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Evaluation of variable speed limits for real-time freeway safety improvement

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Abstract

Use of various variable speed limit (VSL) strategies as a tool for safety improvement on freeways was evaluated using simulation of a section of Interstate 4 in Orlando, FL. Real-time crash likelihood was calculated based on models developed in previous research by the first author [Abdel-Aty, M., Uddin, N., Pande, A., January 2005. Split models for predicting multi-vehicle crashes during high-speed and low-speed operating conditions on freeways. In: Presented at the 84th Annual Meeting of the Transportation Research Board, Washington, DC]. VSL implementation produced safety improvement by simultaneously implementing lower speed limits upstream and higher speed limits downstream of the location where crash likelihood is observed in real-time. This improvement was realized in the case of medium-to-high-speed regimes on the freeway, but no benefit was achieved in low-speed situations (no substantial safety benefit from implementing VSL in congested situation's simulation). The final recommendations for implementing VSL are:

- gradually introducing speed limit changes over time (5 mph every 10 min);
- abruptly changing speed limit in space (no gap distance);
- reducing speed limits upstream and increasing speed limits downstream of location of interest;
- the speed limit changes up- and downstream should be large in magnitude (15 mph) and implemented within short distances (2 miles) of the location of interest.

In addition to the safety benefit, this final strategy also produced travel time savings.

Keywords: Variable speed limit; Traffic safety; ITS applications; Crash potential; Micro-simulation

1. Introduction

This research evaluates Intelligent Transportation System (ITS) implementation through variable speed limits (VSL) strategies to improve the safety of a freeway once a relatively high potential of a crash is detected. VSL are ITS devices, commonly used to calm traffic in an attempt to relieve congestion and enhance throughput. A different aspect of VSL can be realized in improvement of traffic safety. Through the use of multiple microscopic traffic simulations, best practices can be determined, and a final recommendation of VSL strategies with a safety perspective can be made.

2. Application of VSL

Variable speed limits are used to increase average headways and reduce variances in speed (Borrough, 1997; Ha et al., 2003; Pilli-Sivola, 2004). Less variability of speed leads to fewer short headways, and lower mean speeds according to Ha et al. (2003). This translates into fewer crashes (Smulders, 1990). A study in Finland by Rämä (1999) shows that VSL lead to lower speeds and less variability. Borrough (1997) found that the use of VSL and strong enforcement (video cameras) greatly reduced the number of crashes (28% over 18 months). The effect was attributed to not only a smoothing of traffic conditions through longer following distances, but also through reducing the number of lane changes during congestion (Borrough, 1997).

Lee et al. (2004) used VSL to try and reduce crash potentials. The same approach, with a much larger network and a different implementation strategy, is applied in this study to show the

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benefits of implementation of VSL. However, the scope of the study is broadened in both scale and strategy. Lee et al. (2004) only simulated a 1 mile long stretch that included just one ramp, and placed Variable Message Sign (VMS) just upstream of a particular location of interest. In this study, a 20 mile stretch is simulated. The larger network allows more flexibility in the implementation of VSL. Rather than having just two locations that effect traffic speeds, up to 12 miles are investigated via 24 VSL test cases with both up- and downstream introduction of VSL. Also, speed limits are decreased, increased, or simultaneously decreased and increased (up- and downstream, respectively) to investigate all possible cases. This introduces a more dynamic approach for implementation taking into consideration all the possible scenarios—extending significantly over Lee et al. (2004) where they investigated either increasing or decreasing speeds in order to improve safety.

3. Micro-simulation

When studying VSL, micro-simulation appears to be an ideally suited tool to evaluate ITS technologies especially like VSL (Lee et al., 2004). Generally, data are collected using loops (Placer, 2001; Sisiopiku, 2001; Senn, 2004; Borrough, 1997; Portaankorva, 2002) or speed radars (Sisiopiku, 2001; Pilli-Sivola, 2000; Peltola, 1997) and field studies are undertaken to test strategies. In the transportation simulation field there is a general agreement that microscopic simulation, i.e., a computational resolution down to the level of individual travelers, is now a viable alternative and may be the only answer to a wide variety of problems.

Simulation has some desirable qualities that make it useful. First, it is cheaper than field-testing in most cases. The upfront cost of software and hardware does not compare to the cost of outfitting a road network, or the loss in confidence of the driving public on an always-changing driving environment. Second, impossible scenarios maybe carried out. Third, time can be sped up to yield future results now. The effect of a change many months away can be determined in few hours. Fourth, safety issues can be safely tested without the potential of harming any drivers.

For Variable Message Signs which are closely related to VSL, the simulated technology in this instance, only two software packages are compatible. The AEVISUN 2 software has VMS capability as does PARAMICS (Boxill and Yu, 2000). While either would look to be a perfect choice PARAMICS was chosen due to its scalability and proven background on freeways and urban roads.

4. Safety measure

Abdel-Aty et al. (2005), Lee et al. (2003) and Pande et al. (2005) developed statistical models to get a measure of real-time crash potential. Lee et al. (2004) applied the model from one of their previous studies (Lee et al., 2003) to a small simulated freeway network to measure the crash risk before and after the application of certain VSL strategies.

The model developed by Abdel-Aty et al. (2005) is used to assess crash likelihood for the simulated network used in this study. The models were developed for the same segment of Interstate 4 being simulated here, making them the most appropriate choice. Also, real-time crash "prediction" models were separately developed for a moderate-to-high-speed and low-speed traffic speed regime and the threshold for separating the two regimes was set at 37.5 mph based on visual examination of traffic speed distributions. Above this speed, a moderate-to-high-speed model, which takes average occupancy and flow as input, is used. Below this speed, a low-speed model, involving average volume, occupancy, and coefficient of variation in speed variation as inputs, is used. These models may be used to assess the crash potential at any given location in real-time using loop detector data. Since the input parameters to these models were measured 5–15 min before the crash, there would be time to introduce strategies at locations experiencing crash prone conditions before they culminate into a crash. The moderate-to-high and low-speed models are shown in Eqs. (1) and (2), respectively (Abdel-Aty et al., 2005).

$$\begin{aligned}\text{Crash\_Likelihood} = & -0.93423\text{LogAOF2} + 1.14584\text{LogAOH3} \\ & - 0.22878\text{SVH2} - 0.10055\text{AVG2} \\ & + 0.5932\text{AVE3} \end{aligned} \tag{1}$$

where LogAOF2 is the log of average occupancy at the station of interest 5–10 min before the time of interest, LogAOH3 the log of average occupancy 1 mile downstream of the station of interest 10–15 min before the time of interest, SVH2 the standard deviation of volume 1 mile downstream of the station of interest 5–10 min before the time of interest, AVG2 the average volume 0.5 mile downstream of the station of interest 5–10 min before the time of interest, and AVE3 is the average volume 0.5 mile upstream of the station of interest 10–15 min before the time of interest.

$$\begin{aligned}\text{Crash\_Likelihood} = & \ 2.64827\text{LogCVSF2} + 0.88842\text{LogCVSF3} \\ & + 1.33966\text{LogAOE2} + 0.97766\text{LogAOH3} \\ & - 0.43603\text{SVF2} \end{aligned} \tag{2}$$

where LOGCVSF2 is the log of the standard deviation of speed divided by the average speed at the station of interest 5–10 min before the time of interest, LOGCVSF3 the log of the standard deviation of speed divided by the average speed at the station of interest 10–15 min before the time of interest, LogAOE2 the log of average occupancy 0.5 mile upstream of the station of interest 5–10 min before the time of interest, LogAOH3 the log of average occupancy 1 mile downstream of the station of interest 10–15 min before the time of interest, and SVH2 is the standard deviation of volume 1 mile downstream of the station of interest 5–10 min before the time of interest.

The models shown above would provide a measure that may be used to evaluate the impact of our application experiments on the safety situation of the freeway. This measure is specific for every location and a decrease in this measure signifies a decrease in the risk of crash and vice versa. It should be noted,