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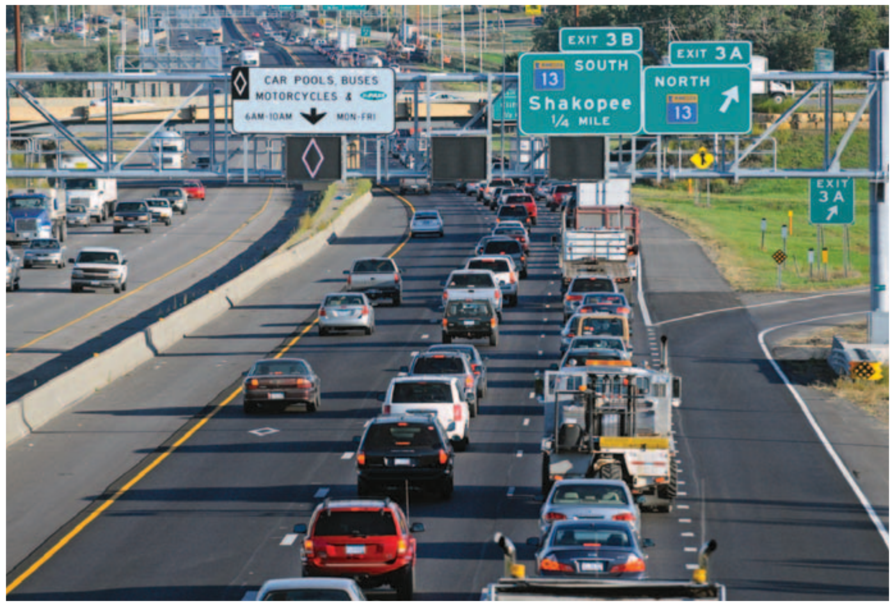
Waves less shocking

Variable speed limits on I-35W near Minneapolis ease the concussion of congestion

In an effort to combat congestion in our country's urban areas, the U.S. DOT launched the Urban Partnership Agreement (UPA) program in 2007. The program infused nearly $900 million into transportation-related projects in four cities nationwide, including the Twin Cities metropolitan area.



Overhead signs known as ILCSs are used to inform drivers of upcoming conditions or controls in place. Overhead signs are used to indicate which lanes are closed or blocked because of a crash or obstruction. The ILCSs also are used to post advisory speeds.

Minnesota's projects—which include the installation of Smart Lanes, among others—focused on improving traffic flow on the I-35W corridor between Minneapolis and the city's southern suburbs. Since then the Smart Lane system was expanded to the most traveled part of the I-94 corridor connecting the cities of Minneapolis and St. Paul.

Smart Lanes is the brand name of Minnesota's active traffic management (ATM) system on I-35W and I-94. The ATM system was first deployed on I-35W in two phases between 2009 and 2010. The original system covered 16 miles of I-35W south of Minneapolis and was extended by 2 miles in 2011. A new 8-mile section of ATM was installed on I-94 between downtown Minneapolis and downtown St. Paul in the summer of 2012.

The ATM system consists of individual electronic signs that sit over each lane of traffic and provide real-time information to help motorists make informed decisions about their commute. The signs display information about road conditions to improve traffic flow, reduce congestion and improve safety.

The signs are illuminated during traffic incidents to indicate whether lanes are open to traffic. Variable advisory speed limits also are displayed to warn motorists of congestion ahead. This use of technology is intended to enhance safety and improve the flow of traffic by providing motorists with information about the conditions within their lane (and alert them to what is up ahead). The information provided in real-time by these overhead lane signs is designed to help motorists navigate safely through traffic.

The ATM system is operated out of the Regional Transportation Management Center (RTMC). The RTMC is a co-located operations center housing Minnesota Department of Transportation (MnDOT) freeway-management staff, Freeway Incident Response Safety Team (FIRST) dispatch, MnDOT arterial-management staff, MnDOT maintenance dispatch and State Patrol metro-area dispatch. From the RTMC, MnDOT operates a freeway management system (FMS) covering more than 400 miles of Twin Cities metro-area freeways, including the I-35W and I-94 ATM corridors. The system includes traffic detection, dynamic message signs (DMSs), ramp meters, cameras and fiber-optic communications. MnDOT's freeway-traffic-management-system software, the Intelligent Roadway Information System (IRIS), was developed in-house to communicate and control loop detectors, DMSs and ramp meters. The software was expanded to control the ATM system.

Impact from above

A series of overhead signs known as Intelligent Lane Control Signs (ILCSs) above each lane of the two freeways are used to inform drivers of upcoming conditions or controls in place. Overhead signs are used to indicate which lanes are closed to access or blocked because of a crash or obstruction, and which adjacent lanes are impacted by such events. The ILCSs also are used to post advisory speed signs, warning travelers to slow in anticipation of stopped traffic ahead. Spacing of the signs is approximately ½ mile apart, but exact spacing is based on relations to bridges, existing signs and sightlines. The managed-lane control system serves four key purposes:

- Inform drivers when the left lanes are open to high-occupancy vehicle (HOV) and/or high-occupancy toll (HOT) lanes;
- Inform drivers of advisory speed limits (when necessary) in order to slow traffic that is approaching stopped traffic. (Note: The practice at this time is that uniform speeds are posted across all lanes. MnDOT has not ruled out the idea of varying speeds in lanes and may opt to implement this in the future.);
- Inform drivers of lanes closed (e.g., when dynamic-shoulder lanes are closed or when general-purpose lanes are closed due to a crash or stalled vehicle); and
- Inform drivers of hazards such as standing water or debris on the roadway and encourage travelers to merge away from the hazardous lanes.

The managed lanes are controlled by RTMC operators, who have full authority to select from available messages after events are verified.

For the display of lane advice, the red X and yellow flashing arrow are posted over the lane with the blockage and adjacent lanes, respectively, at the point of the blockage. Advance warning messages are posted on all signs located upstream of the blockage within a distance of at least 1 mile. As motorists approach a closed lane, they encounter a "Lanes Closed Ahead" sign 1 mile before the closure. The next sign displays a merge sign with an arrow within a ½ mile of the red X sign over the lane that is closed. This is to ensure that travelers have advance warning of the closure before reaching the incident. Farther upstream, the signs display an automated advisory speed posting, which changes based on real-time traffic conditions.

When display signs are posting either a red X or yellow-flashing-arrow message, all other signs display a green arrow.

Variable-speed punch

The selection of advisory variable speed limits (VSLs) to be posted are computed by an algorithm developed by the RTMC and the University of Minnesota-Duluth. RTMC operators have the option to override the calculated advisory speeds or to accept the recommendation and verify the posting of the message.

The goal of the advisory VSL system is to mitigate shock wave propagation from the downstream bottleneck by gradually reducing speed levels of incoming traffic flow. Speed data is collected through traffic sensors on the roadway at various locations. Without advisory VSLs, vehicles approaching congested traffic are forced to change speeds within a very short distance, leading to sudden stopping and possible rear-end collisions. The advisory speed limits are posted to allow for a more gradual deceleration between upstream free-flowing traffic and congested traffic. The speeds displayed on the ILCSs gradually reduce traffic speeds.

As congestion levels develop, two or three sets of signs prior to the congestion display an advisory VSL based on the algorithm, depending on what the speed differential is between upstream and downstream traffic. Speeds are currently posted up to 1½ miles upstream of the congestion.

Advisory speeds posted on the overhead signs change by no more than 5 mph with each change in speed and can be updated every 30 seconds if traffic conditions warrant. The minimum advisory speed displayed is 30 mph, and the maximum advisory VSL displayed is 50 mph. If the current speeds on the roadway are below 30 mph, the signs go blank.

It is important to note a characteristic of the current implementation that, as presented later, may be the reason for not realizing its full potential. The MnDOT freeway detection infrastructure is mainly made up of single-loop detectors measuring volume and occupancy. Speed is estimated from the two primary measurements and a locally calibrated effective-vehicle-length constant. The latter is calibrated offline.

This speed estimation procedure introduces noise in the 30-second speed time series. To alleviate this problem and create a stable algorithm, speed is updated every 30 seconds but averaged over a 90-second window. This helps to reduce outliers but also increases the system's response time. MnDOT has been replacing detection at key locations with radar units and is in the process of updating the system to work on a 10-second update cycle.

Jarring analysis

To understand the effectiveness of the Smart Lanes system, MnDOT and other agencies are supporting a series of research projects looking at all aspects of the system, exploring short-term operational as well as long-term safety benefits. A recently concluded research project by University of

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Minnesota-Twin Cities researchers examined three separate but related areas: the effects of the advisory VSL system; the impact of severe weather conditions on shoulder-lane use; and the behavior and traffic impacts of bus rapid transit (BRT) operations.

The work was funded by the Intelligent Transportation Systems Institute of the University of Minnesota, a U.S. DOT University Transportation Center. The rest of this article is focused on the operational assessment of the VSL system on I-35W. Information on the other aspects of the project can be found in Hourdos et al., 2013. (www.cts.umn.edu/publications/researchreports/reportdetail.html?id=2302)

Vehicle behavior before and after VSL implementation was examined to (1) determine if and how the congestion throughout the corridor is impacted by the system and (2) determine if driver behavior is changed and, if it is, how this affects the traffic flow characteristics of the instrumented freeway segments. This study did not evaluate the compliance and behavior of individual drivers but focused on the aggregate effect such behaviors have on traffic flow.

The study utilized loop-detector measurements combined with speed-sign-activation records available from MnDOT. Through this information, the impact of the variable speed limits was explored through (1) examination of the actuations of each station as compared with the estimated speeds throughout the corridor based on 30-second loop-detector data, (2) generation of fundamental diagram curves for specific detectors and (3) tabulation of speed-based congestion for each region of the I-35W corridor. The first two analysis techniques focused on well-correlated days based on 15-minute aggregated volumes along the boundary of each corridor (upstream station and entrance ramps)

In general, from the available data, a very small compliance to the advisory speed limits is observed.

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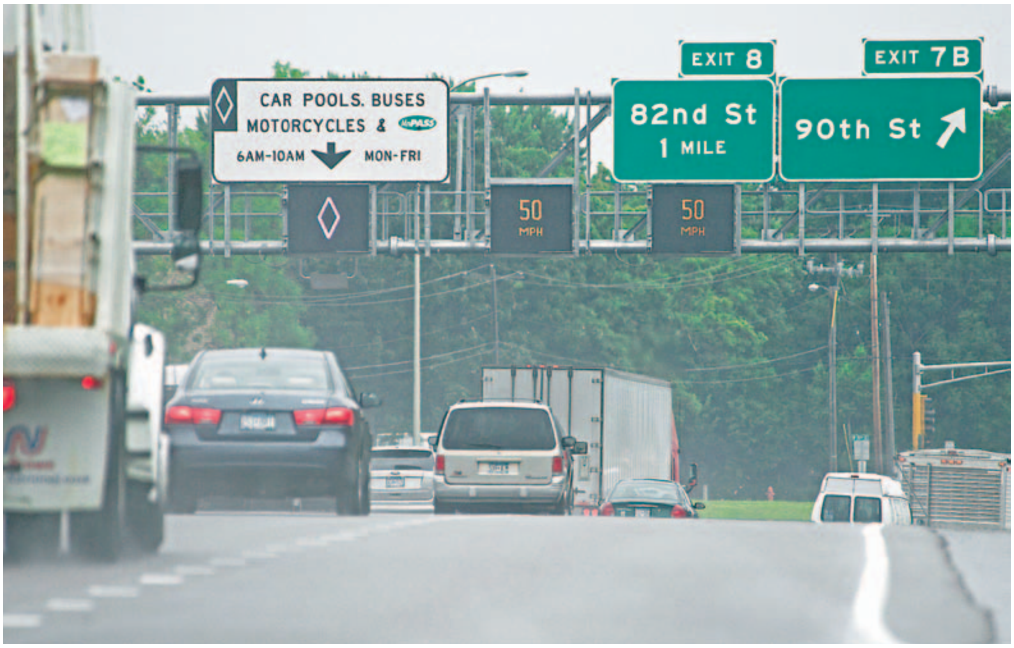
Additionally, for the days when data were collected it seems that the speed of the congestion wave is too fast for the VSL signs to give timely warning to oncoming traffic. As noted earlier, this is an inherent issue related to the detection infrastructure, and MnDOT is improving this part of the system.

Regardless, looking at the general congestion patterns, the VSL system does appear to positively impact the most severe congestion (speeds below 10-15 mph). Specifically, the instances and spread of extreme congestion waves (speeds below 10 mph) have been reduced after the VSL system activation. Severe shock waves propagating upstream are a serious danger of rear-end collisions, therefore their reduction is a valuable effect of the VSLs.



Although drivers do not comply with the advisory speed limit, they do take it into consideration. One can hypothesize that the drivers use the advisory speed limit as a gauge of downstream congestion and prepare themselves for encountering the upcoming shock waves.

Although it is not possible to make definitive observations of this effect through loop-detector data, the analysis of the fundamental diagram curves for specific detectors shows that although drivers do not comply with the advisory speed limit, they do take it into consideration. One can hypothesize that the drivers use the advisory speed limit as a gauge of downstream congestion and prepare themselves for encountering the upcoming shock waves. This behavior may reduce the rate of the speed reduction, i.e., slower-moving shock waves. The effect is observable albeit weak.

Focused impetus

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

Other studies have focused on the effect VSL has on safety. Specifically, the I-94 corridor in the westbound direction included a section with very frequent rear-end collisions, a rate of one every two days. Results show again that drivers do not heed the advisory speed limits, which may be an inherent issue with nonenforceable VSL deployments. Additionally, from the same study, the effect and importance of the detection and measurement infrastructure was further highlighted. The I-94 high-crash area is particularly plagued by isolated, fast-moving shock waves.

MnDOT is currently researching how to modify the advisory speed limit during inclement weather. Currently the system uses a constant deceleration rate to determine advisory speed limit values. Observations of the system have found that the preferred deceleration rates may be different during different weather conditions.

Additionally, in the southern half of the I-35W corridor there are sections where the left lane of traffic was shifted onto the inside shoulder by 2 ft to allow for a buffer zone between the new HOT lane and the general-purpose lanes. This inside shoulder was originally designed to allow for some ponding during heavy rainfall. Now that traffic is shifted onto these shoulders, there is a potential for hydroplaning during heavy rainfall as the shoulder area begins to fill up with water. A part of the aforementioned research project was dedicated to investigating the relationship between road geometry, rainfall intensity and hydroplaning danger and developed a model that relates rain gauge measurements with maximum safe speed limits and can drive the deployment of an inclement weather VSL system. **TM&E**

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