveness used in the B/C analysis include:

- Travel time.
- Travel time reliability.
- Crashes.
- Fuel use.
- Nonfuel vehicle operating costs.
- Emissions/air quality.
- Agency efficiency.[5]

The project team utilized the Tool for Operations Benefit/Cost (TOPS-BC) to conduct the B/C analysis for the TxDOT VSL pilot projects.[6] This tool was developed in parallel with the aforementioned desk reference and is intended to (a) allow users to look up the expected range of TSM&O strategy impacts based on a database of observed impacts in other areas; (b) provide guidance and a selection tool for users to identify appropriate B/C methods and tools based on the input needs of their analysis; (c) provide the ability to estimate life-cycle costs of a wide range of TSM&O strategies; and (d) allow for the estimation of benefits using a spreadsheet-based sketch-planning approach and the comparison with estimated strategy costs.[5]

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[5] Sallman, D., E. Flanigan, K. Jeannotte, C. Hedden, and D. Morallos, *Operations Benefit/Cost Analysis Desk Reference*, Report FHWA-HOP-12-028, Cambridge Systematics for Federal Highway Administration, Washington, D.C., 2012.

[6] Sallman, D., K. Jeannotte, R. Margiotta, and J. Strasser, *Operations Benefit/Cost Analysis TOPS-BC User's Manual*, Report FHWA-HOP-13-041, Cambridge Systematics for Federal Highway Administration, Washington, D.C., 2013.

The high-level results of the B/C analysis are provided in Table H-21. Each individual deployment (Ranger Hill, Eastland County EB and WB, Temple, and San Antonio) was analyzed separately. Data included in the analysis contained the length of the deployment site, cross-section of the facility, free-flow speed on the facility, and historical crash data. The crash data used were the same data used in the safety analysis discussed previously. In all instances, the analysis assumed the speed harmonization installation was a full, permanent installation on the selected facility. Included in the analysis was the value of capital equipment (basic infrastructure equipment and incremental deployment equipment) and operational and maintenance costs annualized over a 20–25 year useful life of the equipment. The B/C ratio estimated for installing future VSL in the four locations as a permanent operational strategy was positive. All of the benefits predicted to be realized in these deployments were based on a 7 percent reduction in crashes.

Table H-21. Benefit-Cost Estimate.

Deployment Site	Annual Benefits	Annual Costs*	Net Benefit	B/C Ratio
San Antonio	$2,112,983	$300,370	$1,812,613	7.03
Temple	$2,358,976	$238,075	$2,120,901	9.91
Ranger Hill, Eastland County	$4,216,950	$300,370	$3,916,580	14.04

*Assumes full permanent installation.