The influence of V-ISA technology on driver behavior along curves with sight limitations

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Abstract

Speed management along curves with limited available sight distance is necessary to guarantee smooth traffic operations and safety. To overcome this problem, we propose a novel Intelligent Speed Adaption (ISA) system for visibility, called V-ISA to define real-time safe speed limits. V-ISA may provide (1) visual information or (2) auditory warning, or (3) intervene directly to control the vehicle speed. This driving simulation-based study aims at (i) investigating the effectiveness of the three V-ISA variants, and (ii) ascertaining the speed and lateral behavioral response of drivers along road curves with limited sight distance values. Research outcomes suggest that V-ISA helps drivers to modulate their driving speed and, consequently, create safer driving conditions.

Keywords: Intelligent Speed Adaptation; Sight Distance; Road Safety; Driver Behavior; Driving Simulation; Human-Machine Interaction.

1. Introduction

Evidence from literature [1], [2] indicates that along curves with limited visibility a relevant number of drivers limit their speed and control the lateral position of the vehicle to prevent collisions with unexpected obstacles along the nonvisible part of the curve. They maintain low speeds to reduce the stopping distance or stay far from the sight obstruction to increase the available sight distance (*ASD*) as illustrated in Figure 1. However, some drivers fail to perceive the level of risk associated with curves suffering from poor visibility conditions, so they adopt unsafe behaviors [2]. This evidence is essentially related to the overestimation of the sight distance, which means that drivers drive at speeds that imply longer stopping distances (*SD*) than the available sight ones (*ASD*). To support driver speed decision, Hazoor et al. developed a concept for an innovative ISA called V-ISA [3], [4] which operates by comparing the front available sight condition (i.e., available sight distance, *ASD*) with the vehicle stopping distance in case of an emergency braking (*SD*).

V-ISA is capable of performing a real-time comparison between the *ASD* and *SD* (Figure 2A), interacting with the driver in three alternative variants: V-ISA1 provides continuous visual information through inside windscreen messages with the help of LED bar (i.e., green color in the case of safe condition $ASD > SD$, yellow for pre-alert and red when driver operates in unsafe condition $ASD < SD$) (Figure 2B); V-ISA2 alerts drivers with an acoustic signal when $ASD < SD$ (unsafe sight condition); finally, V-ISA3 acts on both gas and brake pedals to prevent the vehicle from exceeding a threshold safety speed limit. The driver is informed of the system intervention (V-ISA3) with a blue LED light on the windscreen. The functionality [3] and the validation and acceptability of the system through the human machine interaction (HMI) approach [4] were obtained prior to this investigation.

In this driving simulation study, two objectives were pursued: (i) investigate the effectiveness of three V-ISA variants on speed control as a safety performance measurement [5], and (ii) ascertain the speed and lateral driver behavioral response along road curves with limited sight distance.

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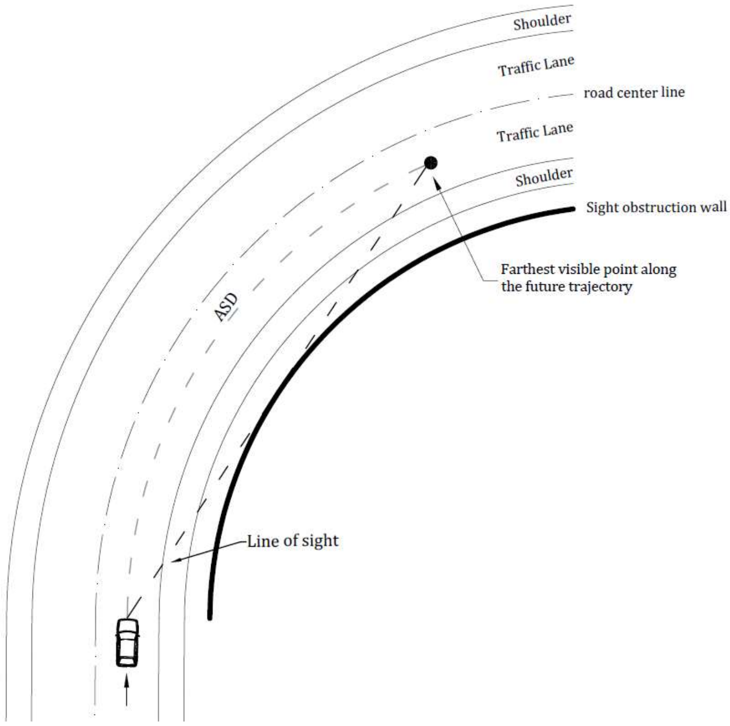

Figure 1: An illustration of available sight distance (ASD) from the driver's point of view along a rightward (RW) curve with radius 225 m.

2. Method

V-ISA was conceived in the SCANeR Studio^{TM} driving simulator environment in cooperation with MATLAB Simulink as a parallel simulation environment. A within-subject design with the V-ISA variants was adopted involving 30 participants A 12.9 km two-lane road segment with a lane width of 3.75 m and a shoulder width of 1.5 m was designed according to the Italian Geometric Design Standards for highways and streets [6]. The alignment was composed of 18 horizontal curves, the parameters of which were manipulated by combining radii (*R*), sight obstruction distances (*d*) from the road edge and curve rightward (RW) and leftward (LW) direction. The instrumentation used for the experiments consists of a fixed-base driving simulator (AV Simulation) at the Road Safety and Driving Simulation Laboratory of Politecnico di Torino.

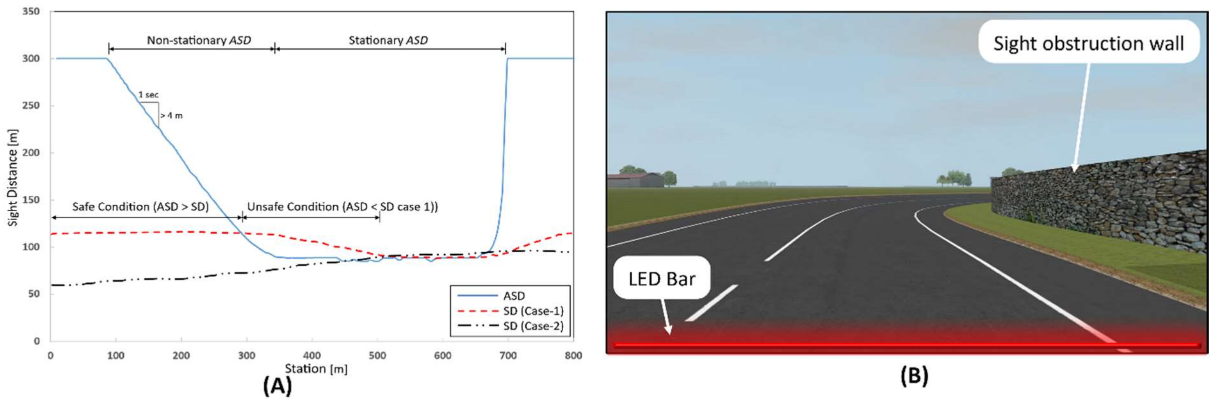

Figure 2: (A) An example of stationary and non-stationary ASD profiles along a rightward (RW) curve with radius 225 m, and two different SD types when approaching the unsafe condition in non-stationary ASD (Case-1) and stationary ASD (Case-2). (B) Driver front display during the experimental drive negotiating a RW curve with informative LED bar at the bottom of the screen. (Note: color of the LED bar depends on the sight condition and V-ISA variant).

3. Results and discussion

The output from the linear mixed-effect models (LMM) showed that the speed at the entrance of the curve (spiral to curve point, SC) for the base condition (system off) remains higher than with the V-ISA variants

($S_{SC,Base} - S_{SC,V\text{-}ISA1} = 4.62$, $t_{1761} = 6.43$, $p < .001$; $S_{SC,\ Base} - S_{SC,V\text{-}ISA2} = 6.83$, $t_{1761} = 9.80$, $p < .001$; $S_{SC,Base} - S_{SC,V\text{-}ISA3} = 11.48$, $t_{1761} = 16.45$, $p < .001$). Moreover, Bonferroni adjusted post-hoc comparison between the V-ISA variants show statistically significant differences ($S_{SC,V\text{-}ISA1} - S_{SC,V\text{-}ISA2} = 2.21$, $t_{1761} = 3.17$, $p = .009$; $S_{SC,V\text{-}ISA1} - S_{SC,V\text{-}ISA3} = 6.86$, $t_{1761} = 9.83$, $p < .001$; $S_{SC,V\text{-}ISA2} - S_{SC,V\text{-}ISA3} = 4.65$, $t_{1761} = 6.66$, $p < .001$). In Figure 3A lower speed values (S_{SC}) for V-ISA3 can be observed comparing to other two variants as in the case of V-ISA3, the variant automatically reduces the speed up to safe speed limit and not allowing drivers to increase the vehicle speed from the limit during the intervening operation, which makes the variant most effective in terms of safety. However, it cannot be neglected that V-ISA1 and V-ISA2 also performed robustly in communicating to the drivers with visual information and sound alert respectively (Figure 3A).

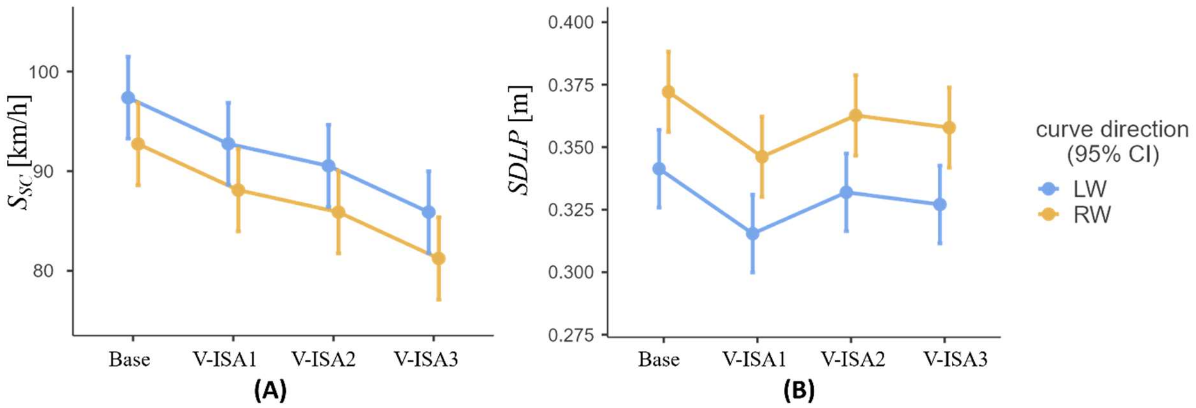

Figure 3: (A) Speed at the entrance of the curve (spiral to curve point, S_{SC}) and (B) standard deviation of lane position (*SDLP*) at the entrance of the curve for different drives under the effect(s) of V-ISA in the case of leftward (LW) and rightward (RW) curves.

Further on, other interesting results were observed from the Generalized Linear Model (GLM) output for the standard deviation of lateral position (*SDLP*) as a dependent parameter. *SDLP* is a driver lateral performance measure for lane-keeping capability in case of external/internal disturbances [7]. V-ISA1 shows lower values for *SDLP* in comparison with the baseline condition ($SDLP_{V\text{-}ISA1} - SDLP_{Base} = -.026$, $z = -2.627$, $p = .009$). The lower value suggests that drivers have more control over the vehicle lateral position, while in the case of other V-ISA variants (warning and intervening) no statistically significant difference was observed comparing the baseline condition (Figure 3B). It is pertinent to mention here that the *SDLP* was calculated over the section where the chances of activation of the V-ISA variants were higher (i.e., entrance of the curves).

4. Conclusions

This study assessed the potential of the novel Intelligent Speed Adaptation (V-ISA) and its variants to improve road safety while also assessing their impact on driver behavior. Overall, current research strengthens the idea that drivers should be assisted with a system that ensures real-time safe speed limits are respected in scenarios where sight distance values are limited due to the presence of permanent or temporary obstructions. In summary, the V-ISA technology can enhance the functionality of the Advanced Driver Assistance System (ADAS) for vehicles operating as a standalone or as part of an integrated system. The general implementation of V-ISA in real vehicles requires field tests.

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