Improving flow and safety in low visibility conditions by applying connected vehicles and variable speed limits technologies

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AUTHOR CONTRIBUTION STATEMENT
The authors confirm contribution to the paper as follows: study conception and design: Yina Wu, Mohamed Abdel-Aty, Ling Wang; data collection: Yina Wu, Md Sharikur Rahman; analysis and interpretation of results: Yina Wu, Ling Wang; draft manuscript preparation: Yina Wu, Mohamed Abdel-Aty, Ling Wang, Md Sharikur Rahman. All authors reviewed the results and approved the final version of the manuscript.
1. Introduction

The effect of fog on both crash occurrence and severity has become a major concern in the traffic safety field. Previous research pointed out that fog can increase crash severity and multi-vehicle involved crash risk (1–4). The reduced-visibility conditions that are caused by fog result in a shorter sight distance and a longer stopping sight distance (5). On freeways, bottlenecks could occur due to various reasons, such as on-ramp, lane closure, special events, and accidents. The bottleneck could reduce the speed and propagate a shockwave to the upstream. Due to the reduced visibility, the drivers from the upstream may not be able to observe the downstream slow traffic and take reaction in time, resulting in increased rear-end crash risk and even severe crashes with multi vehicles pile up as in recent experiences in Florida (3). One of the possible methods to improve safety under fog conditions is implementing Variable Speed Limits (VSL). The basic idea of the VSL control is to provide a proactive intervention by adjusting vehicle speed limit at the upstream of bottlenecks to prevent rear-end crashes (5). Besides, the VSL control can also help enhance traffic safety under inclement weather conditions, such as fog, precipitation, and wind (6).

Recently, there has been considerable interests in using Connected Vehicle (CV) technologies to prevent potential crash. Detailed information about nearby vehicles’ movement could be provided through V2V communications, while V2I communication could inform drivers about weather conditions, speed limits, crashes, etc. Previous research suggested that V2V systems could reduce 79% of crashes and combined V2V & V2I systems could reduce 81% of crashes, which have excluded crashes related to drivers with physiological impairment (7).

This paper aims to combine CV and VSL limit controls to reduce the rear-end crash risk when a bottleneck occurs under fog conditions. A VSL control algorithm will be firstly proposed based on the occurrence of rear-end crashes by using traffic and weather characteristics. Then, the feedback control algorithm of the V2I system was developed to integrate the proposed VSL control strategy with connected vehicles. The developed algorithm has been tested using the VISSIM microsimulation tool via an integrated VISSIM-COM interface. A surrogate safety measure, time to collision (TTC), is used to capture the change of rear-end crash risk with the proposed control strategies. In addition, total travel time (TTT) is used to evaluate the change of network efficiency.

2. Methodology

2.1 Feedback Control System

Figure 1 displays a feedback control system to integrate the VSL and connected vehicle (CV) controls. The proposed control algorithm of integrating the VSL and CV control strategies could mitigate the rear-end risk when a bottleneck occur on freeways in fog. The traffic data (speed and occupancy) collected at Location $x_{i-1}$, posted speed limit at Location $x_i$, and visibility distance are used to calculate the safe speed for upstream vehicles approaching the congested segments. The real speed limit will be posted at Location $x_{i-1}$ accordingly, if the real speed limit is less than the initial speed limit of 70 mph. All variable speed limits are determined spatially from downstream congested segments to the upstream. In this study, it is assumed that the visibility distance keeps the same for each segment between two consecutive detectors.

The connected vehicle control could help to overcome the limitations of VSL only control that manual drivers would respond differently to the suggested speed. Besides, the connected vehicle technology could mitigate the adverse impact of fog by providing the following vehicle the
location information of the leading vehicle. The variable speed limit information could be sent to all connected vehicles through the V2I communication.

Figure 1 Flowchart of the VSL and CV control algorithm

2.2 Microsimulation

The simulation experiments were conducted to test the abovementioned integrated VSL and CV control strategies with a freeway section (westbound of I-4) in Florida, where severe fog-related crashes have happened (2). The feasibility of utilizing the VSL and CV control strategies to proactively improve traffic safety for a bottleneck area on freeway in fog has been investigated. The studied area starts from Mile Post 7.999 and ends Mile Post 17.308 with three lanes in each direction and a speed limit of 70 mph.
The in-field traffic data under heavy fog conditions, from 6:15 am to 8:15 am on February 2nd, 2016 with visibility distance between 45 m and 88 m, was collected for the model calibration to represent traffic conditions during fog. After excluding 30 minutes of VISSIM warm up time and 30 minutes of cool-down time, the VISSIM data of 60 minutes were used for the calibration and validation.

3. Findings

Table 1 provides the comparison of the effects of VSL only with 100% compliance rate, CV only, and VSL&CV. Negative values of the change of $TTC_{brake}$ or the change of $TTT$ indicate reduced crash risks or improved traffic efficiency. As discussed in the previous two subsections, both VSL only and CV only control strategies could efficiently reduce the rear-end crash risk for both low- and high-volume conditions. In addition, the better performance of the VSL control could be found in the CV environment, indicating the advanced characteristics of the V2I and V2V control systems. When a safe speed limit is determined by the proposed VSL control algorithm, the information could be sent to all the CVs at the segment immediately and all vehicles will follow the suggested speed timely. Compared to drivers without any control, the CVs would follow the proposed safe speed homogeneously. Besides, CV could diminish the increase of travel time caused by the VSL strategy, especially for high-volume conditions.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Low Volume</th>
<th></th>
<th>High Volume</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>VSL</td>
<td>CV</td>
<td>VSL &amp; CV</td>
<td>VSL</td>
</tr>
<tr>
<td>Change of $TTC_{brake}$%</td>
<td>-29.4%</td>
<td>-34.6%</td>
<td>-48.7%</td>
<td>-6.3%</td>
</tr>
<tr>
<td>Change of $TTT$</td>
<td>+26.9%</td>
<td>-3.8%</td>
<td>+22.8%</td>
<td>+3.5%</td>
</tr>
</tbody>
</table>

4. Conclusion

This study aimed to reduce the rear-end crash risks near the freeway bottleneck under reduced-visibility conditions by integrating variable speed limit (VSL) and connected vehicle (CV) control techniques. Based on the simulation results, the following conclusions can be made:

- Compared with the manual vehicles without any control, the proposed VSL control strategy could effectively reduce the rear-end crash risk under fog conditions. The safety performance of VSL is better with a higher drivers’ compliance rate. When the compliance rate is 100%, the rear-end crash risk could reduce by 29.5% and 6.3% for low- and high-volume conditions, respectively. However, as the idea of VSL control is to enhance the safety by suggesting lower speed, the VSL control could reduce the traffic efficiency at an acceptable level.

- The results demonstrate that CV could also improve traffic safety and traffic efficiency.

- Implementing VSL under CV environment (VSL&CV) could further enhance safety, while CV could diminish the increase of travel time that was caused by the VSL control.

- Crash risk migration was not observed during the simulation when the control strategy was implemented, suggesting that the traffic safety could be improved consistently.
Reference


